12-1-1990

The Broom Creek Formation (Permian), in Southwestern North Dakota

Marvin E. Rygh

THE BROOM CREEK FORMATION (PERMIAN), IN SOUTHWESTERN NORTH DAKOTA: DEPOSITIONAL ENVIRONMENTS AND NITROGEN OCCURRENCE

by

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Bachelor of Science, University of North Dakota, 1982

A Thesis

Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota

December

1990

This thesis submitted by Marvin E. Rygh in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota has been read by the Faculty Advisory Committee under whom the work has been done, and is hereby approved.

(Chairperson)

This thesis meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

Dean of the Graduate School

Permission

Title The Broom Creek Formation (Permian), In Southwestern North Dakota, Depositional Environments and Nitrogen Occurrence

Department Geology

Degree Master of Science

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Date 11-21-90

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ACKNOWLEDGMENTS

I would like to thank my committee members, Drs. Richard D. LeFever, Kenneth L. Harris, and Patricia E. Videtich for their helpful suggestions and critical review of the manuscript.

I would like to thank the North Dakota Geological Survey, North Dakota Industrial Commission, for allowing me access to cores, logs, and well data. I am very grateful to the personnel of the North Dakota Geological Survey, especially Julie LeFever, for her thoughtful suggestions.

I would like to thank my family for their love and support. I would particularly like to thank my wife, Ragnhild, for her encouragement in all of my academic pursuits.

ABSTRACT

In North Dakota, the Broom Creek Formation (Wolfcampian) exists in the subsurface as the upper unit of the Minnelusa Group. The Broom Creek Formation consists of pink quartzarenite with some intervening dolostone beds. The identification of lithofacies, areal distribution, and stratigraphic relationships were determined from oil well logs, mainly the dual laterolog suite and the FDC-CNL log suite, and macroscopic and microscopic core analysis. Cores were examined from four wells.

The major lithofacies identified are: 1) eolian sandstone, 2) nearshore marine sandstone, and 3) marine carbonate. From the sandstone-dolostone distribution, marine predominance existed in the eastern part of the study area and eolian predominance in the west during the deposition of the Broom Creek Formation.

A four-phase depositional model is proposed for the preservation of eolian dunes within the Broom Creek Formation: 1) migration of eolian dunes over a low-relief erosional surface, 2) marine transgression and partial reworking of dunes, 3) carbonate mud deposition and, 4) marine regression with accompanying diastem and minor erosion. At least two such extensive cycles occurred in the Broom Creek Formation. However, many minor transgressive-regressive events deposited most beds as discontinuous lenses across the study area.

The upper Broom Creek contact reflects considerable

paleotopography. The overlying Opeche Formation was deposited in a sufficiently low energy environment such that much of the original paleosurface on top of the Broom Creek Formation is preserved. In the west, the upper section of the Broom Creek Formation existed as dune fields with accompanying interdune areas.

The main diagenetic events in the nearshore marine sandstone lithofacies include iron oxide precipitation, dolomitization of carbonate cement, quartz overgrowths, and pressure dissolution. The diagenetic history of the eolian sandstone lithofacies is similar to the marine sandstone lithofacies, with two exceptions; the precipitation of interstitial gypsum (anhydrite) and the absence of carbonate cement. Both sandstone lithofacies exhibit excellent porosity. The marine carbonate lithofacies has been completely dolomitized and contains minor amounts of vuggy and moldic porosity.

From FDC-CNL logs, the accumulation and distribution of nitrogen gas within the Broom Creek Formation was determined. A volumetric calculation of mapped reserves resulted in an estimate of 2.3 trillion cubic feet (65 billion cubic meters) of nitrogen gas in place. The occurrence of nitrogen in the Broom Creek Formation appears to be related to hydrocarbon generation in the underlying Amsden and/or Tyler Formations.

INTRODUCTION

Purpose

The purpose of this study is to examine and characterize the Broom Creek Formation in North Dakota. The occurrence of nitrogen gas in the Broom Creek Formation has been common knowledge within the oil industry since the 1950's. The Broom Creek Formation is not oil productive. However, the Upper Minnelusa Formation of Wyoming, which is equivalent to the Broom Creek Formation, is an important oil producing interval in the Powder River basin. The presence of eolian sediments in the Broom Creek Formation has been previously suspected, since eolian strata have been identified in the Upper Minnelusa Formation of Wyoming (Fryberger, 1984).

The purpose of this study is to substantiate the existence of eolian deposits, map accumulations of nitrogen gas, characterize basic depositional patterns, and develop a depositional model for the Broom Creek Formation in North Dakota.

Study Area

The Williston basin is an intracratonic, sedimentary basin covering parts of North Dakota, South Dakota, Montana, Saskatchewan, and Manitoba (Gerhard and others, 1982). Sedimentary rocks from every geologic system occur in the basin. The North Dakota portion of the Williston basin covers 51,600 square miles (133,643 square km),

approximately the western three-quarters of the state (Fig. 1). The maximum thickness of the basin, in excess of 15,000 feet (4,572 meters), occurs near Watford City, North Dakota (Carlson and Anderson, 1965).

Initial subsurface reconnaissance roughly delineated the extent of the Broom Creek Formation in North Dakota. The study area covers the entire subcrop of the Broom Creek, located in the southwestern portion of the state, extending eastward from the Montana border to Range 80 West and northward from the South Dakota border to Township 153 North.

Regional Geology

The Broom Creek Formation is part of an extensive wedge of Wolfcampian sandstone which covers portions of scuthwest North Dakota, eastern Montana, western South Dakota, and eastern Wyoming (Fig. 2). During Late Wolfcampian time, the southern half of the Williston basin was periodically inundated by a shallow sea forming what has been called the "Lusk Embayment" (Bates, 1955). Trotter (1984) refuted the usage "Lusk Embayment" as it refers to a northern marginal embayment extending from a shallow seaway to the south. However, in this paper, Bates' (1955) definition of the "Lusk Embayment" is used. This regional trough existed as an extension of the Anadarko sea to the south. Sediments in the Lusk embayment thicken very little going south, which previous workers have interpreted to indicate a gently

Figure 1. Williston basin location map showing study area and major tectonic features to the south affecting the Broom Creek Formation and equivalent strata.

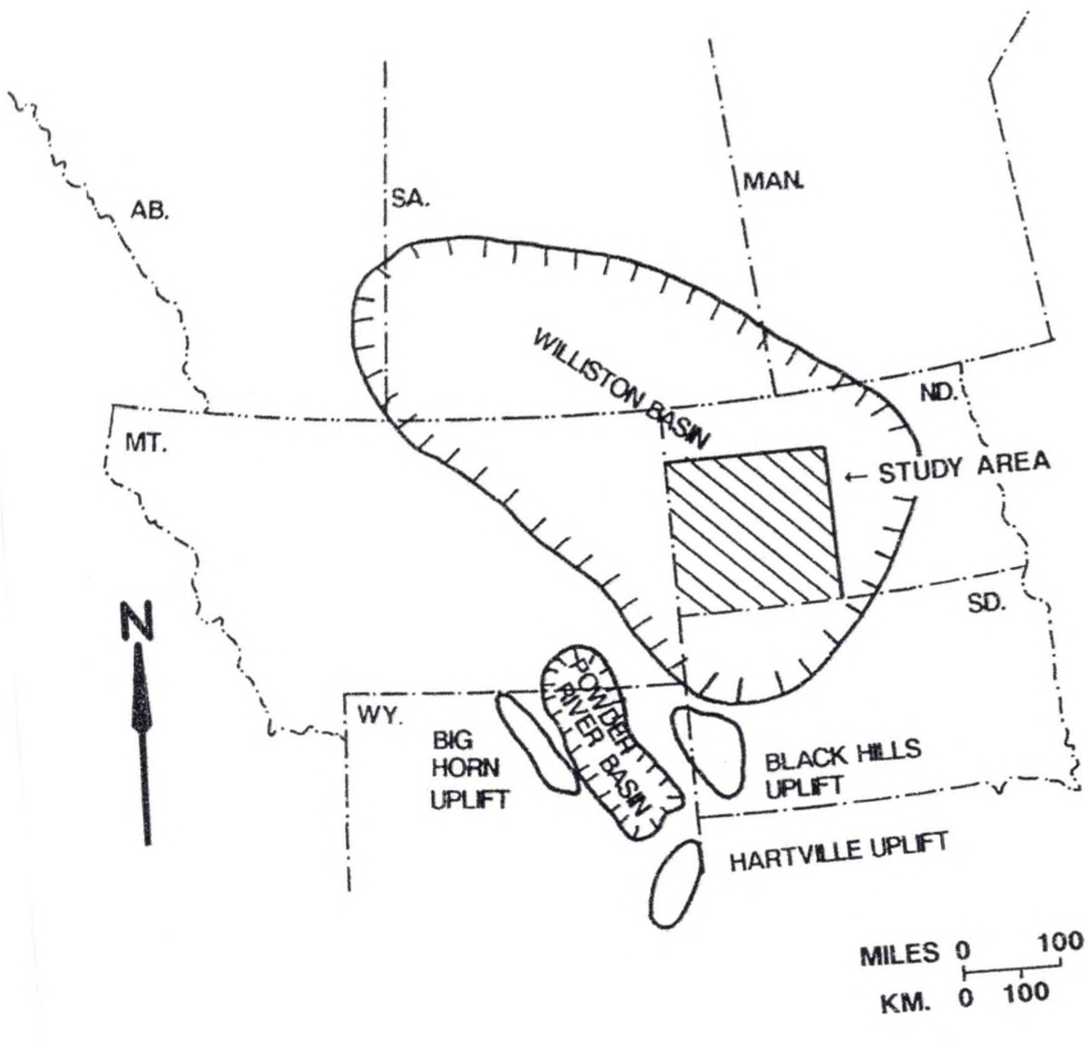
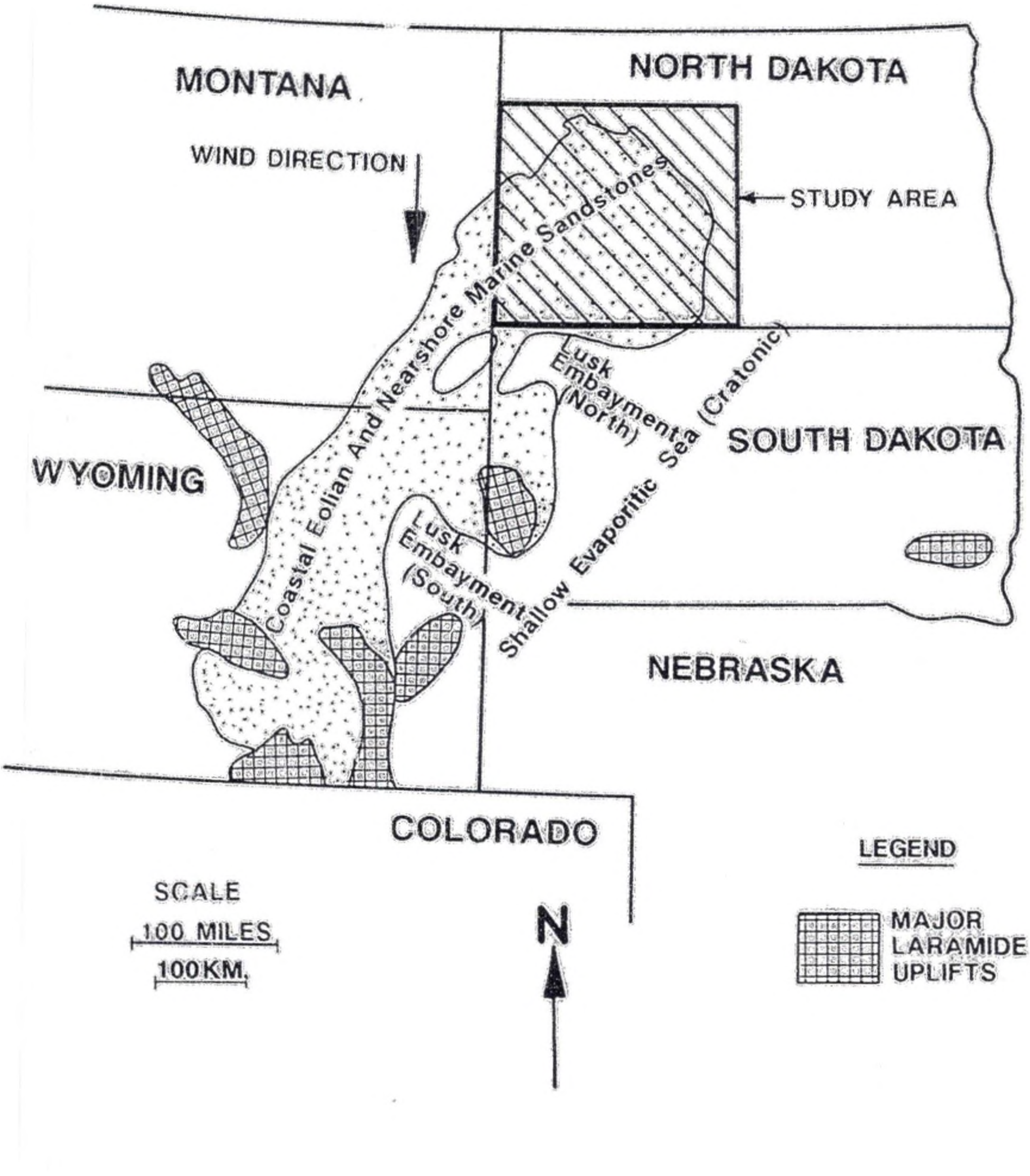

AB.
SA.
MAN.
WILLISTON BASIN
ND.
MT.
STUDY AREA
SD.
N
WY.
POWDER RIVER BASIN
BIG HORN UPLIFT
BLACK HILLS UPLIFT
HARTVILLE UPLIFT
MILES 0 100
KM. 0 100

Figure 2. Map of the Northern Great Plains showing the extent of Wolfcampian sandstone and inferred paleowind direction (modified from Fryberger, 1984).


MONTANA
NORTH DAKOTA
WIND DIRECTION
STUDY AREA
Coastal Eolian And Nearshore Marine Sandstones
Lusk Embayment (North)
Shallow Evaporitic Sea (Cratonic)
SOUTH DAKOTA
WYOMING
Lusk Embayment (South)
NEBRASKA
COLORADO
SCALE
100 MILES
100KM.
N
LEGEND
MAJOR LARAMIDE UPLIFTS

sloping sea floor (Trotter, 1984). Small fluctuations in sea level caused substantial changes in the shoreline position of this shallow sea.

Lower Permian rocks are disconformable on the underlying Pennsylvanian strata in the northern midcontinent area due to a prolonged withdrawal of the Anadarko sea during Early Wolfcampian time. Sedimentation remained nearly continuous in the south (Nebraska and Kansas), where Permian rocks are conformable with Pennsylvanian strata. Wolfcampian strata in the southern midcontinent area are predominantly carbonates, represented by the Chase Group in Kansas and Nebraska.

Despite the intra-Wolfcamp disconformity in the northern midcontinent, sedimentation patterns remained similar from Late Pennsylvanian through Early Permian time. Truncation of Upper Pennsylvanian rocks by Lower Permian strata is not pronounced in the area, which suggests that the midcontinent region did not experience any major regional tectonic activity at that time (Peterson, 1980). The intra-Wolfcamp disconformity and other disconformities in the Middle and Upper Permian are considered to have developed during episodes of gentle cratonic epeirogeny (Rascoe and Baars, 1972). However, periodic glaciation of the southern hemisphere during this time may have caused the cyclical rise and fall of the sea level and cyclical sedimentation on the midcontinent (Heckel, 1980).

During Early Permian time, low-relief land surrounded

much of the midcontinent Anadarko sea. Dipmeter studies of Wolfcampian strata in Wyoming indicate that the predominant dip direction in eolian deposits was southward, parallel with Late Paleozoic wind direction (Fryberger, 1984). Deposition of substantial thicknesses of anhydrite in Wyoming and the recognition of widespread, redbed deposits throughout the midcontinent supports the interpretation of an arid paleoclimate (Peterson, 1980).

Stratigraphy

The Broom Creek Formation comprises the upper portion of the Minnelusa Group in North Dakota. A typical wireline log of the Broom Creek Formation is illustrated in Figure 3. The Amsden Formation unconformably underlies the Broom Creek Formation and the Opeche Formation unconformably overlies the Broom Creek Formation. The Upper Minnelusa Formation, as commonly used in the Powder River basin of Wyoming, is correlative with the Broom Creek Formation in North Dakota (Ziebarth, 1972). A correlation chart of the Broom Creek Formation in the upper midcontinent is given in Figure 4. The Broom Creek Formation consists of a series of sandstone-carbonate cycles and has been determined to be Late Wolfcampian in age by faunal evidence and correlation to strata to the south (McCauley, 1955).

The Minnelusa Group, as described by Ziebarth (1972), consists of the Tyler, Amsden, and Broom Creek Formations. This nomenclature encompasses a package of Pennsylvanian-

Figure 3. Typical wireline log response (gamma-ray and formation density compensated - compensated neutron log) of the Broom Creek Formation and bounding strata. Middle column shows major lithologic distinctions between sandstone and dolostone as determined from log response.

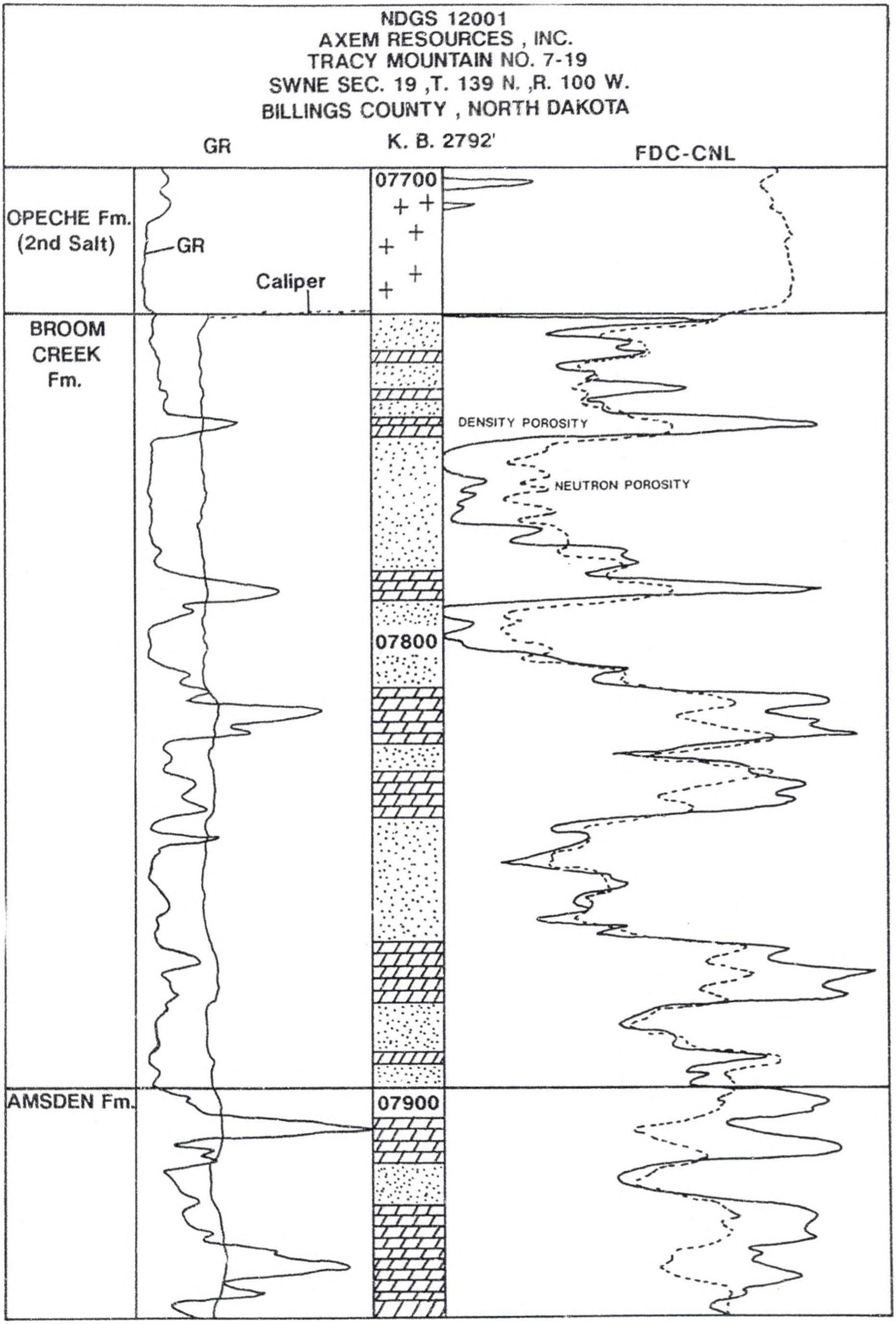
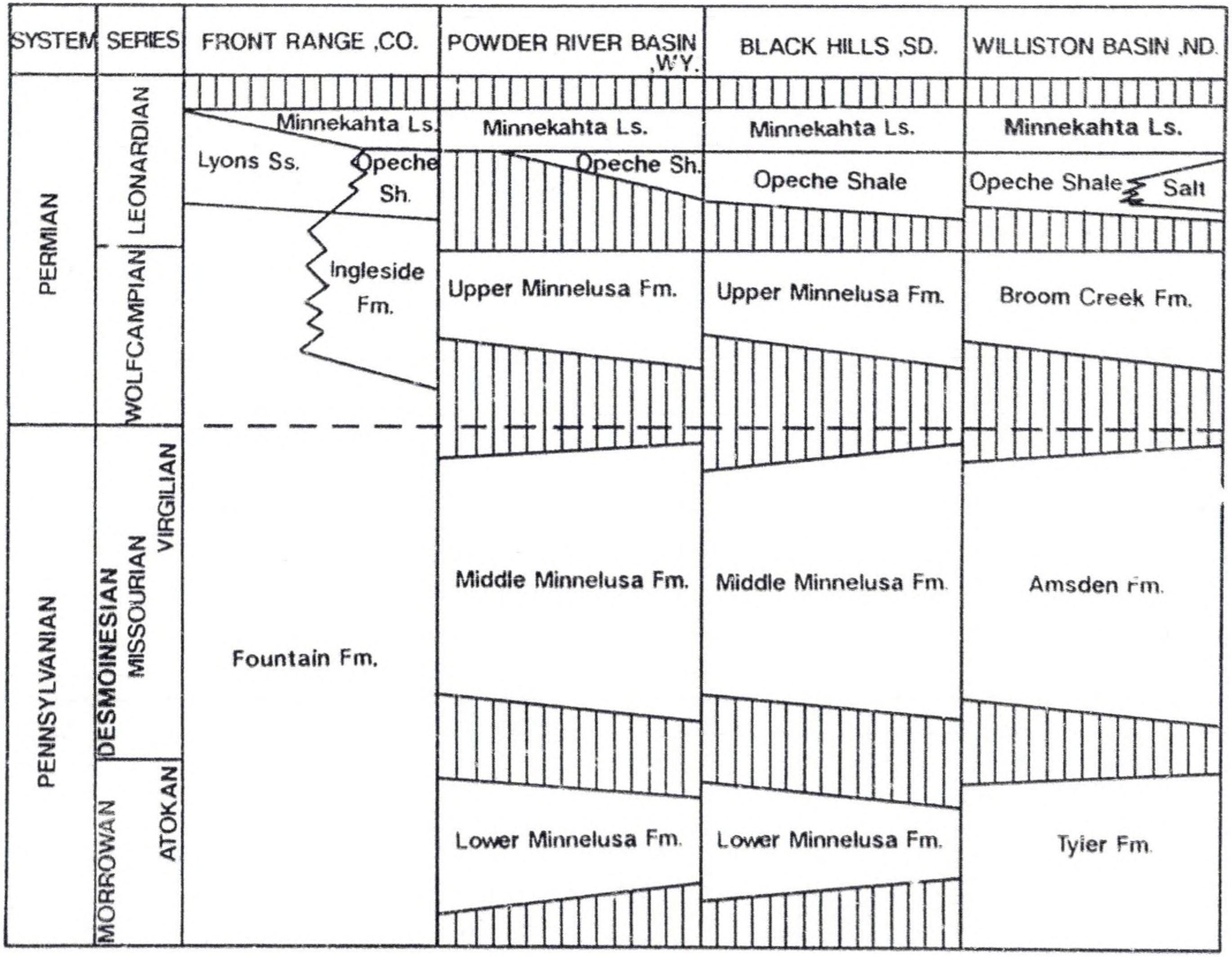

NDGS 12001
AXEM RESOURCES , INC.
TRACY MOUNTAIN NO. 7-19
SWNE SEC. 19 ,T. 139 N. ,R. 100 W.
BILLINGS COUNTY , NORTH DAKOTA
GR
K. B. 2792'
FDC-CNL
OPECHE Fm. (2nd Salt)
GR
Caliper
07700
BROOM CREEK Fm.
DENSITY POROSITY
NEUTRON POROSITY
07800
AMSDEN Fm.
07900

Figure 4. Correlation chart of Pennsylvanian and Permian (partial) strata of the upper midcontinent (modified from Rascoe and Baars, 1972).


SYSTEM
SERIES
FRONT RANGE ,CO.
POWDER RIVER BASIN ,WY.
BLACK HILLS ,SD.
WILLISTON BASIN ,ND.
PERMIAN
PENNSYLVANIAN
LEONARDIAN
WOLFCAMPIAN
VIRGILIAN
MISSOURIAN
DESMOINESIAN
ATOKAN
MORROWAN
Minnekahta Ls.
Lyons Ss.
Opeche Sh.
Ingleside Fm.
Fountain Fm.
Minnekahta Ls.
Opeche Sh.
Upper Minnelusa Fm.
Middle Minnelusa Fm.
Lower Minnelusa Fm.
Minnekahta Ls.
Opeche Shale
Upper Minnelusa Fm.
Middle Minnelusa Fm.
Lower Minnelusa Fm.
Minnekahta Ls.
Opeche Shale
Salt
Broom Creek Fm.
Amsden Fm.
Tyler Fm.

Permian sediments between the Mississippian Big Snowy Group and the Middle Permian Opeche Formation.

The base of the Broom Creek Formation in this study is placed where there is clear evidence on wireline logs of lithologic change from the dolostone and shale beds of the Amsden Formation to the less radioactive and more porous sandstones of the Broom Creek Formation. This choice of contact agrees with Ziebarth (1972). The lithology change is typically quite evident on gamma-ray and dual laterolog wireline traces (Fig. 3). In Wyoming, the base of the Permian is placed at the lower contact of a prominent red mudstone (Maughan, 1967). This red marker bed is not present in the study area.

The unconformity between the Broom Creek Formation and the overlying Opeche Formation is irregular throughout North Dakota. Resistivity and gamma-ray traces on wireline logs show the abrupt change from the porous Broom Creek sandstone to the basal Opeche salt (Fig. 3). The basal Opeche salt is only locally present. A basal Opeche siltstone more commonly overlies the Broom Creek Formation throughout the study area.

Figures 5a and 5b show the major formational markers chosen from wireline logs in the study area. This study recorded all formational markers from the top of the Mississippian unconformity (Big Snowy Group) to the top of the Minnekahta Formation.

Figure 5a. Wireline log (gamma-ray, dual laterolog) showing typical formation markers picked in the study (upper half of stratigraphic column). Unconformities are denoted by wavy lines.

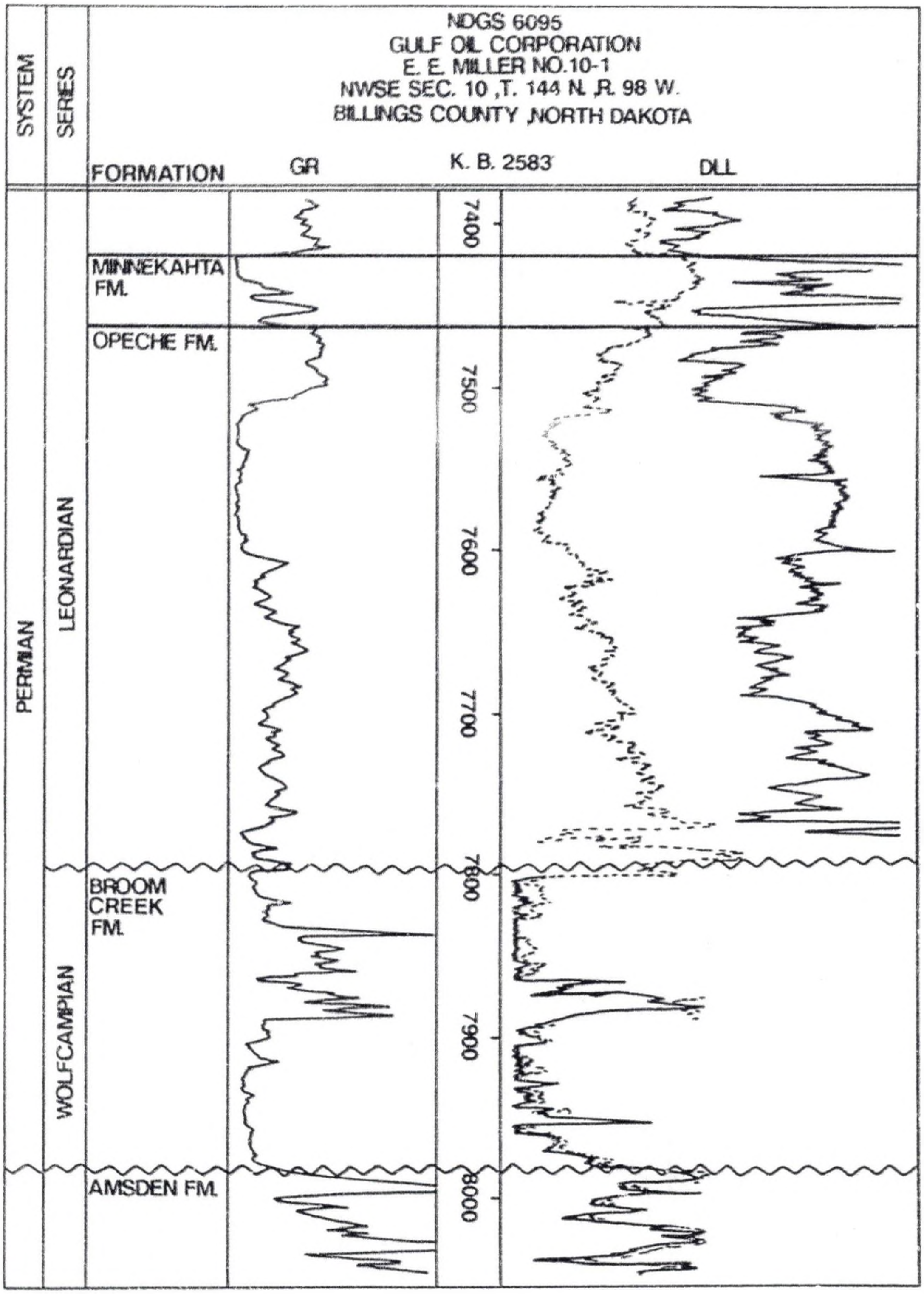
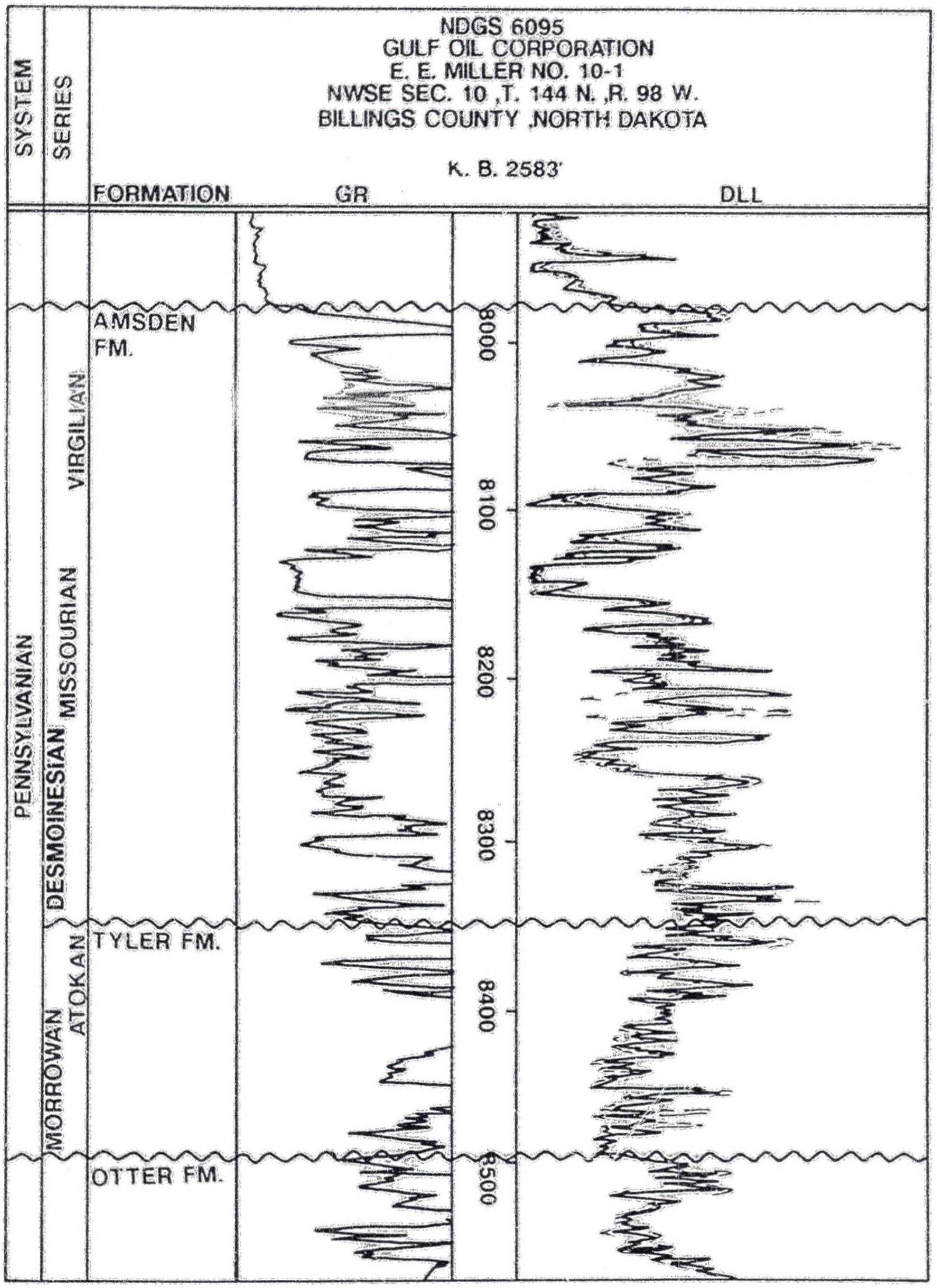

SYSTEM
SERIES
NDGS 6095
GULF OIL CORPORATION
E. E. MILLER NO.10-1
NWSE SEC. 10 ,T. 144 N. ,R. 98 W.
BILLINGS COUNTY ,NORTH DAKOTA
FORMATION
GR
K. B. 2583'
DLL
PERMIAN
LEONARDIAN
WOLFCAMPIAN
MINNEKAHTA FM.
OPECHE FM.
BROOM CREEK FM.
AMSDEN FM.
7400
7500
7600
7700
7800
7900
8000

Figure 5b. Wireline log (gamma-ray, dual laterolog) showing typical formation markers picked in the study (lower half of stratigraphic column). Unconformities are denoted by wavy lines.


NDGS 6095
GULF OIL CORPORATION
E. E. MILLER NO. 10-1
NWSE SEC. 10 ,T. 144 N. ,R. 98 W.
BILLINGS COUNTY ,NORTH DAKOTA
K. B. 2583'
SYSTEM
SERIES
FORMATION
GR
DLL
PENNSYLVANIAN
VIRGILIAN
MISSOURIAN
DESMOINESIAN
ATOKAN
MORROWAN
AMSDEN FM.
TYLER FM.
OTTER FM.
8000
8100
8200
8300
8400
8500

Nomenclature and Previous Works

The name "Broom Creek" was first used as a group name for a red sandstone and carbonate unit lying between the top of the Wendover Group and the base of the Cassa Group in Broom Creek Valley, Platte County, Wyoming (Condra and others, 1940). The age of the Broom Creek Group was uncertain and thought to be either Late Pennsylvanian or Early Permian. In 1943, Condra and Reed expanded the Broom Creek Group to include additional overlying beds originally placed within the Cassa Group and also described a subsurface section in western Nebraska, which included interbeds of anhydrite not found in outcrop. The age of the Broom Creek Group was determined to be Early Permian.

The North Dakota Geological Society (1954) recognized a basal Amsden Formation and overlying Minnelusa Formation in the subsurface of North Dakota. This usage incorporated terminology from Montana (Amsden) and South Dakota (Minnelusa) to describe Upper Pennsylvanian and Lower Permian strata in the North Dakota portion of the Williston basin (McCauley, 1955). The term "Minnelusa" was originally used to describe strata between the Mississippian Pahasapa Formation and the Permian Opeche Shale in the Black Hills of South Dakota (Darton, 1901). Broom Creek terminology was not used at that time to describe any Permian strata in North Dakota.

The Broom Creek Formation was originally correlated from eastern Wyoming to North Dakota by McCauley (1955).

Nomenclature used in Wyoming (Condra and others, 1940), including the Fairbank, Reclamation, Roundtop, Hayden, Wendover-Meek, Broom Creek, and Cassa Groups, was applied to the strata overlying the Mississippian unconformity and underlying the Opeche Shale, which had previously been assigned to the Minnelusa and Amsden Formations (North Dakota Geological Society, 1954). Other than the "Broom Creek Formation", the terminology used by McCauley (1955) was never adopted by the North Dakota Geological Society or the North Dakota Geological Survey.

Ziebarth (1972) further defined the Broom Creek Formation to replace the predominantly sandy upper portion of the Minnelusa Formation as recognized by the North Dakota Geological Society, and raised the Minnelusa to group status. According to Ziebarth (1972), the Minnelusa Group consisted of the basal Tyler Formation, Alaska Bench Formation, Amsden Formation, and Broom Creek Formation. The Broom Creek Formation was bounded unconformably by the overlying Opeche Formation (Middle Permian) and the underlying Alaska Bench Formation (Upper Pennsylvanian).

This paper uses the nomenclature as adopted by the North Dakota Geological Survey (Bluemle and others, 1986). This usage differs from Ziebarth (1972) only by placing the Alaska Bench as a lower member within the Amsden Formation. The Broom Creek Formation remains as the uppermost part of the Minnelusa Group and is bounded disconformably by the Amsden and Opeche Formations. A summary of previously used

stratigraphic nomenclature is given in Figure 6.

The only major North Dakota study of Permian Pennsylvanian strata including the Broom Creek Formation is Ziebarth (1972). The main thrust of his study was the definition of lithotypes within the Amsden Formation. No core from the Broom Creek Formation was studied and a general description of the sedimentary origin was postulated to be nearshore marine. All other studies of Broom Creek equivalent strata have occurred outside the Williston basin, mainly in the Powder River basin (Wyoming) where the correlative Upper Minnelusa Formation produces oil.

Methods

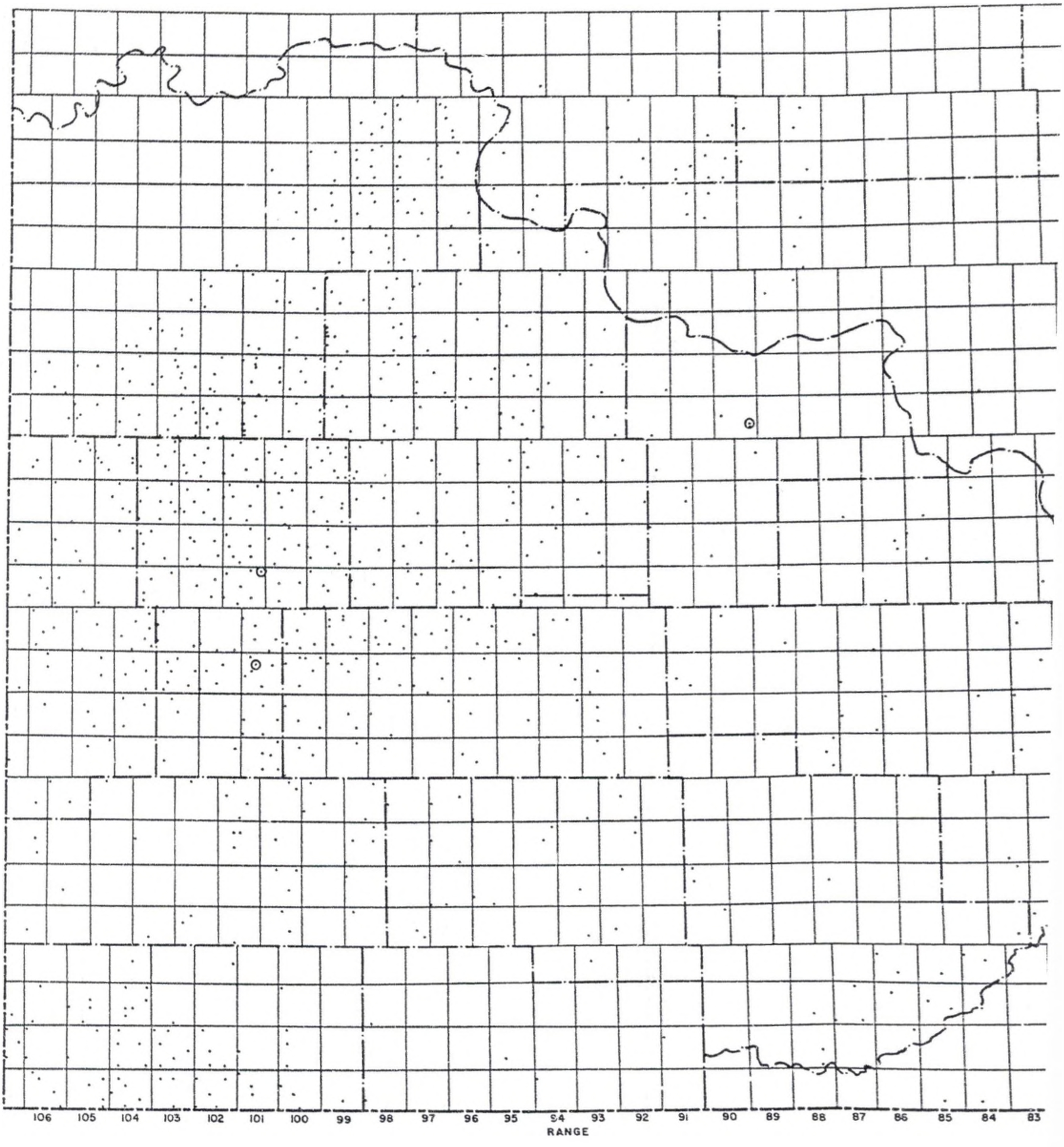
Wireline logs from 885 oil wells (Fig. 7) in the study area were used to determine formational markers, thicknesses, and lithologic changes in the Broom Creek Formation. An attempt was made to obtain a uniform distribution of wells across the study area. In regions of dense well control, approximately six to eight wells per township were studied. All wells were used in the sparsely drilled areas. Log data were used to construct various structure maps, isopach maps, cross sections and lithologic maps. All wireline logs used are part of the oil and gas well records of the North Dakota Geological Survey. Resistivity and gamma-ray logs were primarily used for formation identification and correlation. The main stratigraphic tops determined from logs were: the Big Snowy

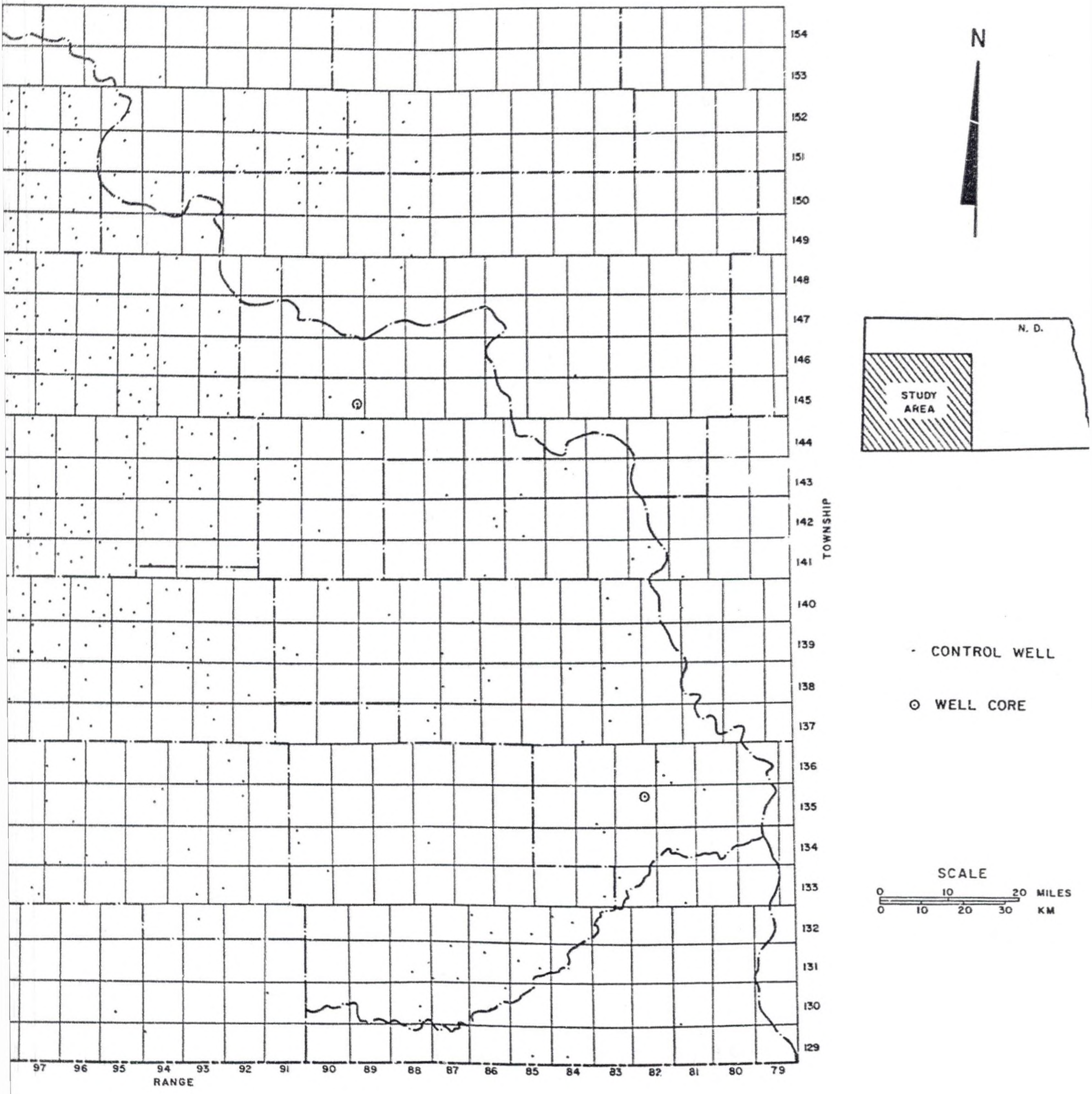
Figure 6. A summary of previously used stratigraphic nomenclature, Pennsylvanian and Permian (partial) strata.

SYSTEM	SERIES	DARTON 1901 (BLACK HILLS)	SMITH 1903 (HARTVILLE UPLIFT)	CONDRA & REED 1935 (HARTVILLE UPLIFT)		CONDRA, et al. 1940 (HARTVILLE UPLIFT)	N.D. GEOL. SOCIETY 1954 (WILLISTON BASIN)	ZIEBARTH 1972 (WILLISTON BASIN)		* N.D. GEOL. SURVEY 1986 (WILLISTON BASIN)	
PERMIAN (PARTIAL)	LEONARDIAN	OPECHE FM.	OPECHE FM.	OPECHE FM.		OPECHE FM.	OPECHE FM.	OPECHE FM.		OPECHE FM.	
		MINNELUSA FM.	HARTVILLE FM.	DIVISION I	HARTVILLE FM.	CASSA GROUP					
	WOLFCAMPIAN					BROOM CREEK GROUP	MINNELUSA FM.	BROOM CREEK FM.	MINNELUSA GROUP	BROOM CREEK FM.	MINNELUSA GROUP
PENNSYLVANIAN	VIRGILIAN / MISSOURIAN / DESMOINESIAN			DIVISION II		WENDOVER GROUP / MEEK GROUP		AMSDEN FM.		AMSDEN FM.	
				DIVISION III		HAYDEN GROUP					
				DIVISION IV		ROUNDTOP GROUP	AMSDEN FM.				
	ATOKAN / MORROWAN			DIVISION V		RECLAMATION GROUP		ALASKA BENCH FM.			
				DIVISION VI		FAIRBANK FM.		TYLER FM.		TYLER FM.	

*TERMINOLOGY USED IN THIS PAPER

Figure 7. Map showing the distribution of wells used in the study. Cored wells shown with open circles.


106 105 104 103 102 101 100 99 98 97 96 95 94 93 92 91 90 89 88 87 86 85 84 83
RANGE


154
153
152
151
150
149
148
147
146
145
144
143
142
141
140
139
138
137
136
135
134
133
132
131
130
129
TOWNSHIP
97 96 95 94 93 92 91 90 89 88 87 86 85 84 83 82 81 80 79
RANGE
N
N. D.
STUDY AREA
CONTROL WELL
WELL CORE
SCALE
0 10 20 MILES
0 10 20 30 KM

Group (Mississippian), Tyler Formation (Pennsylvanian), Amsden Formation (Pennsylvanian), Broom Creek Formation (Permian), Opeche Formation (Permian), and Minnekahta Limestone (Permian). Whenever possible, formation density compensated - compensated neutron logs (FDC-CNL) were used for lithologic determination of beds within the Broom Creek Formation and also to recognize accumulations of nitrogen gas. All formational data acquired from logs were entered on a personal computer spreadsheet and mathematical manipulations were performed, using the spreadsheet software, to attain the desired stratigraphic information. Contour maps of various stratigraphic data were constructed using a computer contouring program. The cursory computer generated maps were subsequently modified by hand using conventional contouring practices.

Only a few cores exist of the Broom Creek Formation in the Williston basin. A computer search of the records of the North Dakota Geological Survey was used to find all the available Broom Creek core in the state. Four wells with core of the Broom Creek Formation were located. Approximately 160 feet (49 meters) of core from the four wells in the study area were described. The cored wells are denoted by open circles in Figure 7. All the cores are curated at the Wilson M. Laird Core and Sample Library operated by the North Dakota Geological Survey. Core lengths ranged from 16 to 60 feet (5 to 18 meters). All cores studied consisted primarily of the Broom Creek

Formation. Three of the cores contained overlying Opeche siltstone and the accompanying Opeche - Broom Creek contact. Fortunately, core sampling was sufficient to recognize different lithofacies from which depositional environments could be discerned. The sparse core data greatly assisted the determination of depositional environments, obviating interpretations based solely on wireline logs of the Broom Creek Formation.

All cores were slabbed and a reflected light microscope and hand lens were used for macroscopic core description. Core descriptions are given in Appendix A. Twenty-three core samples were taken from representative core sections and made into thin sections. Some thin sections were impregnated with blue epoxy to aid in the recognition of pore shape, size, abundance, and distribution. A polarizing light microscope was used for detailed petrographic analysis. Visual estimates were made of individual mineral content and porosity. Thin section descriptions are given in Appendix B.

Black and white photographs and color slides were taken of cores showing significant depositional structures. Slabbed surfaces were illuminated with a light source and water was applied to the core surface to enhance contrast. A 35mm single-lens-reflex camera with a macro lens was used for photographing core. Multiple photos using a range of f-stops were used to achieve a desirable exposure.

RESULTS OF CORE DESCRIPTIONS

Introduction

Three main lithofacies characterize the Broom Creek Formation. These lithofacies were determined primarily from core data and are as follows: 1) nearshore marine sandstone lithofacies, 2) marine carbonate lithofacies, and 3) eolian sandstone lithofacies. Overall, the Broom Creek Formation is a pink sandstone with some intervening beds of dolostone. Core analysis revealed a distinct offshore marine sandstone facies and a distinct eolian sandstone facies. Core diagrams for the four cored wells are shown in Figures 8, 9, 10, and 11. Map locations for all four wells are given in Figure 7.

Nearshore Marine Sandstone Lithofacies

The nearshore marine sandstone lithofacies generally consists of fine- to medium-grained, well-sorted, pink quartzarenite. The marine interpretation is based primarily on sedimentary structure and fossil evidence observed in cored section. Nearshore marine sandstones occur, to some degree, in all of the four wells with cored sections of the Broom Creek Formation. A substantial section of nearshore marine sandstone lithofacies exists in two of the four well cores; the ANG #1 Disposal well (Fig. 8) and the John Gangl #1 well (Fig. 9).

Twenty-six feet (eight meters) of nearshore marine sandstone lithofacies is present in the ANG #1 Disposal well

Figure 8. Core diagram of the ANG Disposal #1 well showing major lithofacies present. Core depths given in feet.

ANG DISPOSAL #1
SE SW SEC. 24, T.145 N., R.88 W.
MERCER COUNTY, NORTH DAKOTA

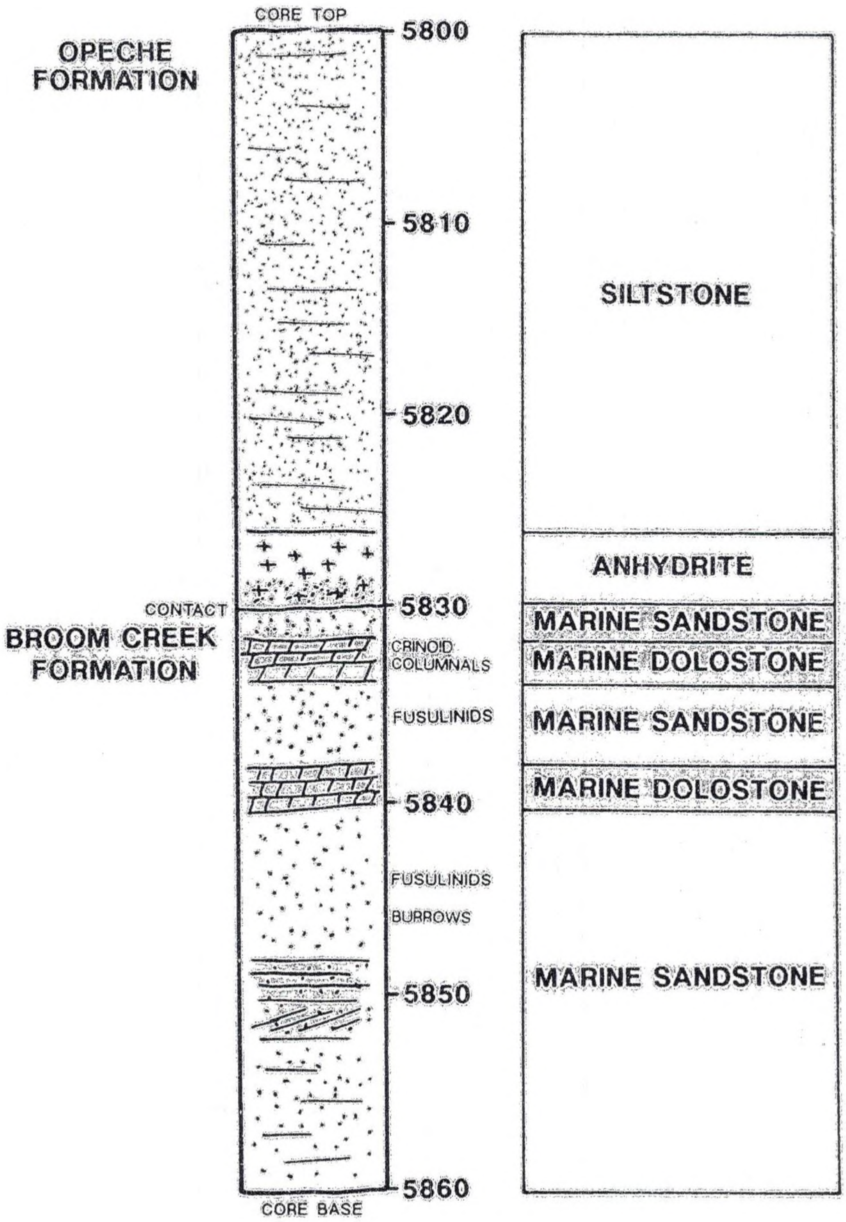
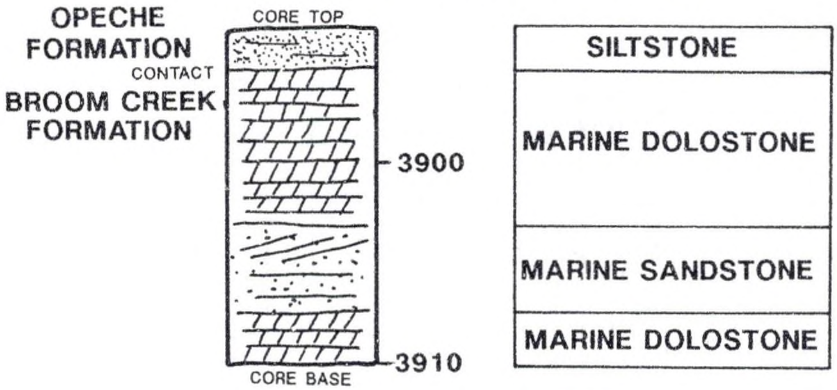


Figure 9. Core diagram of the John Gangl #1 well showing major lithofacies present. Core depths given in feet.

Figure 10. Core diagram of the Burlington Northern #1 well showing major lithofacies present. Core depths given in feet.

NDGS #4989
JOHN GANGL #1
SW NE SEC. 11, T.135 N., R.82 W.
MORTON COUNTY, NORTH DAKOTA



NDGS #5196
BURLINGTON NORTHERN #1
NE SE SEC. 1, T.141 N., R.100 W.
BILLINGS COUNTY, NORTH DAKOTA

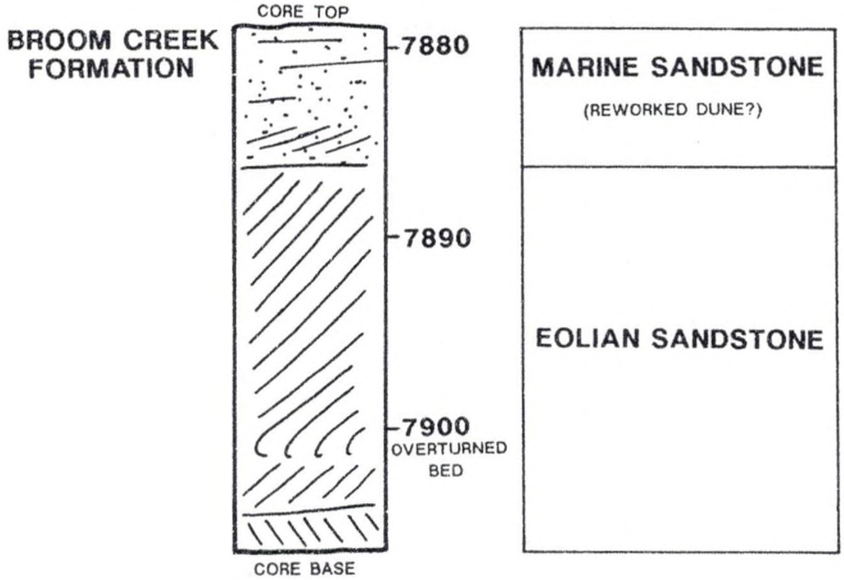
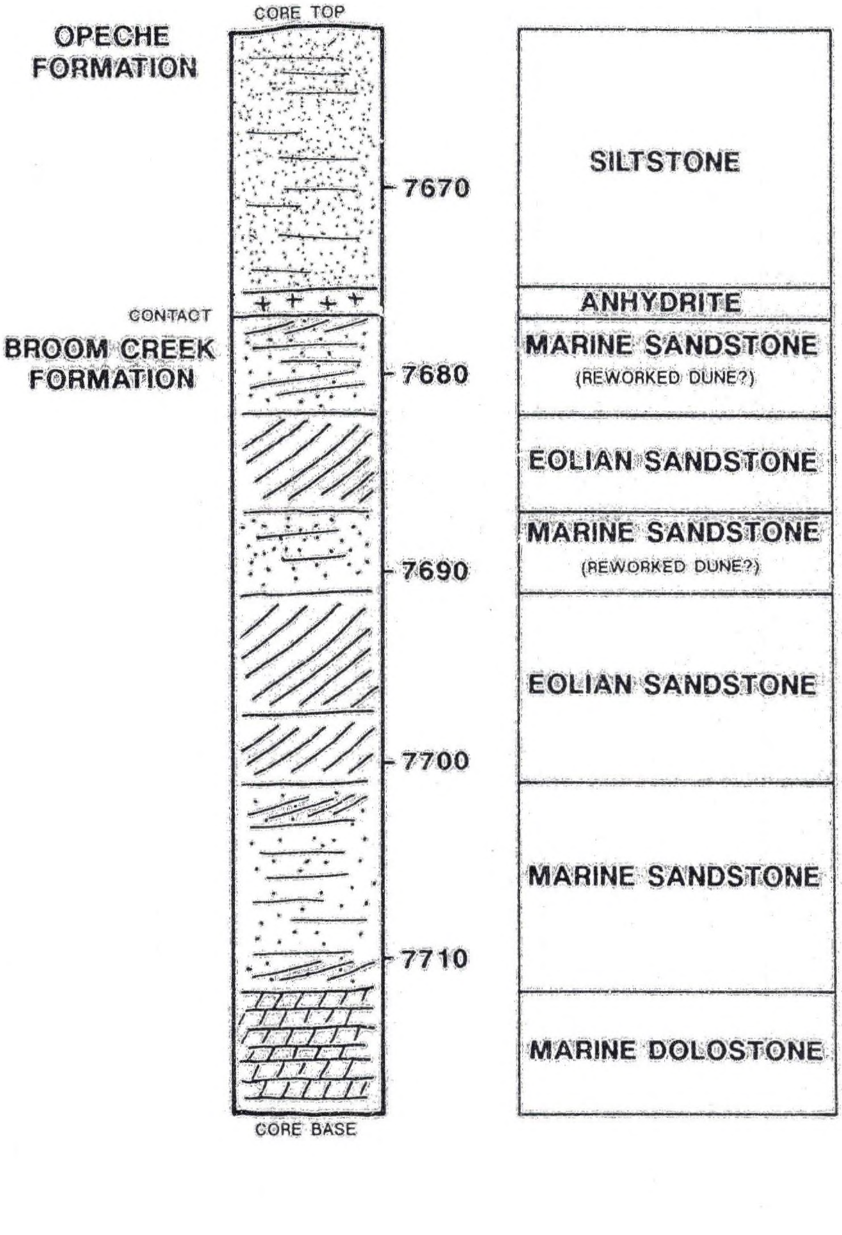


Figure 11. Core diagram of the Herman May #2 well showing major lithofacies present. Core depths given in feet.

NDGS #658
HERMAN MAY #2
SE SE SEC. 9, T.139 N., R.100 W.
BILLINGS COUNTY, NORTH DAKOTA



(Fig. 8). The nearshore marine sandstone lithofacies makes up the bulk of the cored section. The majority of the Broom Creek section in the ANG well is a pink quartzarenite with a few intervening dolostone beds. A number of marine sedimentary structures are found in the ANG well. The lowest part of the Broom Creek cored section consists of approximately eight feet (2.4 meters) of very friable, thinly laminated quartzarenite. This thinly laminated section grades upward to a four-foot-thick bed (1.2 meter) of moderately to well cemented quartzarenite containing some ripple cross lamination. Further up section in the ANG well, the pink quartzarenite becomes well cemented and there is evidence of burrow structures and a moderate abundance of fusulinids. The fusulinids are scattered fairly evenly throughout the upper section. The net thickness of the burrowed fossiliferous section is approximately 15 feet (4.5 meters). A core photograph of a typical section of the burrowed, fossiliferous sandstone core is shown in Figure 12.

The contact between the Broom Creek Formation and the Opeche Formation in the ANG well consists of medium- to fine-grained pink Broom Creek quartzarenite overlain by a four-foot-thick bed (1.2 meter) of Opeche anhydrite (Fig. 8). This Opeche anhydrite is primarily massive and contains a few thin beds of poorly sorted quartzarenite. A few chert fragments also occur in the anhydrite bed. The bulk of the remaining Opeche section consists of very-fine-grained

Figure 12. Core photograph of marine sandstone lithofacies. Note scattered fusulinids.


ANG COAL GASIFICATION CO.
DEEP WELL #1
SESW SEC. 24-T145N-R88W
MERCER COUNTY
5844
5 cm.

siltstone which is much darker red than the underlying Broom Creek quartzarenite.

The John Gangl #1 well has a total of 15 feet (4.6 meters) of core from the uppermost part of the Broom Creek Formation (Fig. 9). The cored section of nearshore marine sandstone lithofacies in the John Gangl #1 well consists of a four-foot-thick bed (1.2 meter) of fine-grained, well-sorted, pink quartzarenite, with some ripple cross lamination; no fossils are present. In the John Gangl #1 well, the marine sandstone lithofacies lies between beds of fine-grained, pink dolomudstone. The upper bed of dolomudstone is nine feet thick (2.7 meters) and directly underlies the very-fine-grained, dark-red Opeche siltstone. There is no evidence of an eolian sandstone lithofacies in either the ANG #1 Disposal or John Gangl #1 wells.

A few sandstone beds in the Burlington Northern #1 well (Fig. 10) and the Herman May #2 well (Fig. 11) appear to be part of the nearshore marine sandstone lithofacies. However, a substantial thickness of nearshore marine sandstone lithofacies is not present in either the Burlington Northern #1 or Herman May #2 wells. The cored Broom Creek intervals in the Burlington Northern #1 well and the Herman May #2 well lack fossils. A ten-foot-thick bed (three meters) of fine- to medium-grained, pink quartzarenite occurs in the lower part of the Herman May #2 core (Fig. 11). This bed contains low-angle, cross-laminated structures and appears to be a nearshore marine

sandstone directly overlying a dolomudstone. A few other relatively thin beds (one foot thick) of quartzarenite, containing no particular distinguishing sedimentary structures, are present in the Herman May #2 well. These beds, interbedded with much thicker beds of steeply dipping, laminated sandstone, may also be part of the nearshore marine sandstone lithofacies.

The uppermost part of the Broom Creek core in the Burlington Northern #1 well consists of seven feet (2.1 meters) of fine- to medium-grained, moderately well-sorted, red quartzarenite (Fig. 10). The bedding is indistinct and there are some faint, wispy laminations and some thin beds of friable sandstone. This uppermost Broom Creek bed directly overlies a thick section of steeply inclined, laminated sandstone, which is the most dominant structure throughout the cored section in the Burlington Northern #1 well. It is postulated that this uppermost, laminated section represents reworked eolian sediments directly overlying undisturbed eolian beds. The same relationship of marine sandstone overlying eolian sandstone occurs twice in the Herman May core (Fig. 11).

Marine Carbonate Lithofacies

The marine carbonate lithofacies in the Broom Creek Formation, as determined from core examination and wireline log characteristics, consists of a dolomitized carbonate mudstone. This lithofacies is present in three of the four

wells with Broom Creek core; the ANG #1 Disposal, the John Gangl #1, and the Herman May #2 wells (Figures 8, 9, and 11). The lithology of the dolomudstone is quite consistent throughout the different well cores. These carbonate sections consist of very-fine-grained, mainly massive, pink dolomudstone. A few beds exhibit faint, thin laminations. Beds of dolomudstone range in thickness from two to seven feet (.6 to 2.1 meters). Much of the dolomudstone contains minor amounts of quartz grains scattered throughout the matrix.

Only relics of fossils can be discerned in most of the dolomudstone beds. The dolostone generally appears to be moderately burrowed. From the available core, the only distinct fossils occur in a three-foot-thick bed (one meter) of dolostone near the upper contact of the Broom Creek Formation in the ANG #1 Disposal well (Fig. 8). This fine-grained dolomite bed contains bryzoan fenestrae and small diameter (less than three mm) crinoid columnals. Lower in the ANG #1 Disposal core, two beds (two to four feet thick) of massive pink dolomudstone contain scattered fusulinids. These beds of dolostone occur within the burrowed, fossiliferous sandstone section, which also contains fusulinids.

Eolian Sandstone Lithofacies

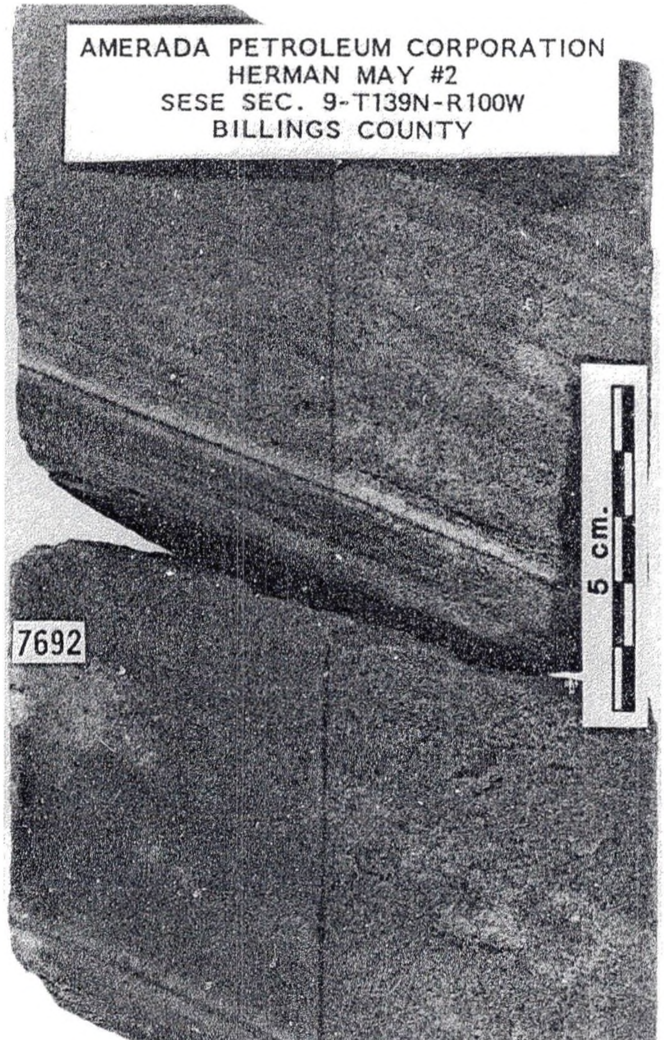
The eolian sandstone lithofacies, as found in core, consists of a fine- to medium-grained, well-sorted, pink

quartzarenite. The eolian interpretation is based primarily on distinguishing sedimentary structures and some textural relationships.

The eolian sandstone lithofacies occurs in the Burlington Northern #1 well (Fig. 10) and the Herman May #2 well (Fig. 11), which are both located in the western part of the study area (Fig. 7). The most diagnostic sedimentary structure, in the two western well cores, is relatively thick beds of steeply inclined, uniformly oriented, parallel laminae, one to two millimeters thick. Some of these steeply inclined laminae are very distinct, however, most laminae tend to be very faint. Bed orientation is uniform over sections of core five to ten feet (1.5 to 3 meters) in length. The uniformly dipping strata contain few truncated beds or reactivation surfaces. These large sections of uniformly dipping planar beds are the most convincing evidence of eolian sedimentation. The steeply dipping, inclined strata are interpreted as foreset beds deposited by eolian dunes. A typical section of steeply dipping, eolian foreset strata is shown in Figure 13.

Forty-one feet (12.5 meters) of Broom Creek Formation was cored in the Herman May #2 well (Fig. 11). Near the middle portion of the cored Broom Creek section, three beds of steeply dipping laminae attain a combined thickness of 15 feet (4.6 meters). These eolian strata are separated by beds of massive quartzarenite and some thin dolostone beds. The lower section of the core in the Herman May #2 well does

Figure 13. Core photograph of eolian sandstone lithofacies showing steeply dipping parallel laminae.

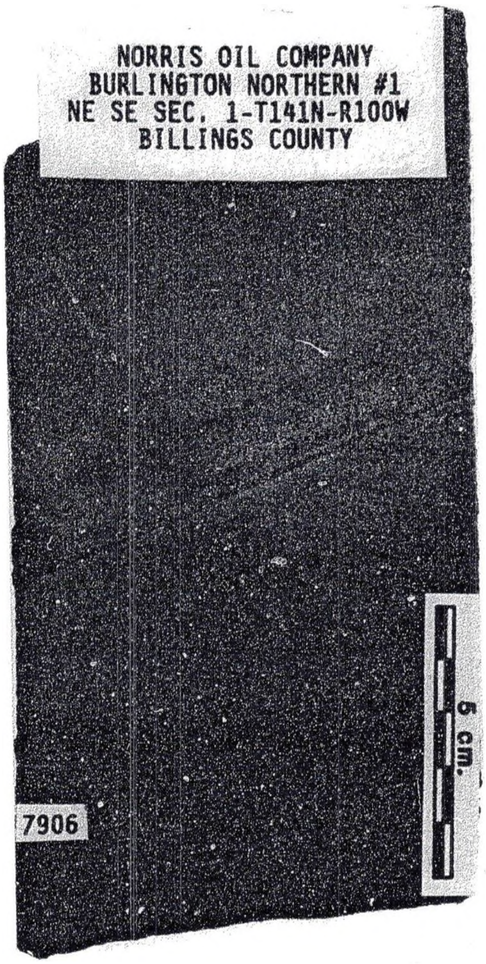

AMERADA PETROLEUM CORPORATION
HERMAN MAY #2
SESE SEC. 9-T139N-R100W
BILLINGS COUNTY
5 cm.
7692

not show any distinct eolian features. Low-angle, cross-bedding and massive, sandstone beds predominate in the lower section. Similarly, the uppermost Broom Creek strata in the Herman May #2 well, near the Opeche Formation contact, does not contain any eolian sedimentary structures.

The Broom Creek core in the Burlington Northern #1 well is entirely made up of pink quartzarenite (Fig. 10). No dolostone beds are present in the cored section. A total of 27 feet (8.2 meters) of upper Broom Creek Formation was cored. The lower 20 feet (6.1 meters) of cored section consists solely of steeply dipping, foreset strata. Eolian sediments from the Burlington Northern #1 and the Herman May #2 cores are very similar. As in the Herman May #2 well, bedding orientation of the foreset strata in the Burlington Northern #1 well remains consistent throughout the entire cored section. The steeply dipping, inclined strata in the Burlington Northern #1 core contain sets of thin distinct laminae alternating with some thicker beds, which have only faint bedding plane boundaries. A few thin laminae, one or two quartz grains in thickness, tend to be much coarser-grained than the surrounding material. These laminae appear to be lag deposits.

A rare set of large-scale, cross stratification is preserved in core from the Burlington Northern #1 well (Fig. 14). This is the only evidence, in core, of a major change in bedding orientation within the eolian deposits. As shown in Figure 14, the large, cross-bed set shows truncation of

Figure 14. Core photograph of eolian sandstone lithofacies showing cross laminations.


NORRIS OIL COMPANY
BURLINGTON NORTHERN #1
NE SE SEC. 1-T141N-R100W
BILLINGS COUNTY
7906
5 cm.

underlying dipping strata and subsequent deposition of differently oriented strata. Note that the truncation surface is not level, but also dips. This is typical cross-bedding formed by the migration of one dune over another (Fryberger and others, 1983).

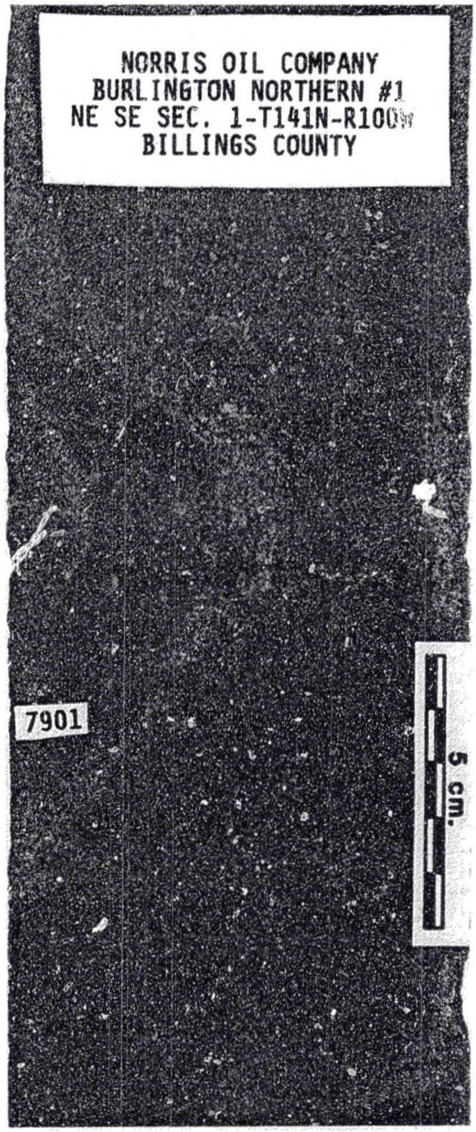
Evidence of an overturned and contorted eolian bed is also present in the Burlington Northern #1 core (Fig. 15). A three-inch-thick bed (7.5 cm), completely overturned, is preserved in the Burlington Northern #1 well. The steeply inclined, parallel laminae retain continuity below and above the overturned bed.

The eolian lithofacies contains a few thin beds (1-3 mm) of alternating pink and white quartzarenite. The alternating color change from pink to white roughly follows bedding planes and occurs predominantly in the steeply inclined strata. Small sets of cross-bedded structures and low-angle, parallel laminae also exhibit alternating pink to white color changes, although rarely. The color alternation appears to be a function of the amount of interstitial anhydrite in the sandstone. The white beds contain larger amounts of anhydrite.

Overlying Strata

The overlying Opeche Formation consists of beds of fine-grained siltstone and locally thin beds of salt or anhydrite. Three wells contained core of the Opeche Formation, the ANG #1, the John Gangl #1, and the Herman May

Figure 15. Core photograph of eolian sandstone lithofacies showing overturned bedding.


NORRIS OIL COMPANY
BURLINGTON NORTHERN #1
NE SE SEC. 1-T141N-R100W
BILLINGS COUNTY
7901
5 cm.

#2 (Figures 8, 9, and 11). In core, the Opeche is a massive siltstone with a few faint, horizontal laminations. A thin basal salt section is identified on logs but no cored section exists. A thick middle salt section, in excess of 100 feet (30.5 meters), occurs in the north-central part of the study area. A typical section of the Opeche Formation, showing the middle salt member, is illustrated in Figure 5a. In core, the erosional nature of the Broom Creek - Opeche contact is subtle. Some angular chert fragments occur in the Opeche siltstone near the Broom Creek contact. A brecciated zone or other evidence of high-energy reworking of Broom Creek strata does not exist in any core of the basal Opeche section.

DIAGENESIS

Introduction

Three distinct lithofacies have been identified in the Broom Creek Formation. Macroscopic descriptions involving texture, mineralogy, and sedimentary structure have previously been described. The following section describes the major diagenetic features of each lithofacies as determined from thin section analysis.

Nearshore Marine Sandstone Lithofacies

The nearshore marine sandstone lithofacies is a fine-grained, well-sorted, texturally mature quartzarenite. Dolomite and quartz constitute the major cementing agents in this lithofacies. Dolomite exists as a fine-grained intergranular cement making up 15 percent of the bulk volume of the rock on average. All carbonate material, including fossils, has been completely dolomitized in the nearshore marine sandstone lithofacies. Some sections of sandstone have an abundance of fine-grained dolomite (>25 percent). These sections appear to be a transitional lithofacies between a pure marine sandstone and marine dolomudstone.

Quartz cement exists as overgrowths on the sandstone grains. The extent of quartz overgrowth development is difficult to determine as only a few original quartz grain boundaries are distinguishable in thin section. However, the quartz overgrowths do not appear to be extensive. Quartz cement never occludes the entire intergranular space.

The majority of the quartz grains have partial suture contacts with surrounding grains as a result of pressure dissolution of quartz.

Anhydrite is a minor constituent (five percent or less) in the nearshore marine lithofacies. Blocky anhydrite fills vugs and fractures. Anhydrite appears to replace some of the intergranular dolomite, although the replacement is not pervasive throughout the marine sandstone section. Anhydrite also occurs throughout the nearshore marine sandstone lithofacies as scattered patches entirely occluding pore space between quartz grains.

A minor amount of fine-grained iron oxide, seen as opaques in thin section, is dispersed evenly throughout the nearshore marine sandstone lithofacies. This fine-grained iron oxide is responsible for the pervasive pink coloration found in the bulk of Broom Creek core. All the iron oxide is intergranular and disseminated throughout both the quartz and dolomite cements.

The porosity in the marine sandstone lithofacies is fairly well developed. Average values of porosity are approximately 15 percent. The predominant porosity type is intergranular where cementing material (quartz and dolomite) has not occluded the primary porosity. Evidence in thin section indicates development of secondary porosity from dissolution of some of the interstitial anhydrite. Dissolution of anhydrite is not very common throughout the marine sandstone lithofacies.

The diagenetic history of the marine sandstone lithofacies appears to consist of a number of early stage, diagenetic events and a number of later stage events. The early stage diagenetic events were minor iron oxide precipitation, the formation of quartz overgrowths and subsequent partial cementation by quartz, dolomitization of all carbonate material including fusulinids, and minor gypsum precipitation. Later stage diagenetic events include porosity reduction from compaction and pressure dissolution of quartz grains, minor replacement of dolomite with anhydrite, and minor dissolution of anhydrite. This study did not examine the clay mineralogy of the Broom Creek Formation but other studies (Schenk and others, 1988) report illitization of clays as an additional late stage diagenetic event.

Marine Carbonate Lithofacies

The marine carbonate lithofacies is predominantly a fine-grained dolomudstone, which has a number of distinctive diagenetic features.

As previously mentioned, all carbonate material in the Broom Creek core has been dolomitized. The dolomudstone section is entirely made up of small rhombs (less than .25 mm in length) of dolomite. All fossil material has been dolomitized and only faint outlines of original fossils and burrow structures remain in the dolomudstone sections. Stylolites are rare and occur only in the dolostone section

in the John Gangl #1 well. One bed in the John Gangl #1 core contains a few stylolites with a maximum height of one-half inch (1.25 cm).

Overall, the porosity of the dolomudstone is not well developed (less than five percent). Molds of small crinoid columnals occur in an upper dolostone bed in the ANG #1 Disposal well. This is the only evidence of moldic porosity in the dolomudstone. Minor amounts of vuggy porosity exist in the carbonate lithofacies. Vug size is usually no more than one or two millimeters.

The pervasive dolomitization of all carbonate material in the Broom Creek Formation appears to be an early diagenetic feature. A possible mechanism for dolomitization consists of magnesium-rich, reflux brines, which formed during the deposition of the overlying Opeche evaporite beds. Fine-grained dolomite rhombs replaced the original fine-grained, bioturbated carbonate mud. This model for dolomitization is very similar to Schenk and others' (1988) proposed method of dolomitization of the Upper Minnelusa carbonates in Wyoming. However, the origin of the reflux brines in the Upper Minnelusa Formation were attributed to intraformational anhydrite deposition, not to the overlying Opeche Formation.

Eolian Sandstone Lithofacies

The eolian sandstone lithofacies consists of a fine- to medium-grained, well-sorted, texturally mature

quartzarenite. The mineralogies of the eolian sandstone lithofacies from the Herman May #2 and Burlington Northern #1 well are quite similar. Quartz is the dominant constituent with minor amounts (five to ten percent) of anhydrite. Iron oxide (hematite) is another minor constituent, and makes up less than five percent of the bulk volume.

Quartz is the dominant cement in the eolian sandstone lithofacies, which is distinctly different than the pervasive dolomite cement in the nearshore marine sandstone lithofacies of the Broom Creek Formation. The quartz cement exists as overgrowths on the sandstone grains. Quartz overgrowths are not so well developed that pore space is completely occluded. Partial suture contacts between quartz grains are common. Anhydrite (originally gypsum) also serves as a cementing material. The presence of pervasive anhydrite cement is a localized feature. Several beds of eolian sandstone are almost completely cemented with anhydrite. In a few cases, some thin beds of eolian sandstone consist of quartz grains completely suspended in anhydrite cement. The anhydrite-cemented beds are more common in the coarser-grained, laminated sections.

The eolian lithofacies has excellent porosity, with average values of 15 to 20 percent. Porosity development appears to be a combination of primary porosity and secondary porosity. The primary porosity has been reduced as the result of compaction and pressure solution of quartz.

Secondary porosity has developed from the partial dissolution of interstitial anhydrite.

As in the marine sandstone lithofacies, iron oxide is pervasive in the eolian sandstone lithofacies, which gives the section the familiar pink to red coloration. This red coloration from iron oxide staining is not evenly distributed in the eolian sandstone lithofacies. Where present, the iron oxide exists as a very-fine-grained precipitate disseminated throughout interstitial spaces in the sandstone. Iron staining is distinctly absent in a number of beds throughout the eolian cored section. Several sections of very white, unstained eolian sandstone, up to six inches thick (15 cm), are present in core. These unstained sections roughly follow bedding plane boundaries. Some beds of cross strata exhibit alternating pink and white coloration. The absence of iron staining usually coincides with a relative abundance of anhydrite cement, particularly in beds where anhydrite had totally occluded all porosity.

There is a distinctive mineralogical difference between the eolian lithofacies in the Herman May #2 and Burlington Northern #1 wells and the marine sandstone lithofacies in the ANG #1 core. The marine facies has substantial amounts of dolomite cement along with the quartz cement. The predominance of dolomite cement in the marine sandstone lithofacies is attributed to the incorporation of primary carbonate material during the time of deposition. The eolian lithofacies is virtually devoid of any dolomite.

Schmoker and Schenk (1988) used analogous mineralogical differences, determined from the FDC-CNL log response, to distinguish and correlate lithofacies in the Upper Minnelusa Formation in the Powder River basin. Close well control along with high core density enabled the authors to determine depositional facies based on FDC-CNL log response quite effectively. This paper does not use such a specific technique for identifying lithofacies. However, wireline logs are used to distinguish major lithologic changes throughout the Broom Creek Formation.

The diagenetic history of the eolian sandstone lithofacies appears to have followed a slightly less complex path than the marine sandstone lithofacies. This is mainly due to the lack of carbonate material in the eolian sandstone lithofacies. The early stage diagenetic events were gypsum precipitation (possibly syndepositional), iron oxide precipitation, and the formation of quartz overgrowths and subsequent quartz cementation. Later stage diagenetic events include porosity reduction from compaction and pressure dissolution of quartz grains, and minor dissolution of anhydrite. As previously discussed, clay diagenesis in the Broom Creek Formation was not studied, but another study (Schenk and others, 1988) reports illitization of clays in Wolfcampian eolian sediments as an additional late-stage diagenetic event.

RESULTS OF WELL LOG INTERPRETATIONS

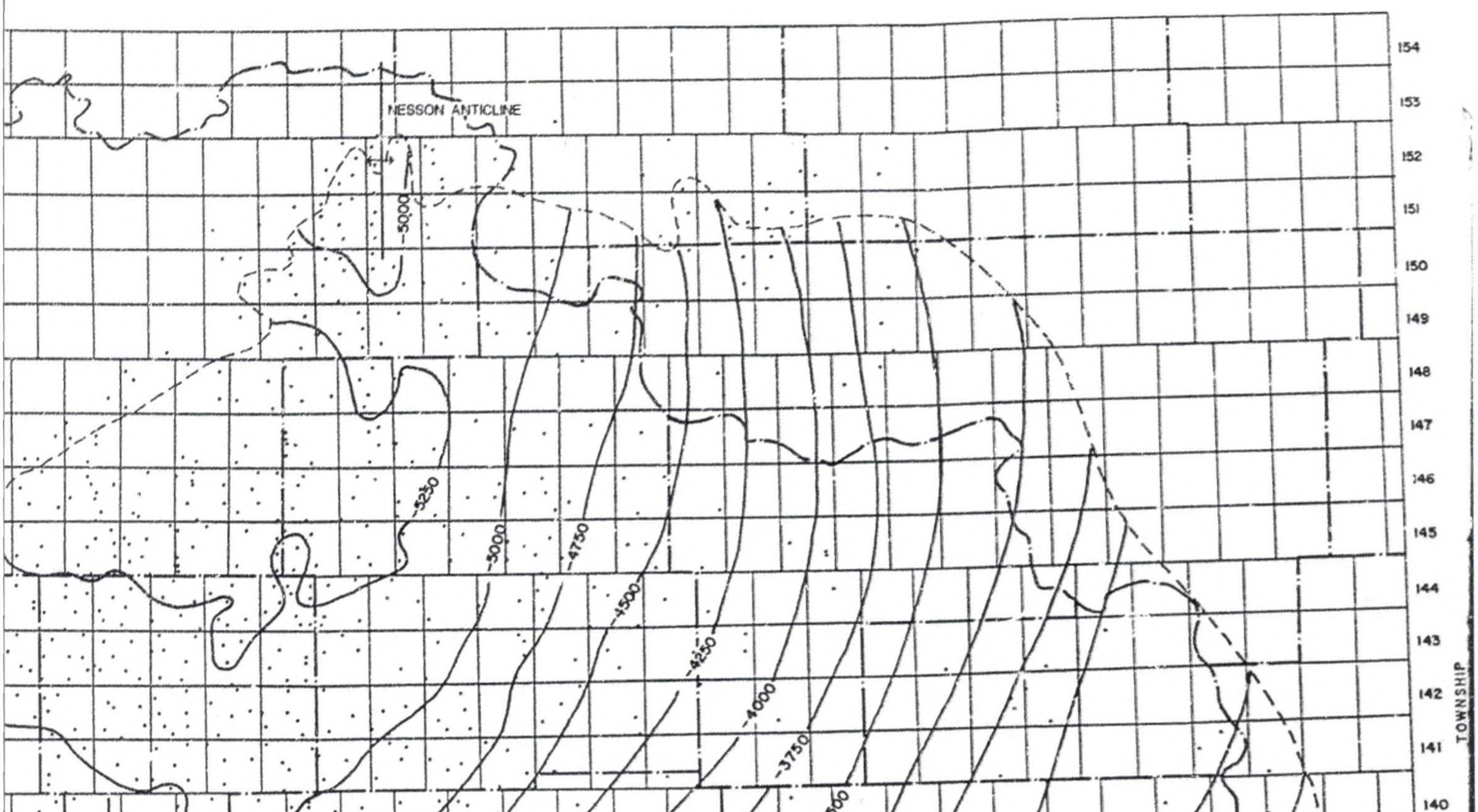
Structure

The present structure of the Broom Creek Formation conforms to the general shape of the Williston basin, as mapped on other subsurface stratigraphic horizons. Well-known, major, tectonic features are evident from the structure map of top of the Broom Creek Formation (Fig. 16), such as the southern portion of the Nesson anticline (T.151 N., R.96 W.), the Billings anticline (T.139 N., R.101 W.), and the Cedar Creek anticline (T.129 N., R.106 W.). Small disruptions in the structure contour lines are mapped as minor anticlines and synclines. However, these structures may be fault-controlled.

Cross Sections

Four stratigraphic cross sections using gamma-ray and dual laterolog wireline logs are presented in Figures 17, 18, 19, and 20. The stratigraphic datum used for the cross sections is a highly resistive carbonate unit near the top of the Amsden Formation. This unit is quite prevalent throughout the study area and corresponds to the middle portion of what Ziebarth (1972) termed the "Bismarck Lithozone". There are no laterally continuous strata within the Broom Creek Formation or the overlying Opeche Formation to use as a stratigraphic datum. The erosional nature of the upper and lower Broom Creek Formation contacts negates their use as a stratigraphic datum.

Figure 16. Map showing the structure on top of the Broom Creek Formation. Contour interval equals 250 feet (76 meters). Datum is sea level. Dashed line shows present extent of the Broom Creek Formation.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S ANTICLINE
EEK ANTICLINE
-5000
-5250
-5000
-4750
-4500
-4250
-4000
-3750
-3500
-3250
-3000
-2750
-2500
-2250
-2000
-750
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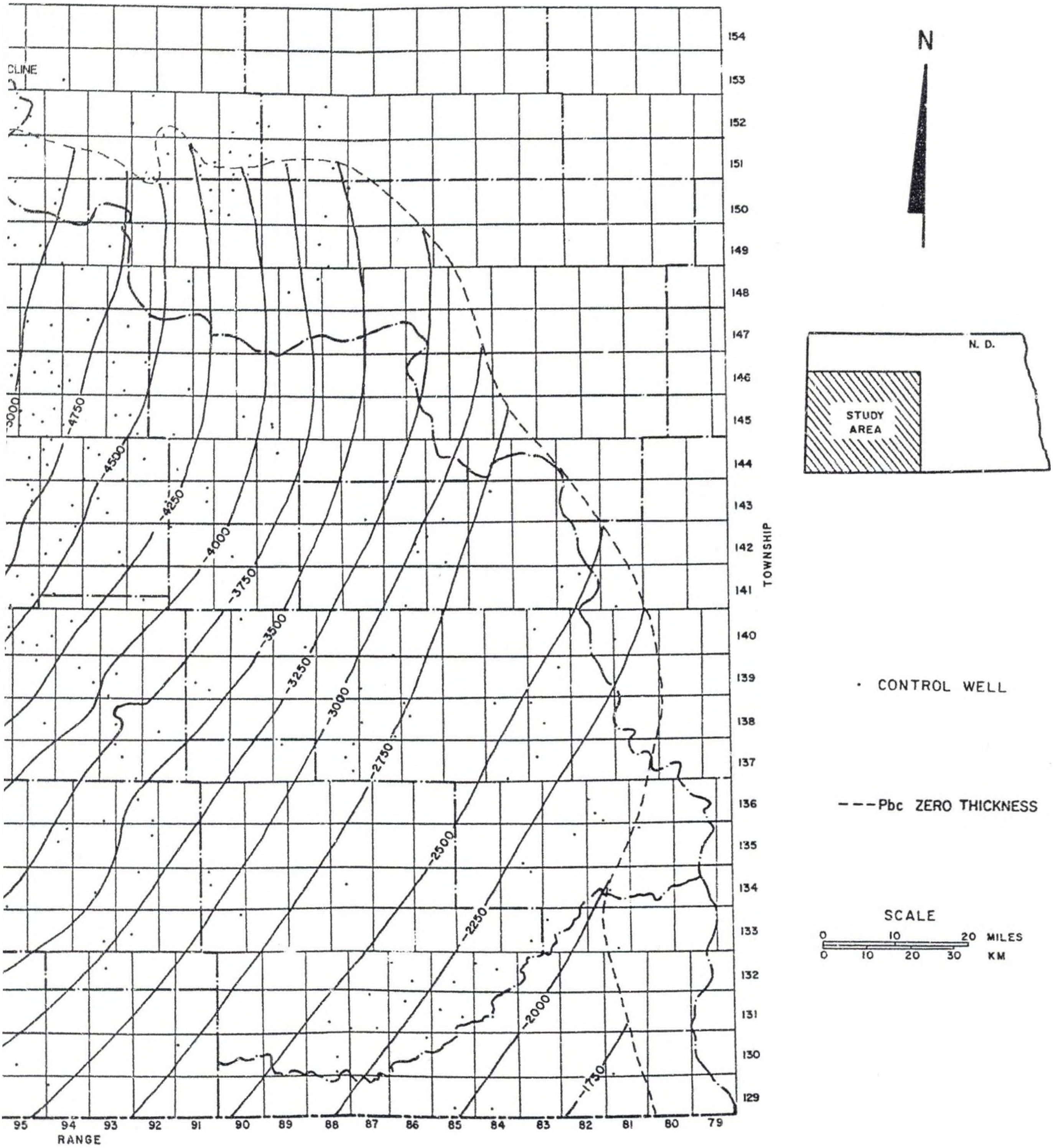
TOWNSHIP
104 103 102 101 100 99 98 97 96 95 94 93 92 91 90 89 88 87 86 85 84 83 82 81 80 79
RANGE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135
134
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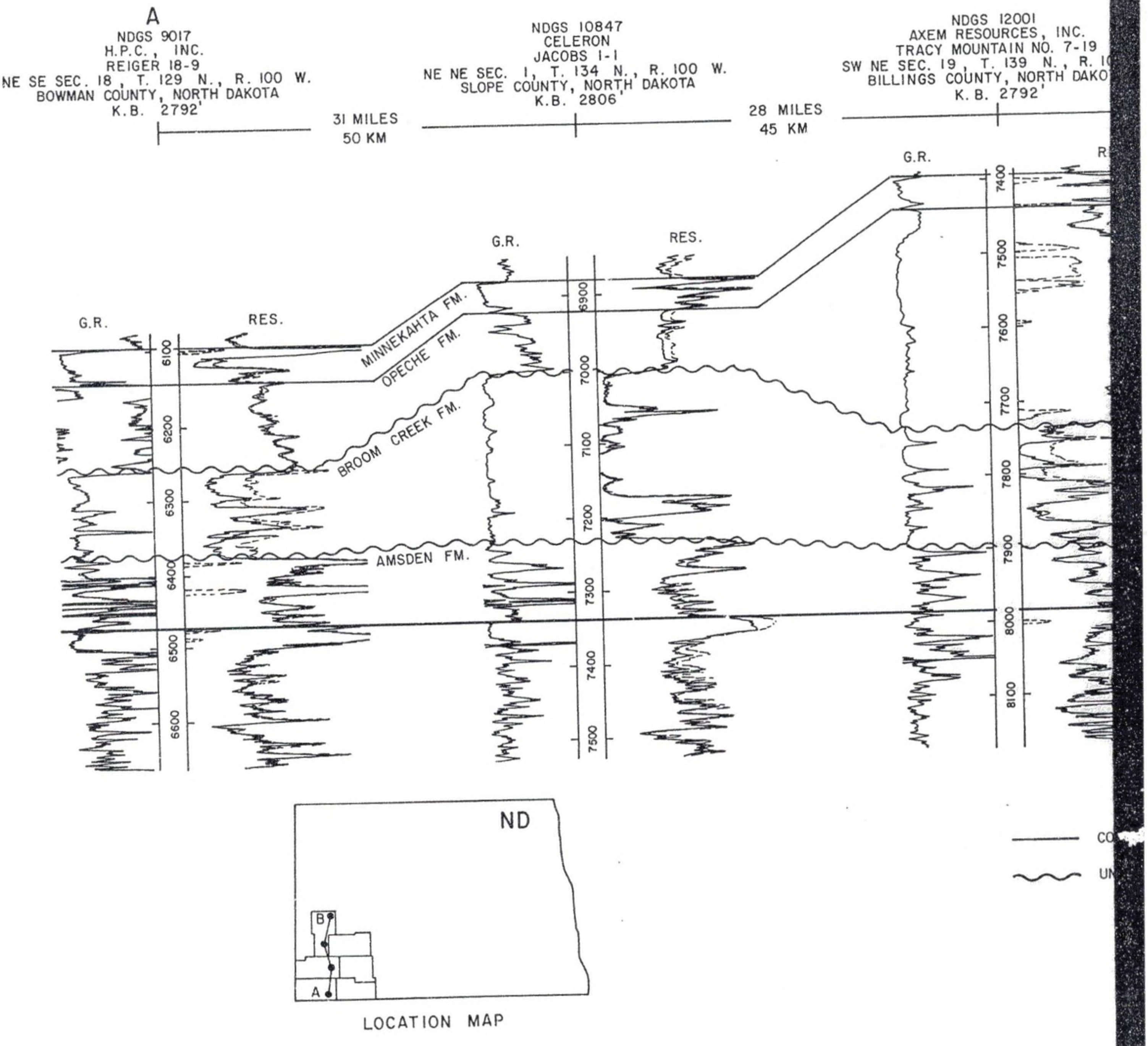
130
129
TOWNSHIP
95 94 93 92 91 90 89 88 87 86 85 84 83 82 81 80 79
RANGE
5000
4750
4500
4250
4000
3750
3500
3250
3000
2750
2500
2250
2000
1750
N
N. D.
STUDY AREA
CONTROL WELL
---Pbc ZERO THICKNESS
SCALE
0 10 20 MILES
0 10 20 30 KM

Figure 17. Stratigraphic cross section A-B.


A
NDGS 9017
H.P.C., INC.
REIGER 18-9
NE SE SEC. 18, T. 129 N., R. 100 W.
BOWMAN COUNTY, NORTH DAKOTA
K.B. 2792'
31 MILES
50 KM
NDGS 10847
CELERON
JACOBS 1-1
NE NE SEC. 1, T. 134 N., R. 100 W.
SLOPE COUNTY, NORTH DAKOTA
K.B. 2806'
28 MILES
45 KM
NDGS 12001
AXEM RESOURCES, INC.
TRACY MOUNTAIN NO. 7-19
G.R.
RES.
MINNEKAHTA FM.
OPECHE FM.
BROOM CREEK FM.
AMSDEN FM.
6100
6200
6300
6400
6500
6600
6900
7000
7100
7200
7300
7400
7500
7600
7700
7800
7900
8000
8100
ND
B
A
LOCATION MAP

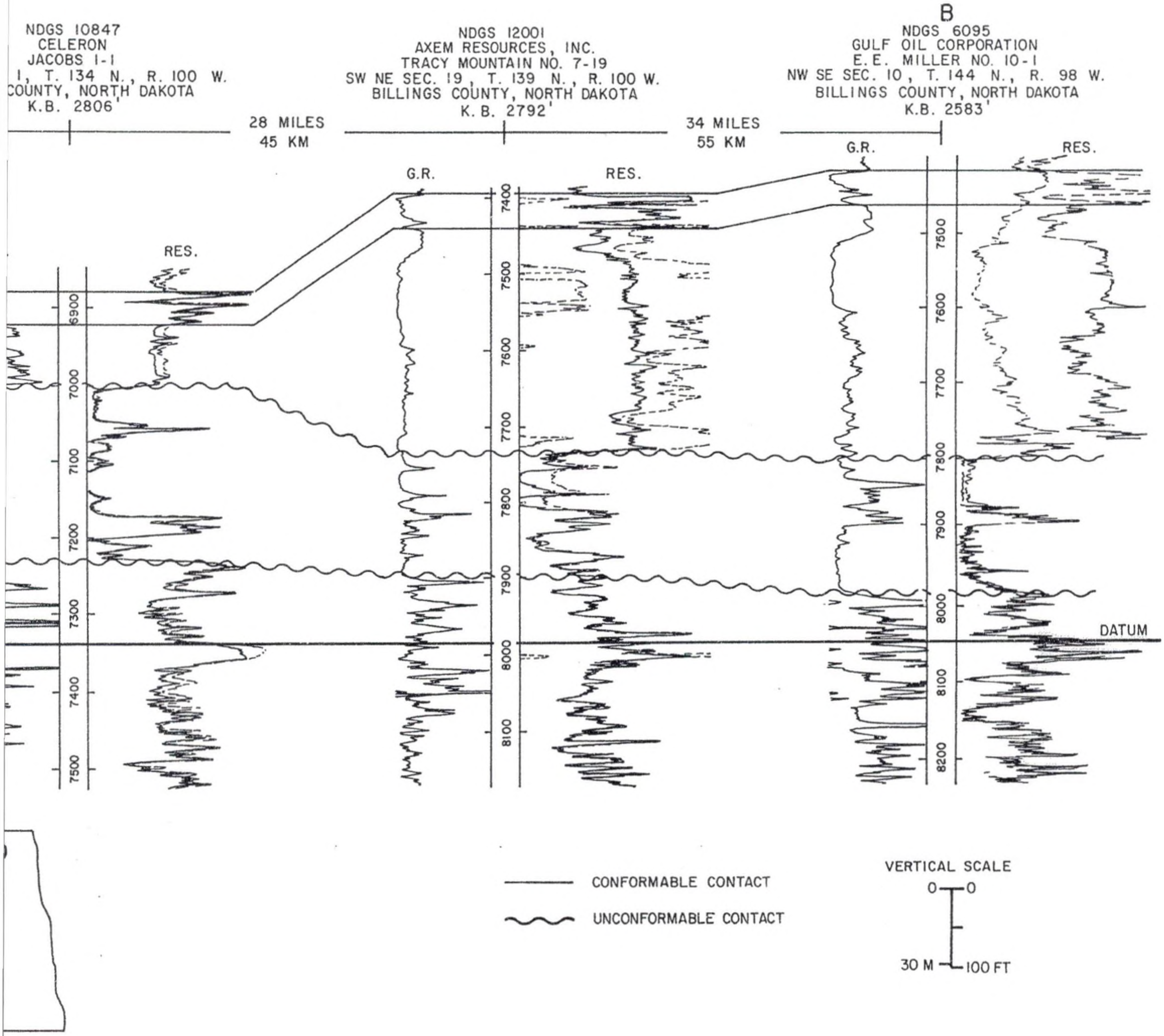
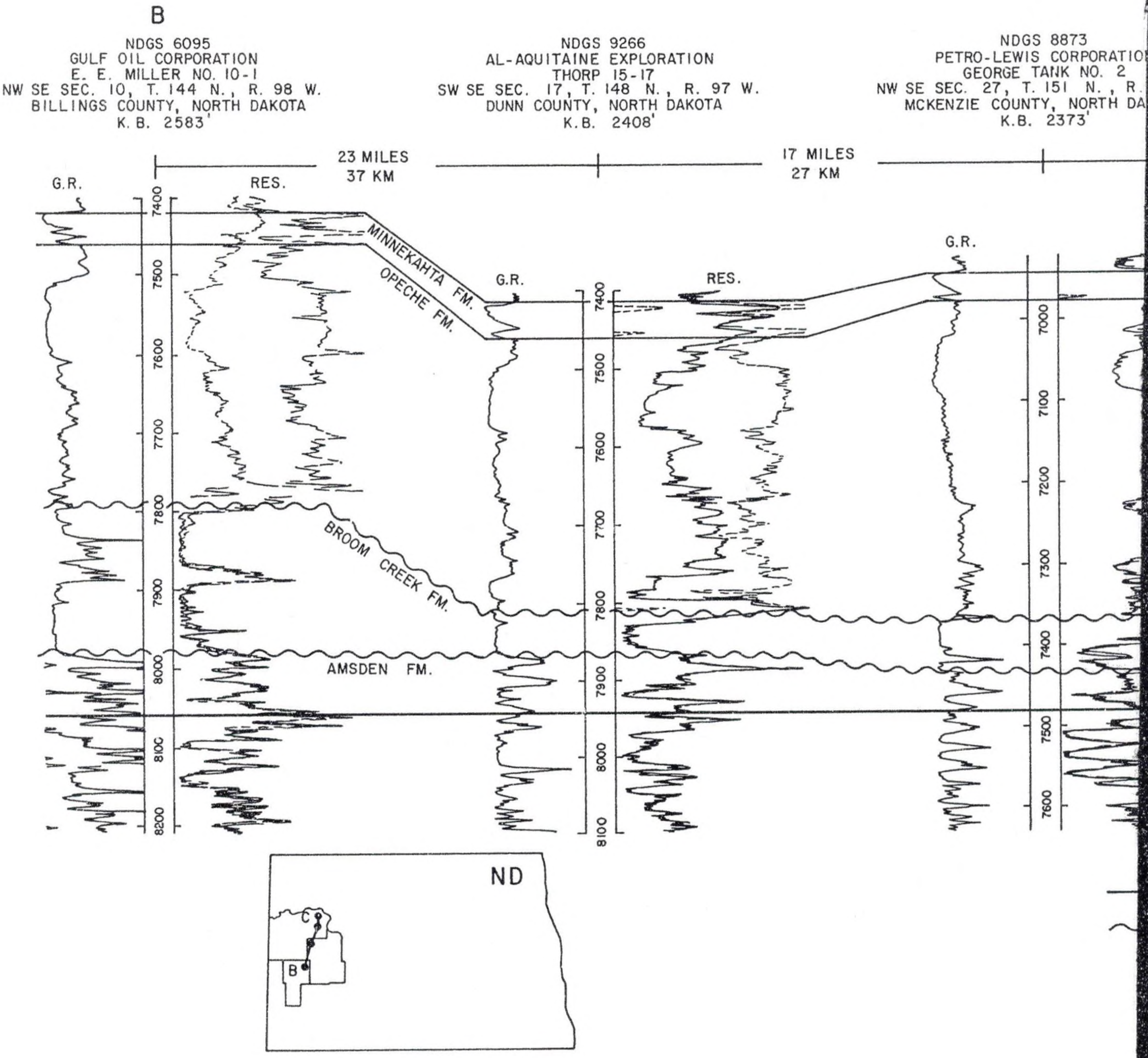

NDGS 10847
CELERON
JACOBS 1-1
1, T. 134 N., R. 100 W.
COUNTY, NORTH DAKOTA
K.B. 2806'
28 MILES
45 KM
NDGS 12001
AXEM RESOURCES, INC.
TRACY MOUNTAIN NO. 7-19
SW NE SEC. 19, T. 139 N., R. 100 W.
BILLINGS COUNTY, NORTH DAKOTA
K.B. 2792'
34 MILES
55 KM
B
NDGS 6095
GULF OIL CORPORATION
E.E. MILLER NO. 10-1
NW SE SEC. 10, T. 144 N., R. 98 W.
BILLINGS COUNTY, NORTH DAKOTA
K.B. 2583'
G.R.
RES.
DATUM
CONFORMABLE CONTACT
UNCONFORMABLE CONTACT
VERTICAL SCALE
0
0
30 M
100 FT

Figure 18. Stratigraphic cross section B-C.



LOCATION MAP

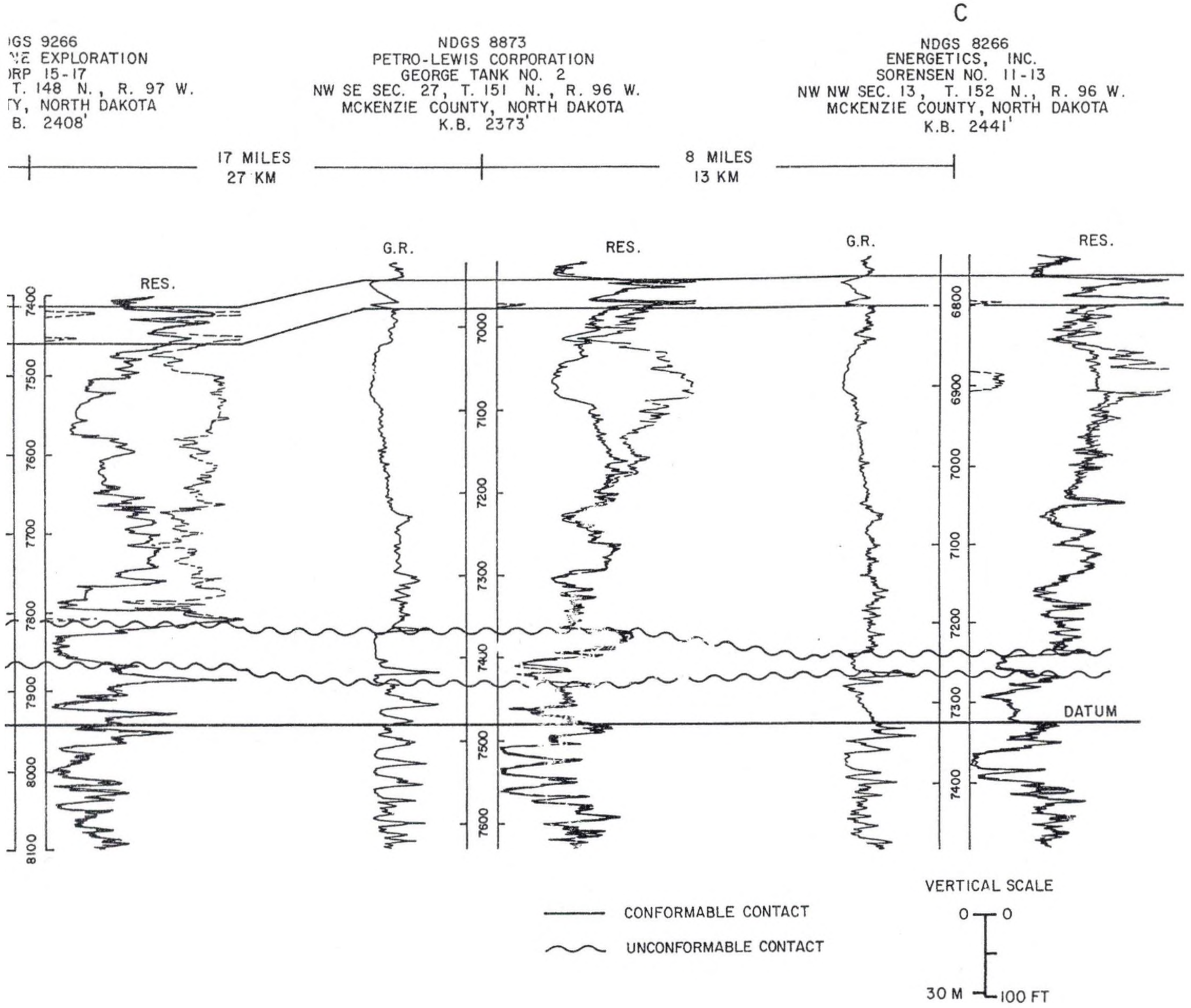
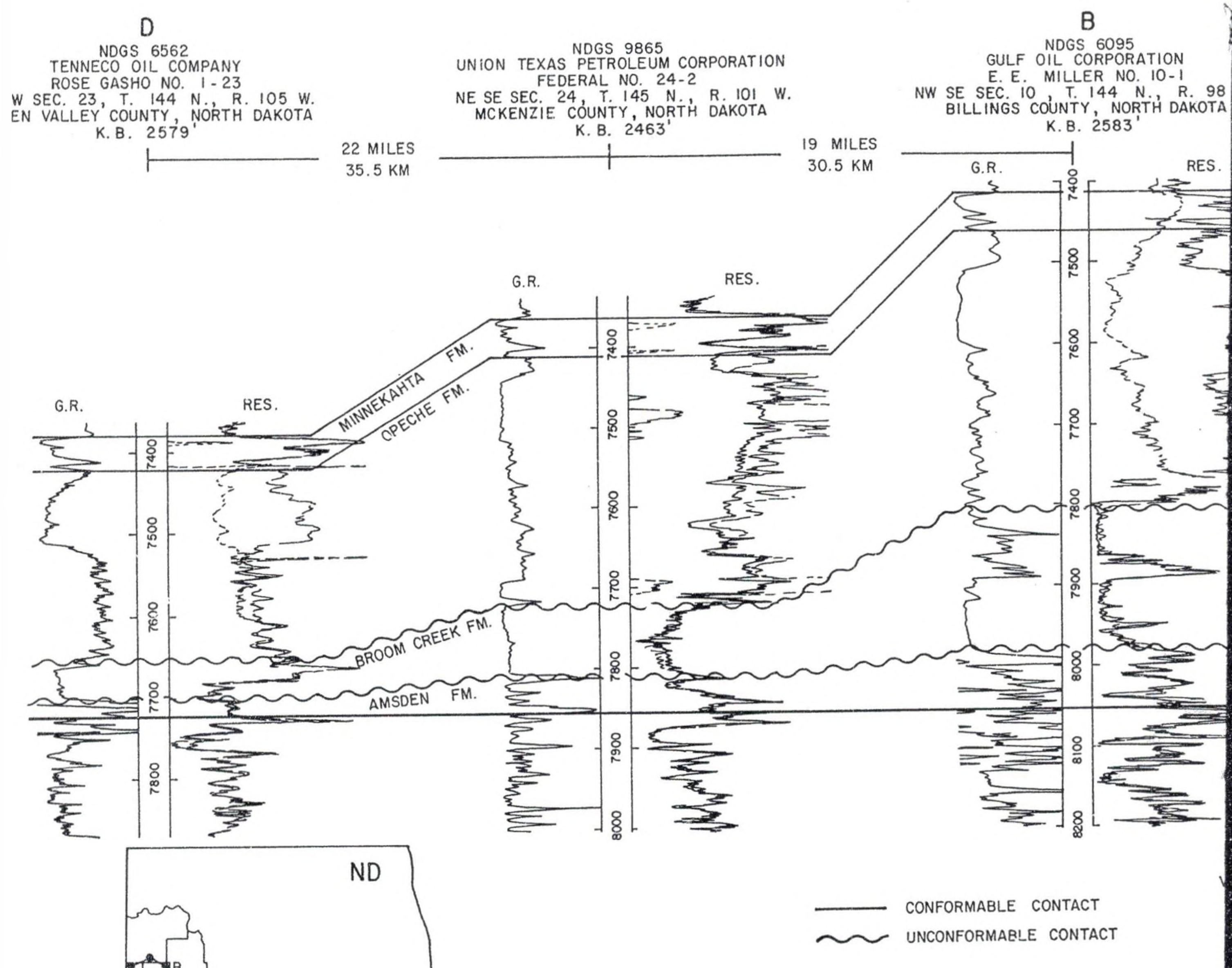
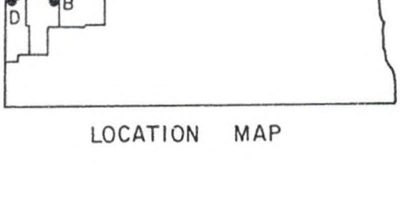

C
)GS 9266
NE EXPLORATION
)RP 15-17
T. 148 N., R. 97 W.
TY, NORTH DAKOTA
B. 2408'
NDGS 8873
PETRO-LEWIS CORPORATION
GEORGE TANK NO. 2
NW SE SEC. 27, T. 151 N., R. 96 W.
MCKENZIE COUNTY, NORTH DAKOTA
K.B. 2373'
NDGS 8266
ENERGETICS, INC.
SORENSEN NO. 11-13
NW NW SEC. 13, T. 152 N., R. 96 W.
MCKENZIE COUNTY, NORTH DAKOTA
K.B. 2441'
17 MILES
27 KM
8 MILES
13 KM
RES.
G.R.
RES.
G.R.
RES.
7400
7500
7600
7700
7800
7900
8000
8100
7000
7100
7200
7300
7400
7500
7600
6800
6900
7000
7100
7200
7300
7400
DATUM
CONFORMABLE CONTACT
UNCONFORMABLE CONTACT
VERTICAL SCALE
0
0
30 M
100 FT

Figure 19. Stratigraphic cross section D-B.





LOCATION MAP

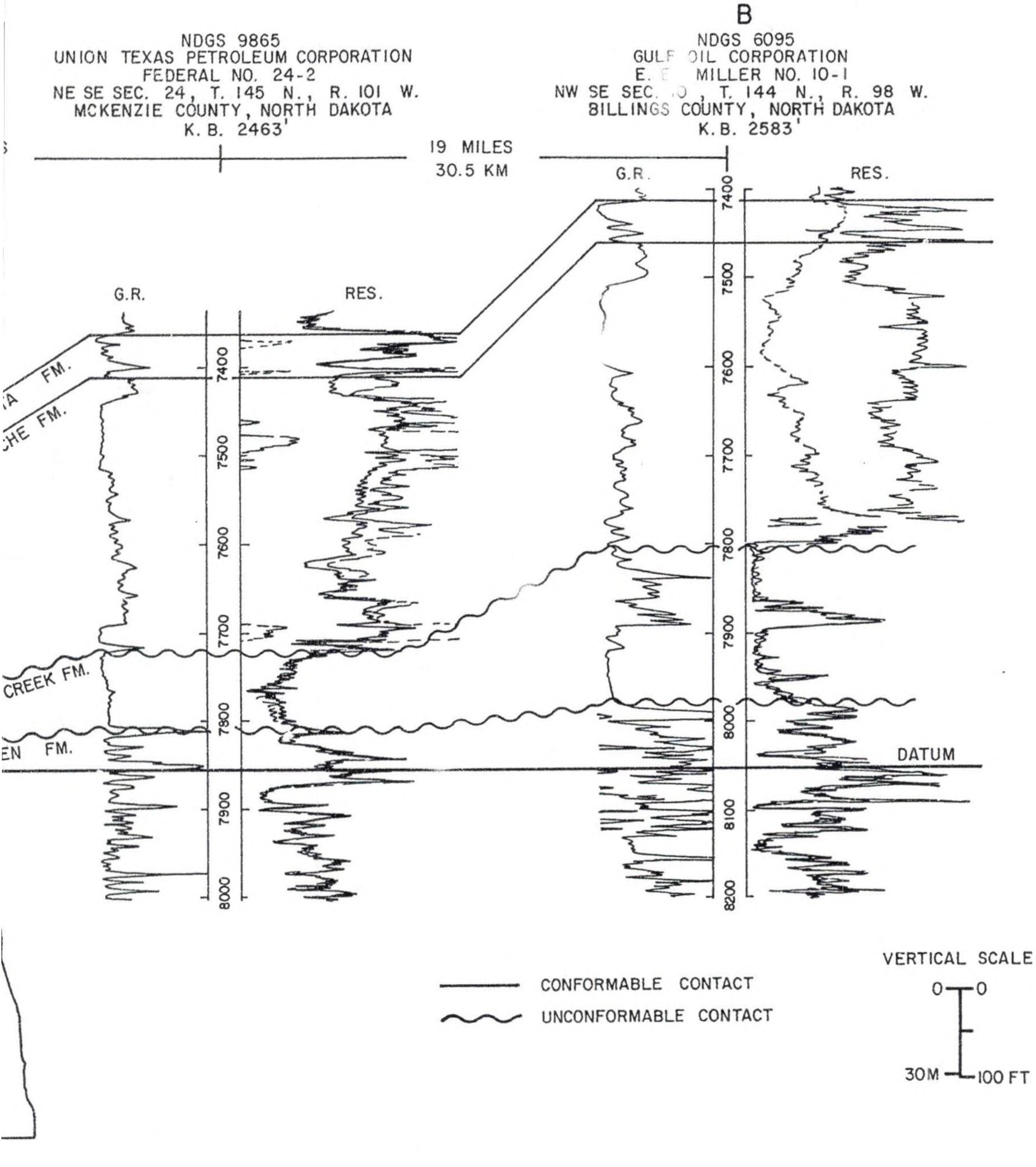
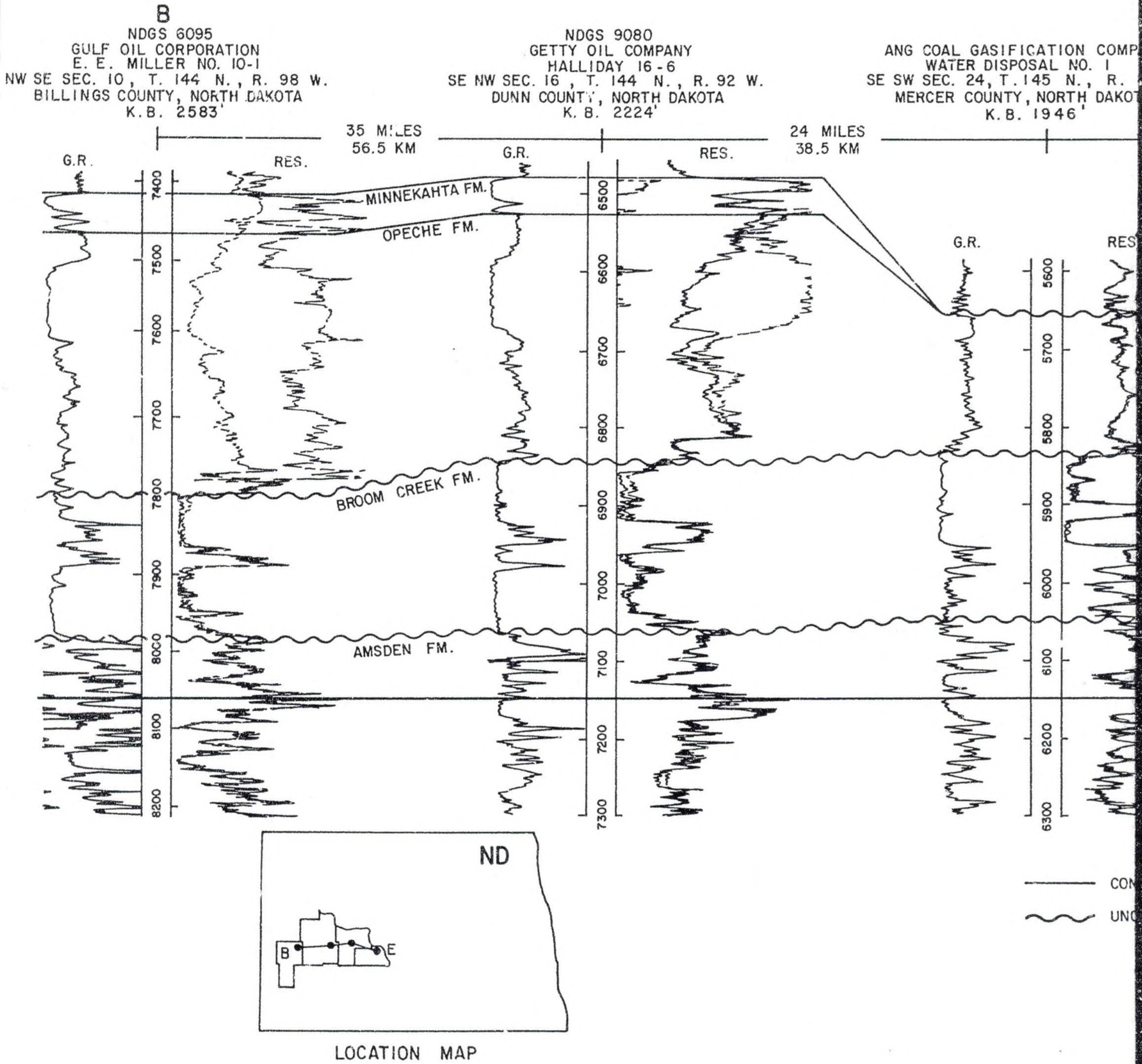
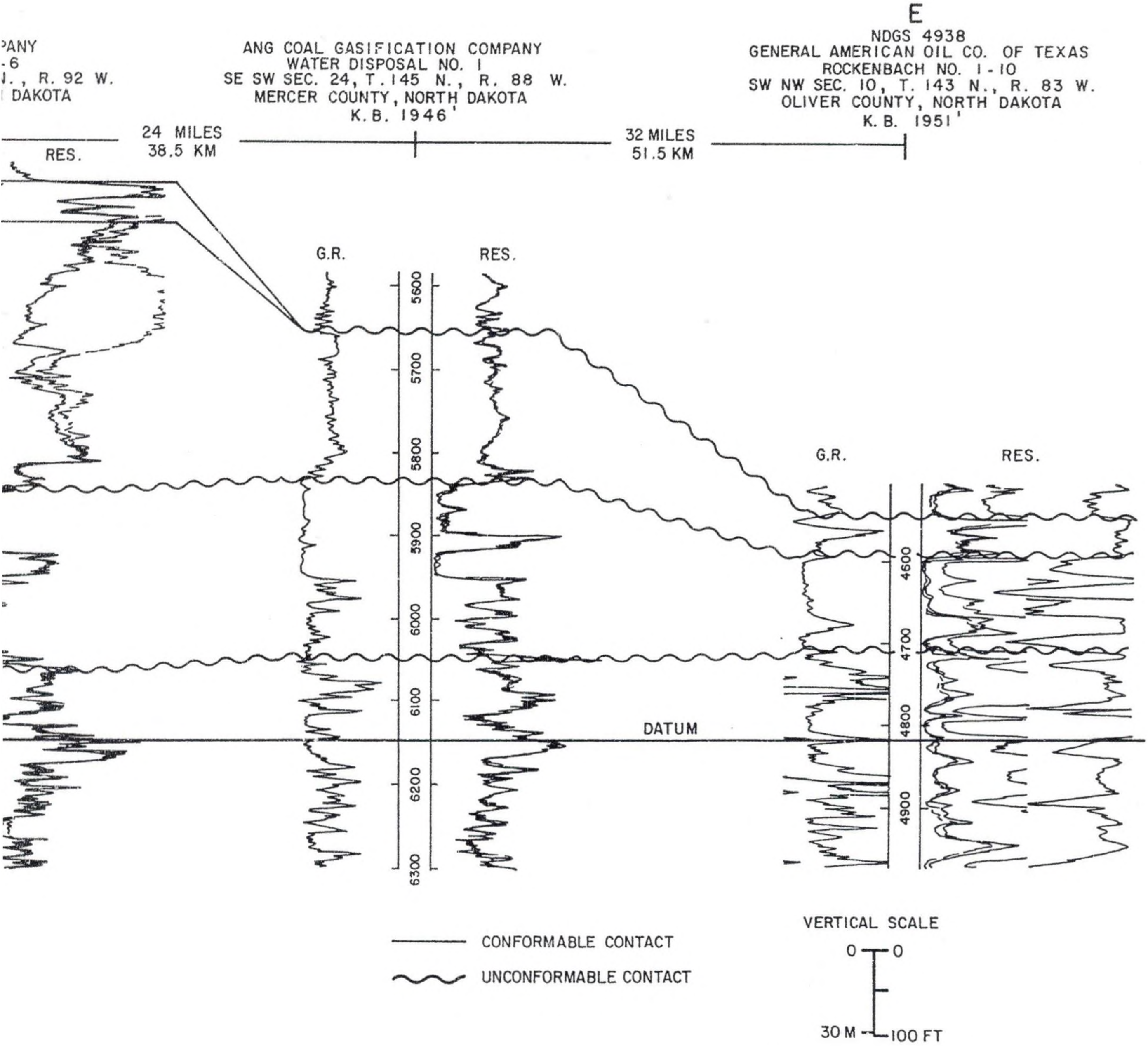

B
NDGS 9865
UNION TEXAS PETROLEUM CORPORATION
FEDERAL NO. 24-2
NE SE SEC. 24, T. 145 N., R. 101 W.
MCKENZIE COUNTY, NORTH DAKOTA
K. B. 2463'
NDGS 6095
GULF OIL CORPORATION
MILLER NO. 10-1
BILLINGS COUNTY, NORTH DAKOTA
K. B. 2583'
19 MILES
30.5 KM
G.R.
RES.
FM.
CREEK FM.
DATUM
CONFORMABLE CONTACT
UNCONFORMABLE CONTACT
VERTICAL SCALE
0
0
30M
100 FT

Figure 20. Stratigraphic cross section B-E.


B
NDGS 6095
GULF OIL CORPORATION
E. E. MILLER NO. 10-1
NW SE SEC. 10, T. 144 N., R. 98 W.
BILLINGS COUNTY, NORTH DAKOTA
K.B. 2583'
NDGS 9080
GETTY OIL COMPANY
HALLIDAY 16-6
SE NW SEC. 16, T. 144 N., R. 92 W.
DUNN COUNTY, NORTH DAKOTA
K.B. 2224'
ANG COAL GASIFICATION COMP
WATER DISPOSAL NO. 1
SE SW SEC. 24, T.145 N., R.
MERCER COUNTY, NORTH DAKO
K.B. 1946'
35 MILES
56.5 KM
24 MILES
38.5 KM
G.R.
RES.
MINNEKAHTA FM.
OPECHE FM.
BROOM CREEK FM.
AMSDEN FM.
CON
UNC
ND
B
E
LOCATION MAP


E
PANY
-6
N., R. 92 W.
DAKOTA
ANG COAL GASIFICATION COMPANY
WATER DISPOSAL NO. 1
SE SW SEC. 24, T. 145 N., R. 88 W.
MERCER COUNTY, NORTH DAKOTA
K.B. 1946'
NDGS 4938
GENERAL AMERICAN OIL CO. OF TEXAS
ROCKENBACH NO. 1-10
SW NW SEC. 10, T. 143 N., R. 83 W.
OLIVER COUNTY, NORTH DAKOTA
K.B. 1951'
24 MILES
38.5 KM
32 MILES
51.5 KM
RES.
G.R.
RES.
G.R.
RES.
5600
5700
5800
5900
6000
6100
6200
6300
4600
4700
4800
4900
DATUM
CONFORMABLE CONTACT
UNCONFORMABLE CONTACT
VERTICAL SCALE
0
0
30 M
100 FT

As determined from the cross sections, the upper Amsden section between the carbonate datum and the Amsden-Broom Creek disconformity does not vary appreciably in thickness across the study area (Figures 17, 18, 19, and 20). Because of this nominal regularity in thickness between the datum and Amsden-Broom Creek contact, it is assumed that minimal relief existed on the Amsden surface prior to Broom Creek deposition.

The lateral discontinuity of beds within the Broom Creek Formation is evident on all cross sections. Easily recognized, highly porous Broom Creek sandstone beds are discontinuous and difficult to correlate from township to township within the study area. The dolostone beds are characterized on wireline logs by their high resistivity on the laterolog and low porosity response on the FDC-CNL log. From the cross sections, it is also evident that the dolostone beds, while present in most of the wells studied, are laterally discontinuous. Generally, two major dolostone beds occur in the Broom Creek section, although their distribution and thickness are highly irregular over the study area. Single beds of dolostone can be confidently correlated for no more than one township.

A group of highly radioactive beds is present in many of the wells in the study area. A good example of this appears in the Tracy Mountain No. 7-19 well on cross section A-B (Fig. 17). These radioactive spikes are most common in the central portion of the study area. The intense gamma-

ray response normally coincides with dolostone beds but is not exclusive to a certain lithology. In some instances, the surrounding sandstone beds manifest a large gamma-ray response similar to that of the dolostone beds. These high intensity zones on the gamma-ray log appear to be more common in the lower to middle Broom Creek section than in the upper one-third of the formation. Radioactive zones are noticeably absent or very minor in thick sections of the Broom Creek Formation. An example of this can be seen in the upper Broom Creek section of the ANG Water Disposal No. 1 well in cross section B-E (Fig. 20). Highly radioactive zones do not appear to be very common in Broom Creek equivalent strata in South Dakota or Wyoming (George, 1984).

The irregular surface of the upper contact of the Broom Creek Formation is evident on cross section. Cross section A-B (Fig. 17) shows the relief on the upper Broom Creek surface. The Jacob 1-1 well, in the NE NE Section 1, T.134 N., R.100 W., has a much greater thickness than the surrounding wells. The paleosurface in and around the Jacob 1-1 well appears to have been approximately 100 feet (30.5 meters) higher than the surrounding area during post Broom Creek-pre Opeche time. Lateral thickness changes of 50 to 100 feet (15.3 to 30.5 meters) within the Broom Creek Formation occur over relatively short distances, commonly less than one mile (1.6 km), throughout the study area. The overlying Opeche Formation often contains a compensating section of abnormally thick evaporite, usually salt, so that

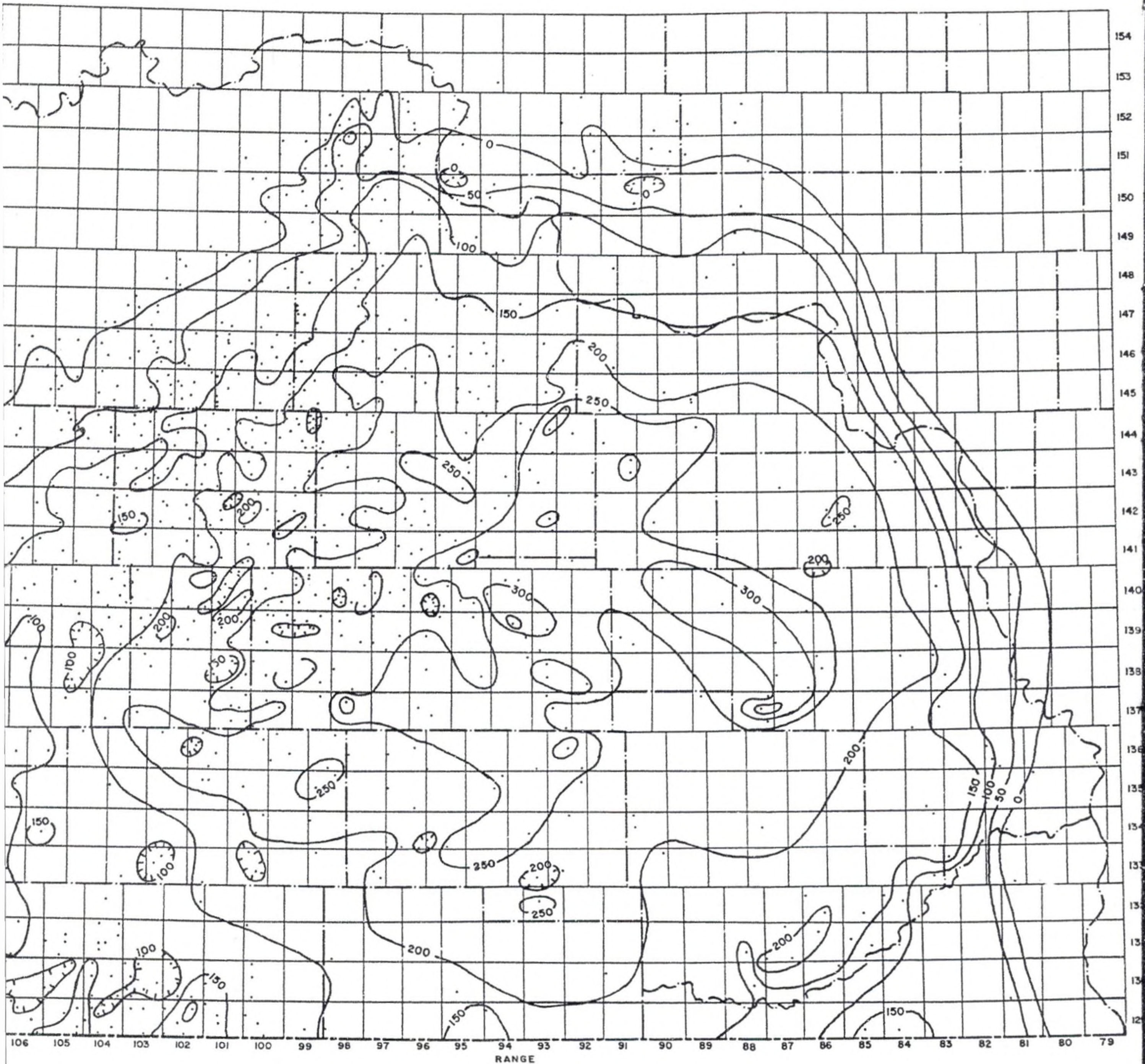
the overlying Minnekahta Formation shows no trace of the irregular paleotopography, which existed after Broom Creek deposition.

Isopach Maps

The Broom Creek Formation attains a maximum thickness of 378 feet (115 meters); the thickest area of occurrence is in an area around T.137 N., R.87 W. (Fig. 21). The thickest portion of the Broom Creek Formation does not coincide with the present center of the Williston basin, which is located approximately at T.149 N., R.98 W. The isopach map of the complete Minnelusa Group (Fig. 22) shows a distribution similar to the Broom Creek Formation. The underlying Mississippian System has a substantially different distribution than the Minnelusa Group or the Broom Creek Formation. The Mississippian System attains maximum thickness at approximately T.152 N., R. 99 W. (Carlson and Anderson, 1966). This is approximately 80 miles (128 km) to the northwest of the Minnelusa Group depocenter.

The similarity in distribution of the complete Minnelusa Group (Fig. 22) and the Broom Creek Formation indicates that during much of the Pennsylvanian and Early Permian, the center of deposition remained relatively stationary. However, a major shift in the basin depocenter occurred from Mississippian to Pennsylvanian time. The general trend of the Mississippian System is east-west, which is quite different than the more northeast-southwest-trending

Figure 21. Isopach map of the Broom Creek Formation. Contour interval equals 50 feet (15 meters). Hachured contour lines denote areas of thinning.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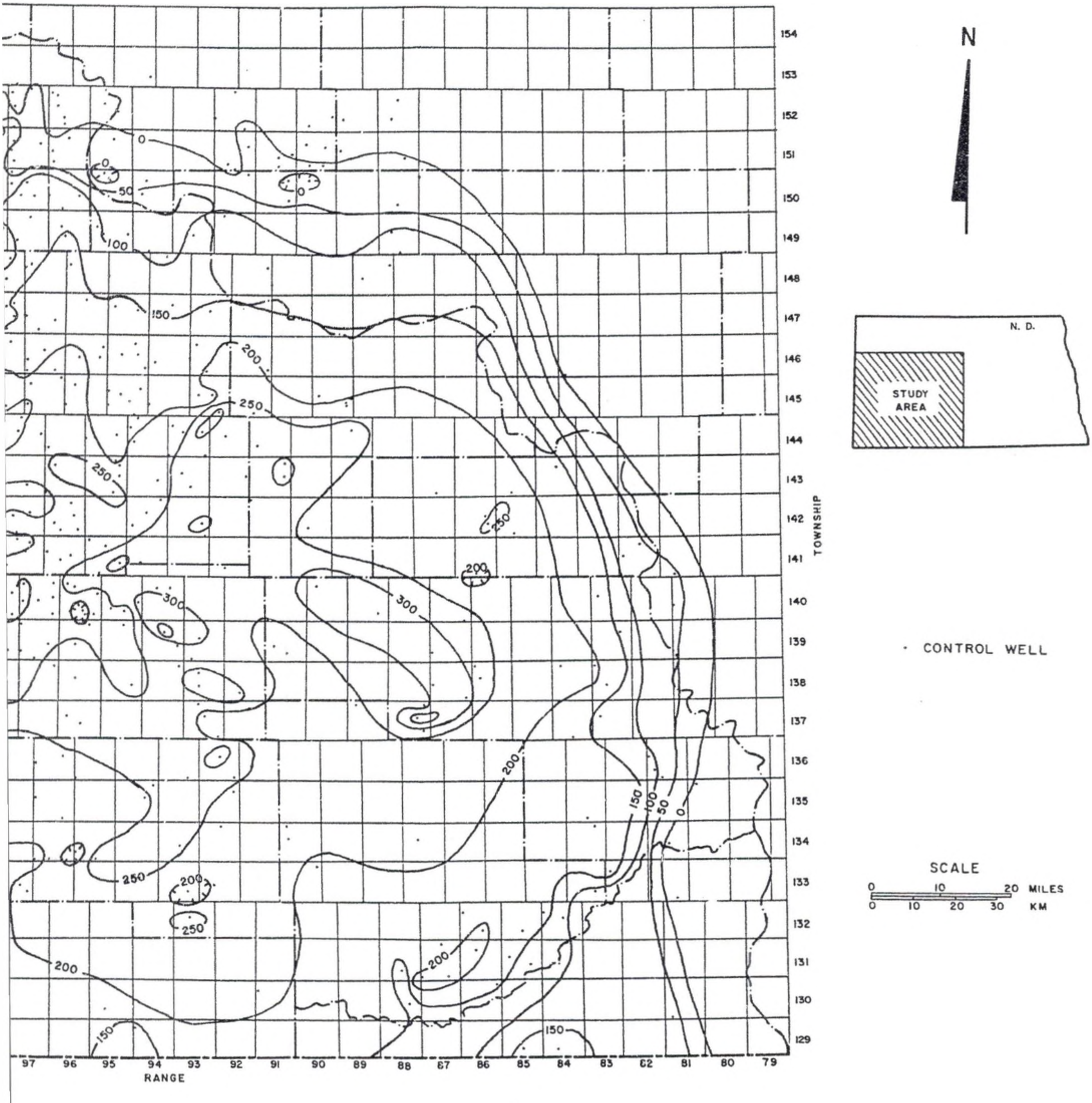
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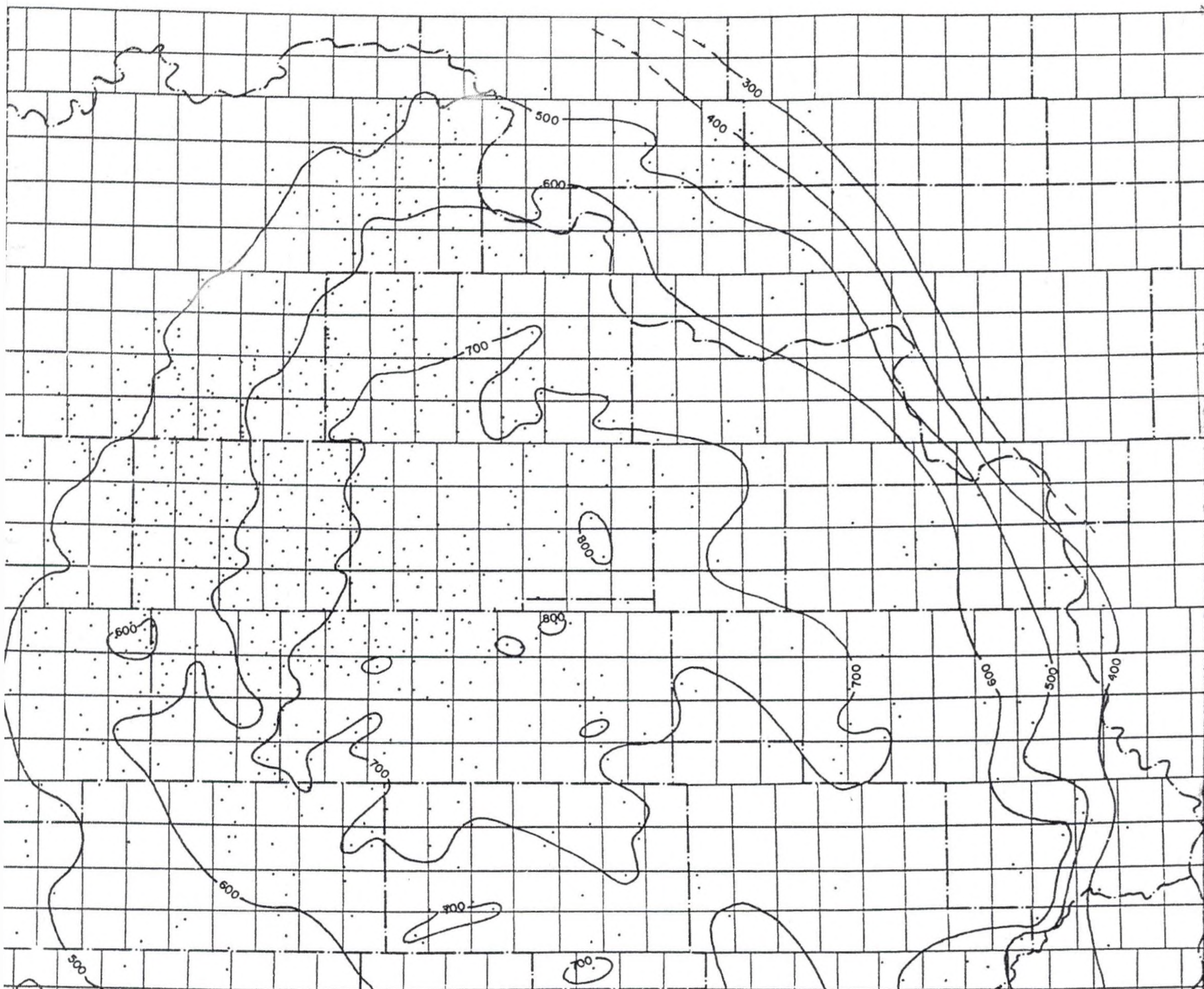
N. D.
STUDY AREA
TOWNSHIP
RANGE
· CONTROL WELL
SCALE
0 10 20 MILES
0 10 20 30 KM

Figure 22. Isopach map of the Minnelusa Group. Contour interval equals 100 feet (30 meters).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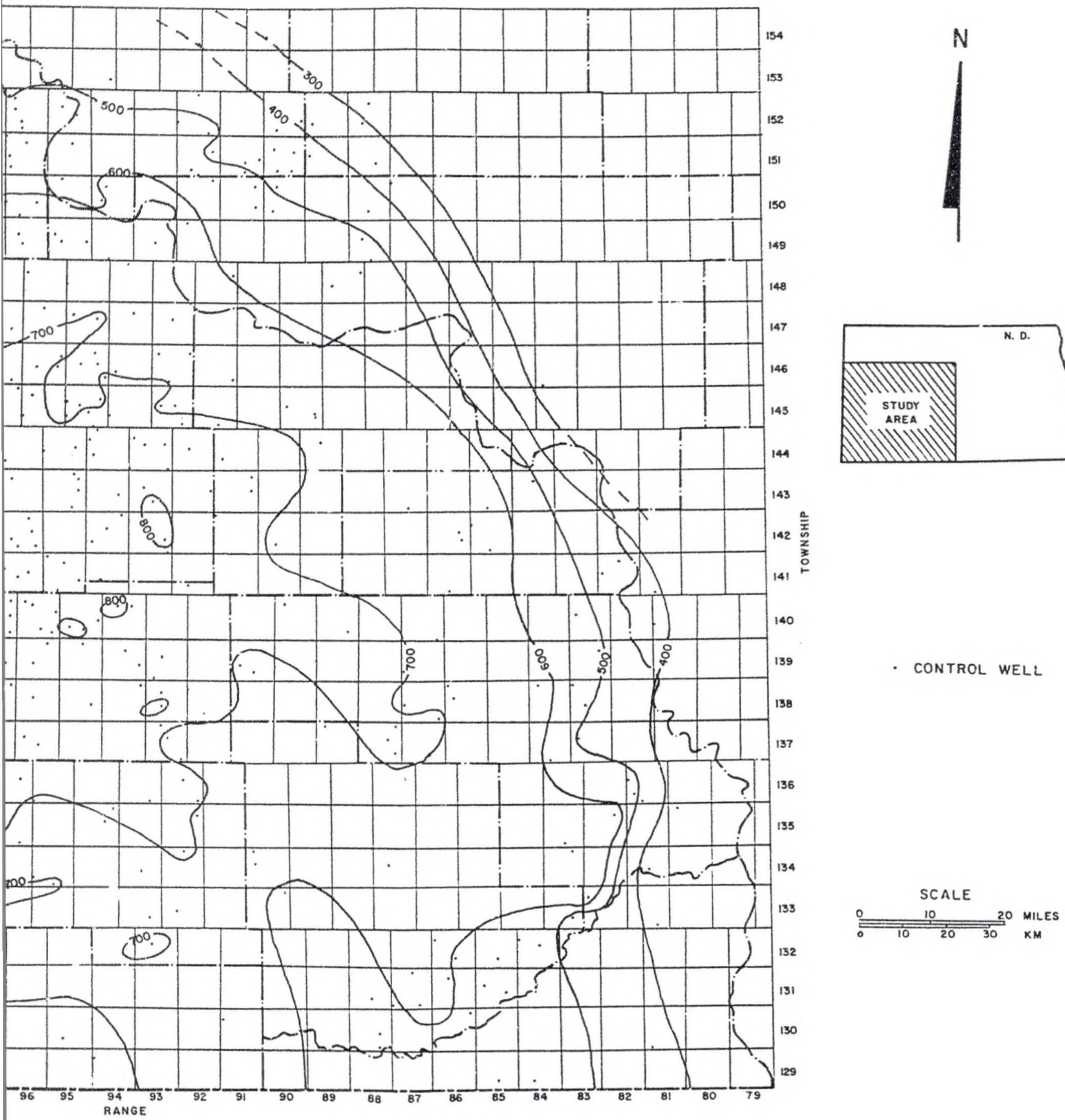
400
106 105 104 103 102 101 100 99 98 97 96 95 94 93 92 91 90 89 88 87 86 85 84 83 82 81 80
RANGE


N
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STUDY AREA
· CONTROL WELL
SCALE
0 10 20 MILES
0 10 20 30 KM
TOWNSHIP
RANGE
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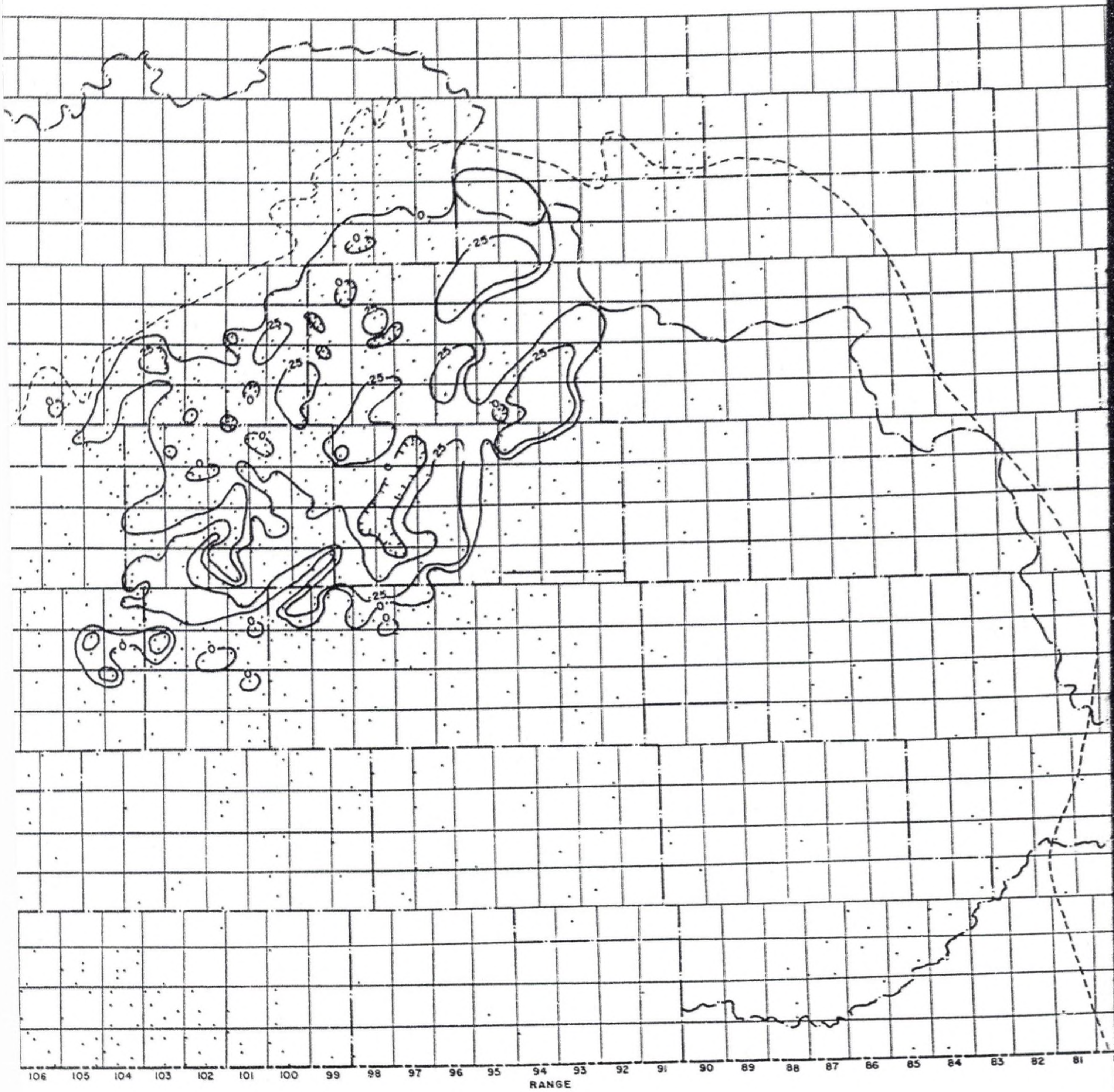
500
600
700
800

Minnelusa Group.

The isopach map of the Broom Creek Formation (Fig. 21) shows numerous areas with irregular thickening and thinning. Areas with increased well control generally define more local irregularities in the thickness of the Broom Creek Formation. Within the study area, the thickness of the Broom Creek Formation decreases much more gradually on the western edge of the subcrop than eastward. On the eastern edge of the subcrop, the Broom Creek Formation decreases from 200 feet (61 meters) in thickness to its zero edge in less than 20 miles (32 km), with an average thinning rate of ten feet per mile (two meters per km). To the west, the Broom Creek Formation extends into Montana thinning at an average rate of three feet per mile (.6 meters per km). Within the study area, the Broom Creek Formation thins to the south, but does not thin to a zero edge and is laterally continuous throughout southwestern North Dakota, western South Dakota, and eastern Wyoming.

In the northwestern part of the study area, the Broom Creek Formation is directly overlain by a thin basal salt of the Opeche Formation. The thickness distribution of this basal Opeche salt is shown in Figure 23. The basal Opeche salt bed attains a maximum thickness in excess of 50 feet (15.3 meters), but is commonly less than 10 feet (3 meters) thick where present. The basal Opeche salt bed is laterally discontinuous and there are many areas within its depositional extent where the basal salt is absent. The

Figure 23. Isopach map of the basal Opeche salt. Contour interval equals 25 feet (8 meters). Hachured contour lines denote areas of thinning. Dashed line shows present extent of the Broom Creek Formation.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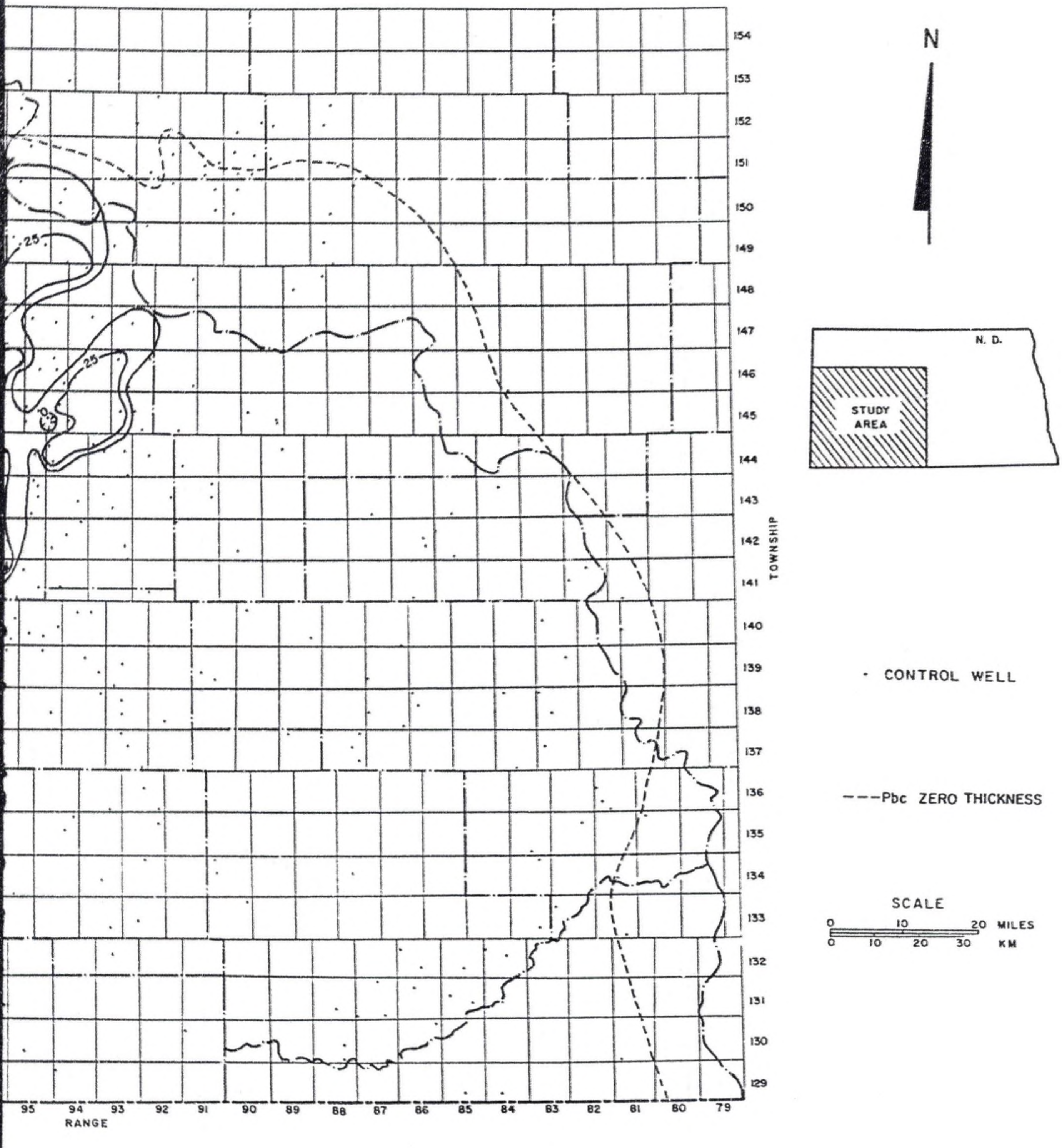
81
RANGE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90
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87
86
85
84
83
82
81
80
79
RANGE
25
25
· CONTROL WELL
---Pbc ZERO THICKNESS
SCALE
0 10 20 MILES
0 10 20 30 KM

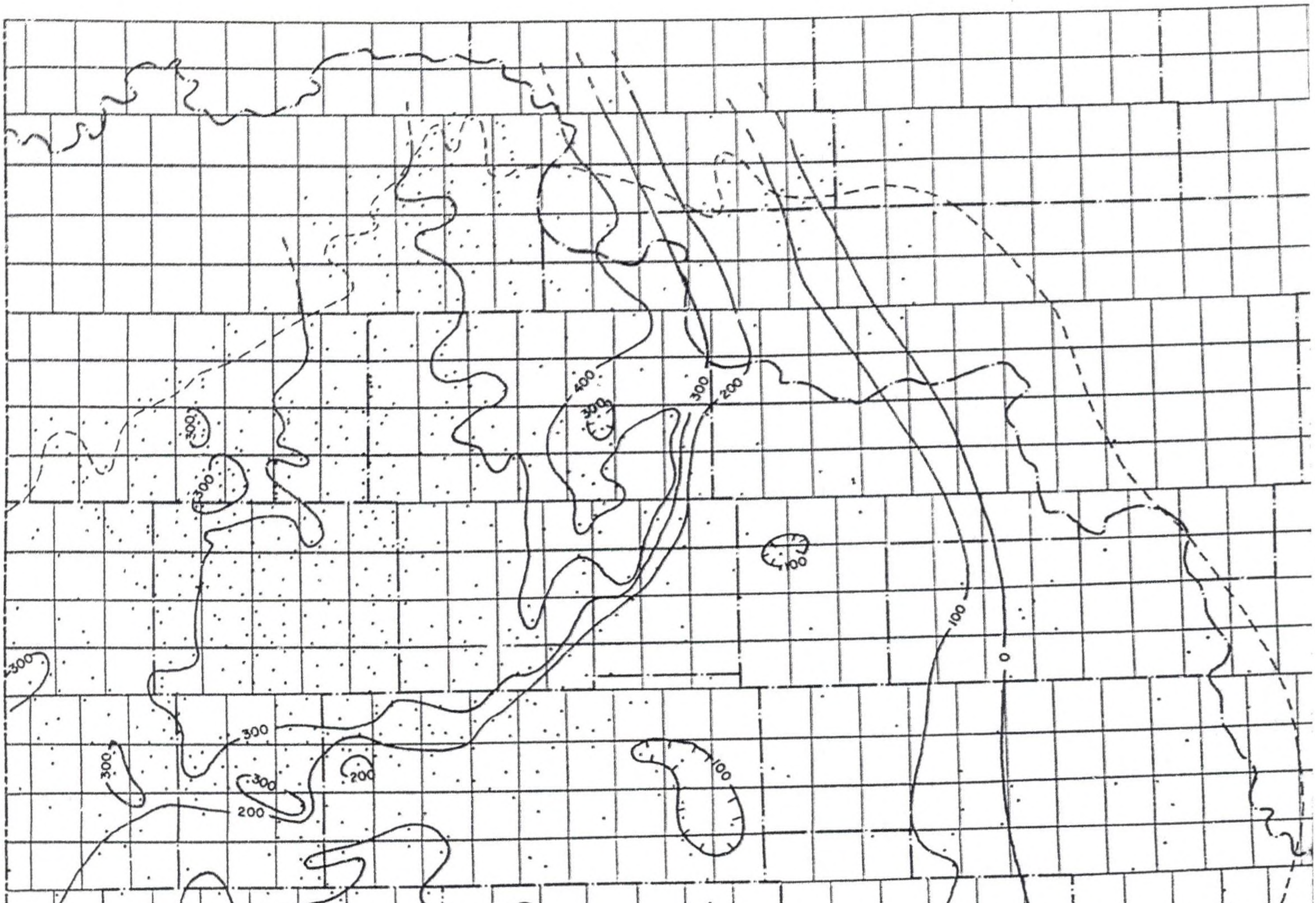
distribution of the basal salt bed in the Opeche Formation does not mimic the overall thickness distribution of the Opeche Formation (Fig. 24).

The overall thickness distribution of the Opeche Formation (Fig. 24) is substantially different from the underlying Broom Creek Formation. The maximum thickness of the Opeche Formation occurs in the northern part of the study area, approximately 50 miles (80 km) northwest of the Broom Creek depocenter. The Opeche Formation abruptly thins to the southeast due to dissolution and/or nondeposition of a substantial middle salt member. The Opeche Formation does not extend as far east as the Broom Creek Formation, but extends farther than the Broom Creek to the north, beyond the limits of the study area.

Sandstone Distribution Maps

A map of the percentage sandstone present in total thickness of Broom Creek Formation shows a general trend of decreasing sandstone content to the east and to the south in the study area (Fig. 25). A contour line of 75 percent sandstone runs north-south at approximately R. 96 W. and separates areas of less than 75 percent sandstone to the east and greater than 75 percent sandstone to the west. The 75 percent contour line has no specific depositional significance and its use, for descriptive purposes, is primarily a consequence of the arbitrarily chosen contour interval. However, distinctive depositional trends are

Figure 24. Isopach map of the Opeche Formation. Contour interval equals 100 feet (30 meters). Hachured contour lines denote areas of thinning. Dashed line shows present extent of the Broom Creek Formation.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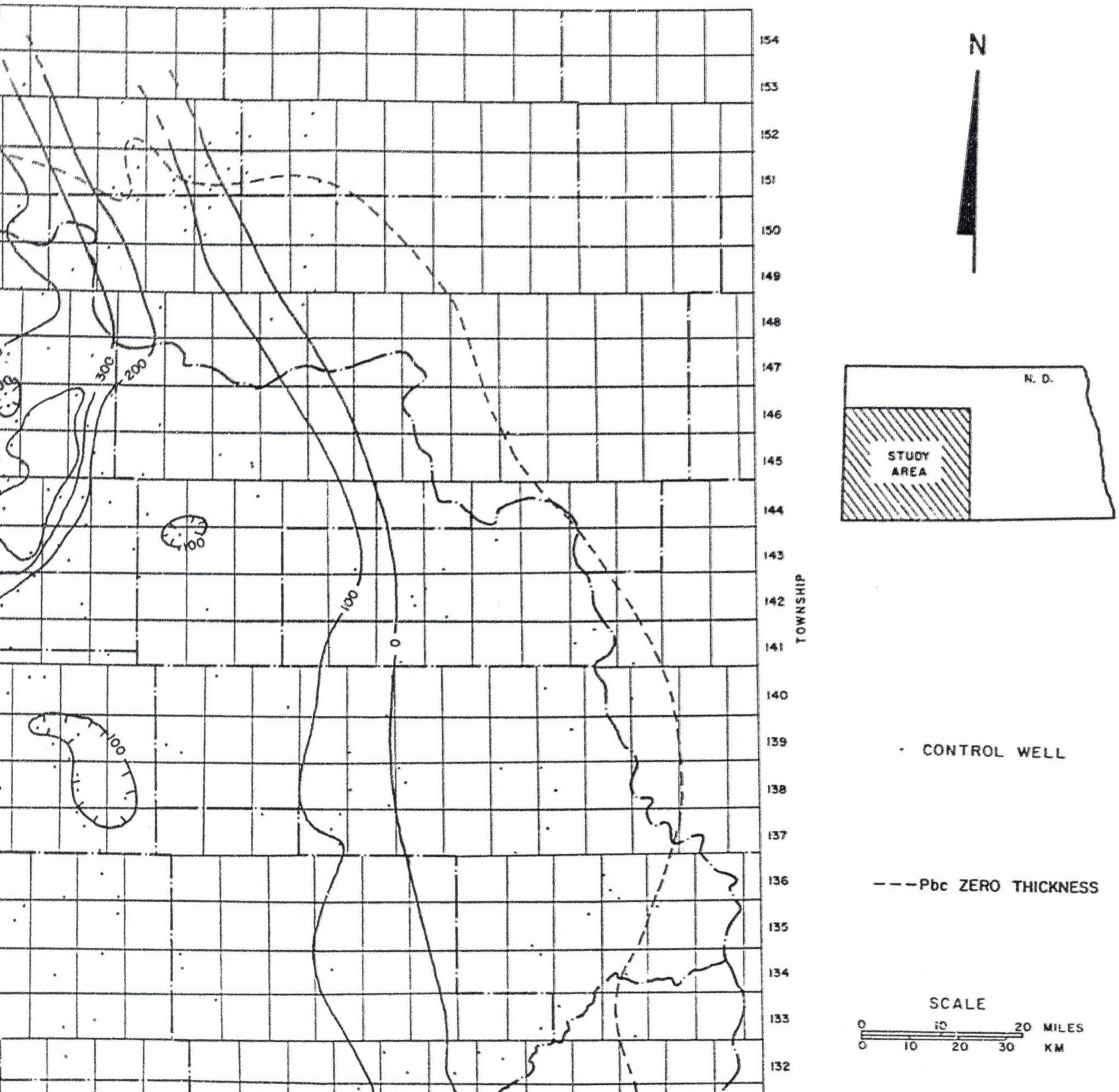
RANGE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94 93 92 91 90 89 88 87 86 85 84 83 82 81 80 79
RANGE
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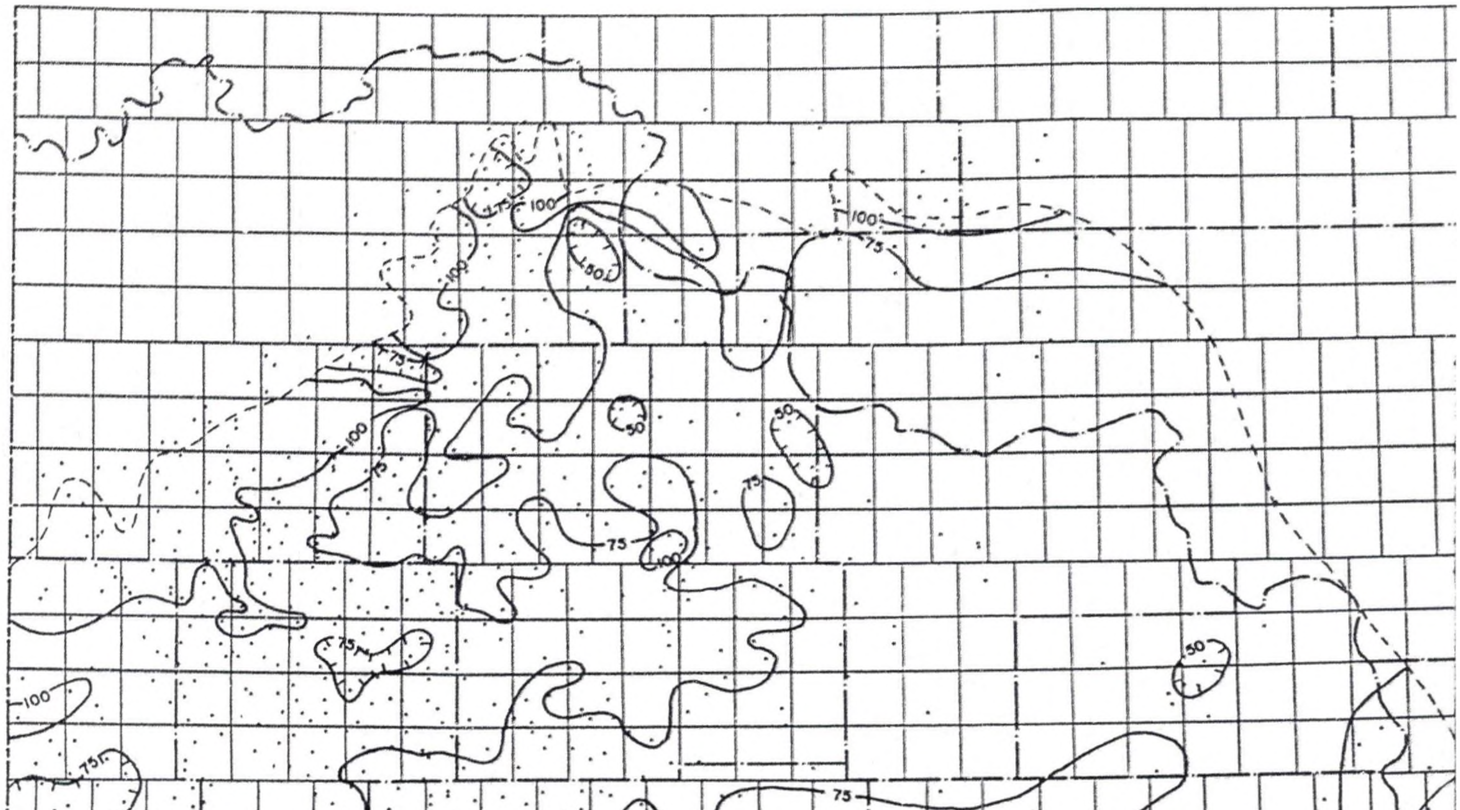
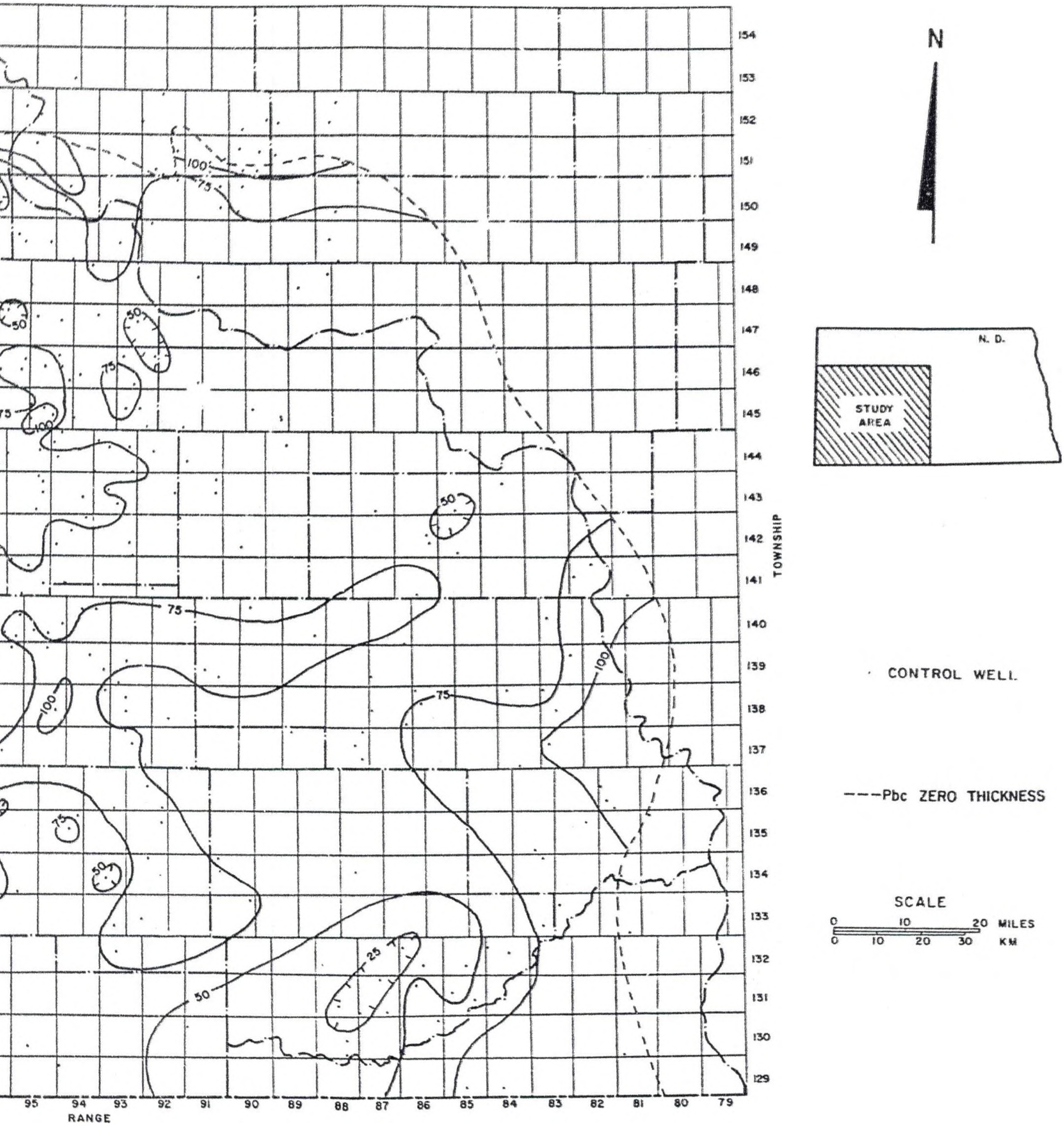
· CONTROL WELL
---Pbc ZERO THICKNESS
SCALE
0 10 20 MILES
0 10 20 30 KM

Figure 25. Map showing the percentage sandstone present in total thickness of Broom Creek Formation. Contour interval is in units of 25 percent. Hachured contour lines denote areas of decreasing sandstone percentage. Dashed line shows present extent of the Broom Creek Formation.


106 105 104 103 102 101 100 99 98 97 96 95 94 93 92 91 90 89 88 87 86 85 84 83 82
RANGE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80
79
RANGE
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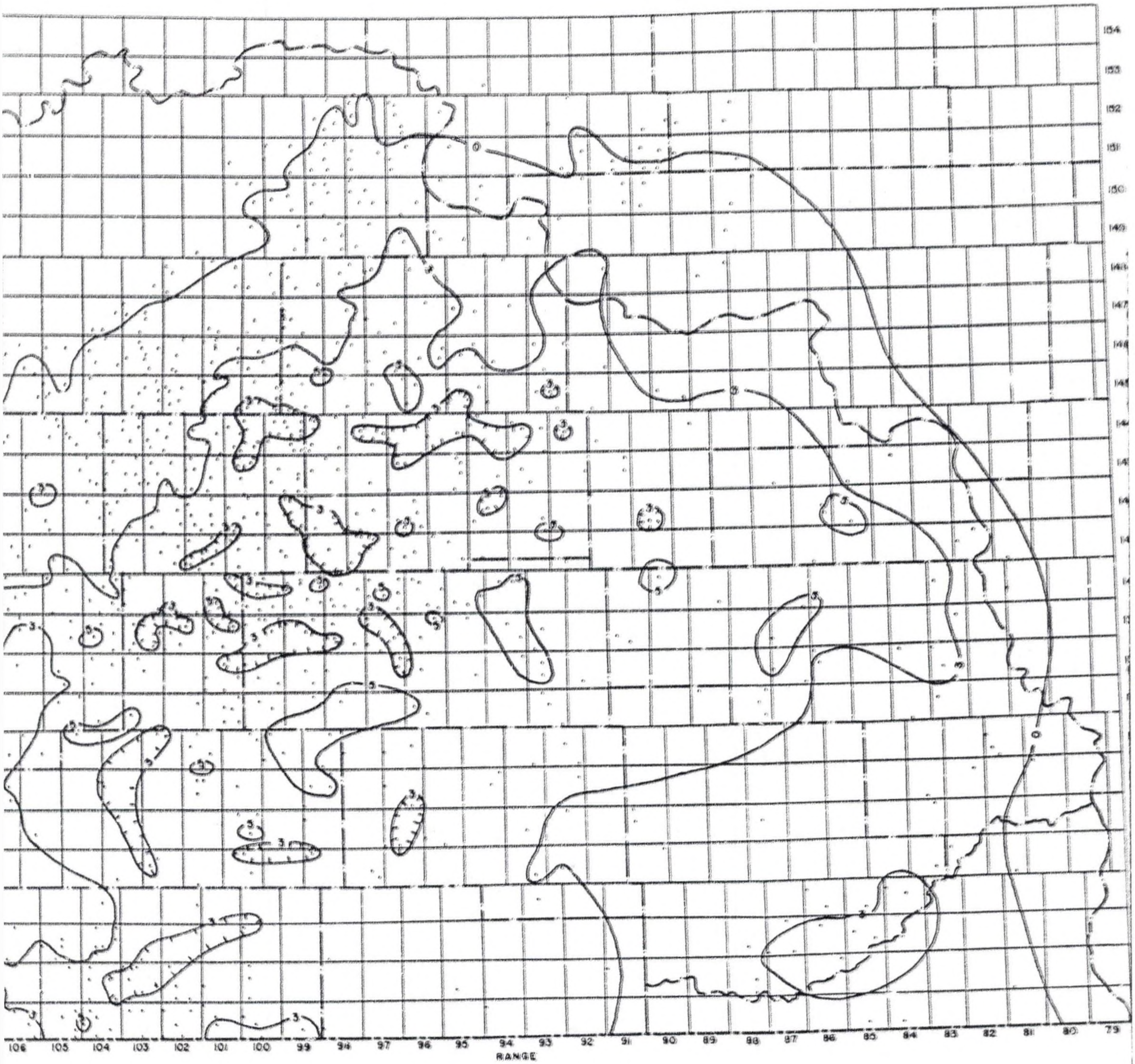
25
· CONTROL WELL
---Pbc ZERO THICKNESS
SCALE
0 10 20 MILES
0 10 20 30 KM

recognized using this contour interval. The 75 percent contour line meanders across the study area showing marked variability in sandstone percentage on a local scale. Three distinct reentrants of the 75 percent contour line extend into the western part of the study area. There are also numerous small scale variations or pods of higher and lower sandstone percentage scattered throughout the area. Greater variation generally occurs where there is greater well control. Sandstone percentage greatly decreases in the southeastern portion of the map and that trend appears to continue southward into South Dakota.

A map of the total number of sandstone beds within the Broom Creek Formation (Fig. 26) reveals some general depositional trends. In the majority of the study area, the Broom Creek Formation consists of three to five beds of sandstone, each greater than ten feet thick. Only one or two beds of sandstone exist around the perimeter of the Broom Creek subcrop where the formation is relatively thin. Generally, there are a greater number of beds of sandstone in the east-central part of the study area. The sandstone sections are usually separated by beds of dolostone. The Broom Creek Formation characteristically has two major dolostone beds with varying numbers of discontinuous thin dolostone and sandstone lenses.

Figure 26. Map showing the number of sandstone beds in the Broom Creek Formation. Contour interval is two beds. Hachured contour lines denote areas with decreasing number of sandstone beds.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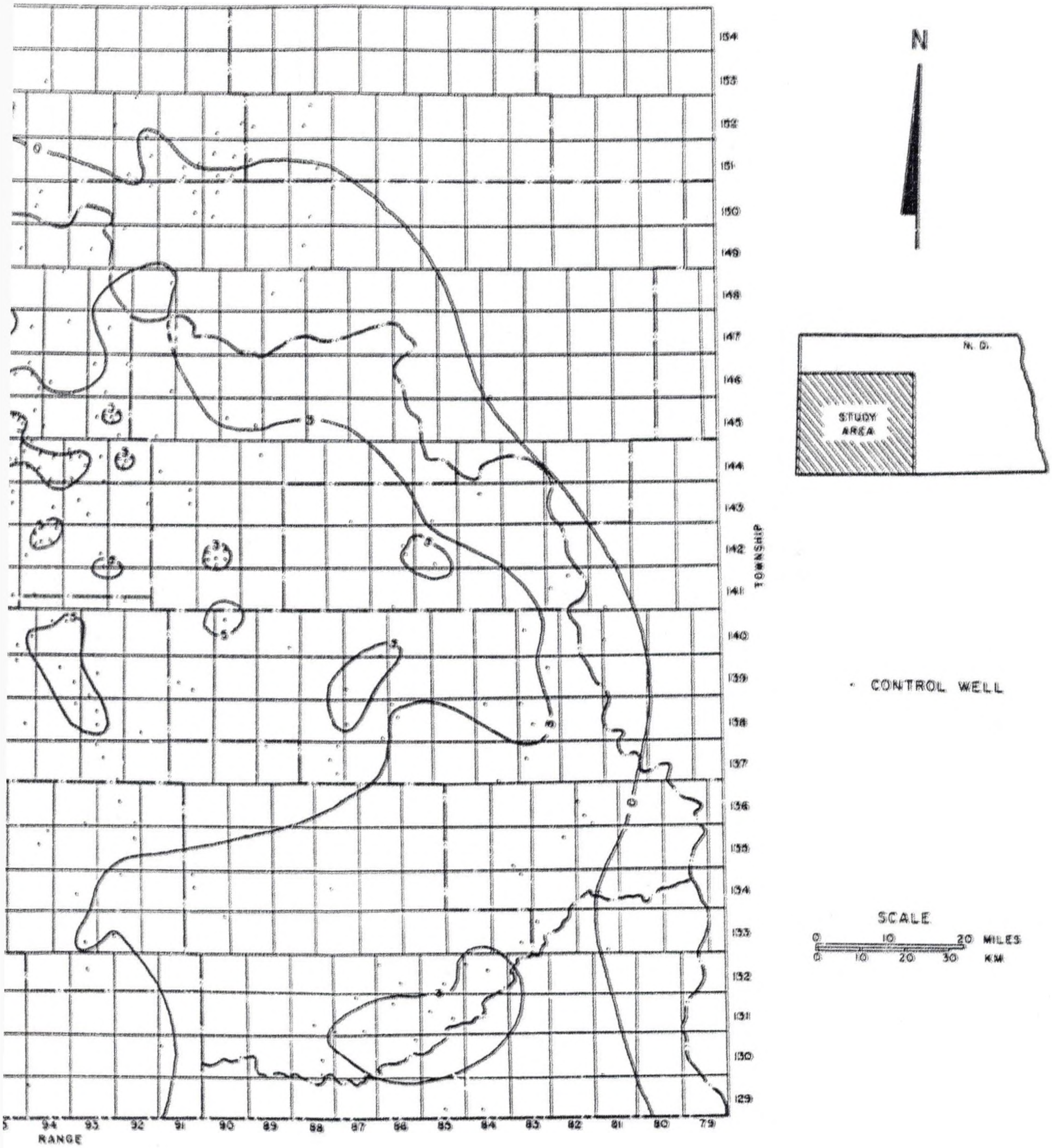
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RANGE
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STUDY AREA
CONTROL WELL
SCALE
0 10 20 MILES
0 10 20 30 KM

NITROGEN GAS OCCURRENCE

Detection of Nitrogen

The presence of nitrogen gas in the Minnelusa Group in North Dakota has been documented for quite some time (Marchant, 1966). Nitrogen gas has been encountered in the drilling of oil wells in the study area. Along the Nesson anticline, a few nitrogen wells have been used to supply gas for oil wells completed with gas lift systems. In some instances, the presence of nitrogen gas in the Broom Creek Formation and upper Amsden Formation has been a nuisance for oil well drilling. A number of blowouts have occurred while drilling through the nitrogen zones. These uncontrolled blowouts are very costly and can be dangerous. Part of this study involved mapping the nitrogen accumulations, which were detected on wireline logs, within the Broom Creek Formation.

Primarily, the FDC-CNL log was used to detect nitrogen gas in the Broom Creek Formation. The FDC-CNL tool is commonly used for gas detection in petroleum exploration (Helander, 1983). More commonly, natural gas is the product being sought, although nitrogen gas will manifest very similar responses to natural gas (methane) using the FDC-CNL tool. In gas-saturated zones, such as the Broom Creek sandstone, where there is moderate to good porosity and moderate invasion of borehole fluids, the FDC-CNL tool response is markedly different than the normal response in fluid-filled zones (Helander, 1983). The compensated

neutron log is a deep focused tool that responds to the hydrogen content in the zone of investigation. A gas-filled zone, in this case nitrogen gas, will show an anomalously low porosity on the compensated neutron trace due to the absence of hydrogen atoms. Conversely, the formation density compensated tool may show an anomalously high porosity value in the gas saturated zone. This is due to the overcorrecting of tool response in the gas zone, which is calibrated for the fluid densities of water and oil. These anomalous readings on the FDC-CNL log traces form what is called "gas effect", which is a good indication of gas saturation (Asquith and Gibson, 1982). Most of the FDC-CNL "gas effect" responses in the Broom Creek Formation were indicative of gas zones with moderate to high porosity and moderate borehole fluid invasion. An example of the typical FDC-CNL tool response in a nitrogen saturated zone can be seen in the Moore Federal No. 1-28 well (Fig. 27).

The geographical occurrence of nitrogen gas accumulations in the Broom Creek Formation has not previously been published. Using mainly FDC-CNL wireline logs when available, the thickness of the nitrogen gas saturated Broom Creek sandstone was mapped (Fig. 28). Most of the nitrogen gas accumulations occur in the northwest portion of the Broom Creek subcrop area. Sixty-five wells in the study area reveal the presence of gas in the Broom Creek Formation. Nitrogen-saturated zones vary in thickness from 4 to 50 feet (1.2 to 15 meters).

Figure 27. Typical wireline log (gamma-ray, formation density compensated - compensated neutron log) of the nitrogen gas saturated zone in the Broom Creek Formation.

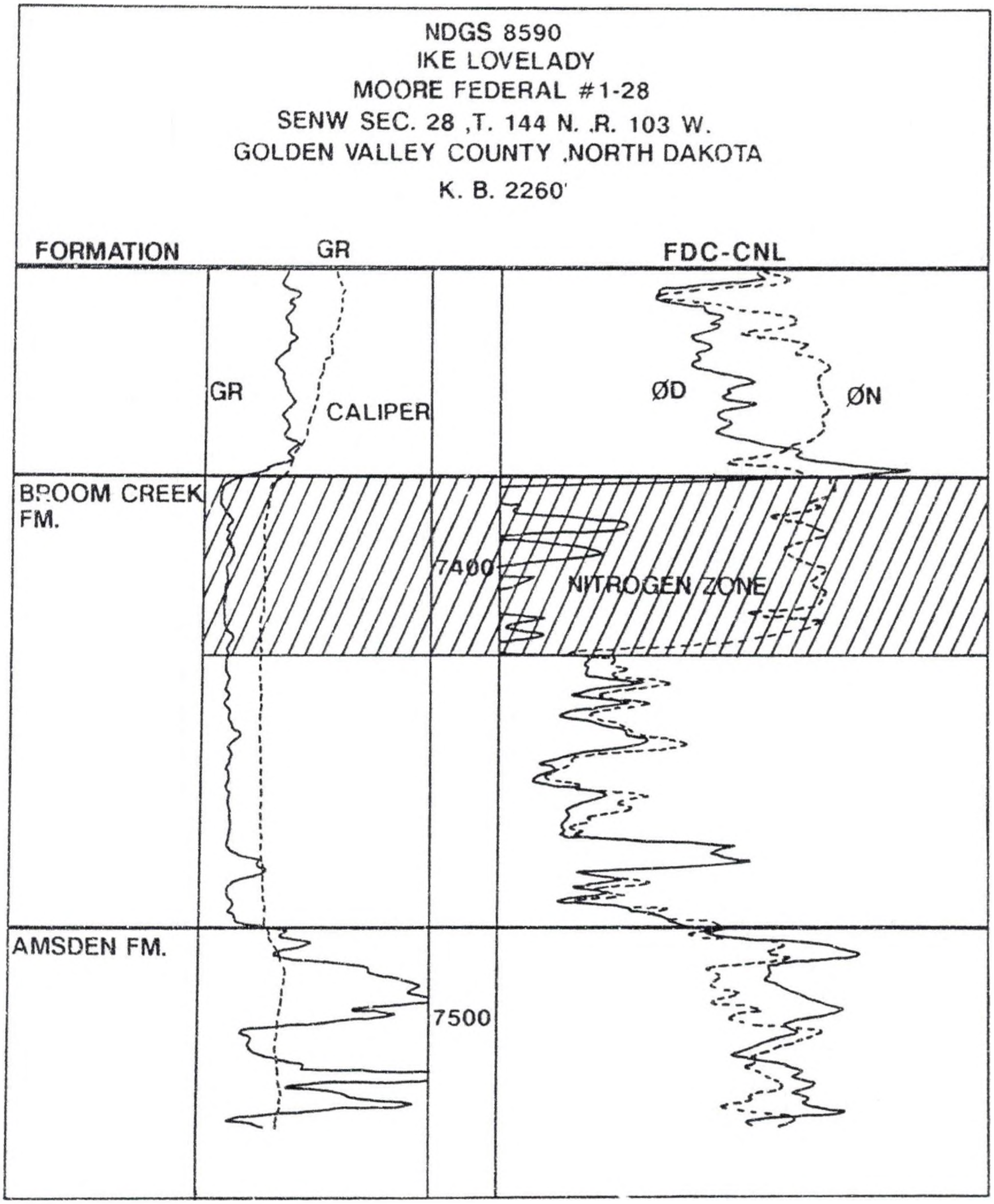
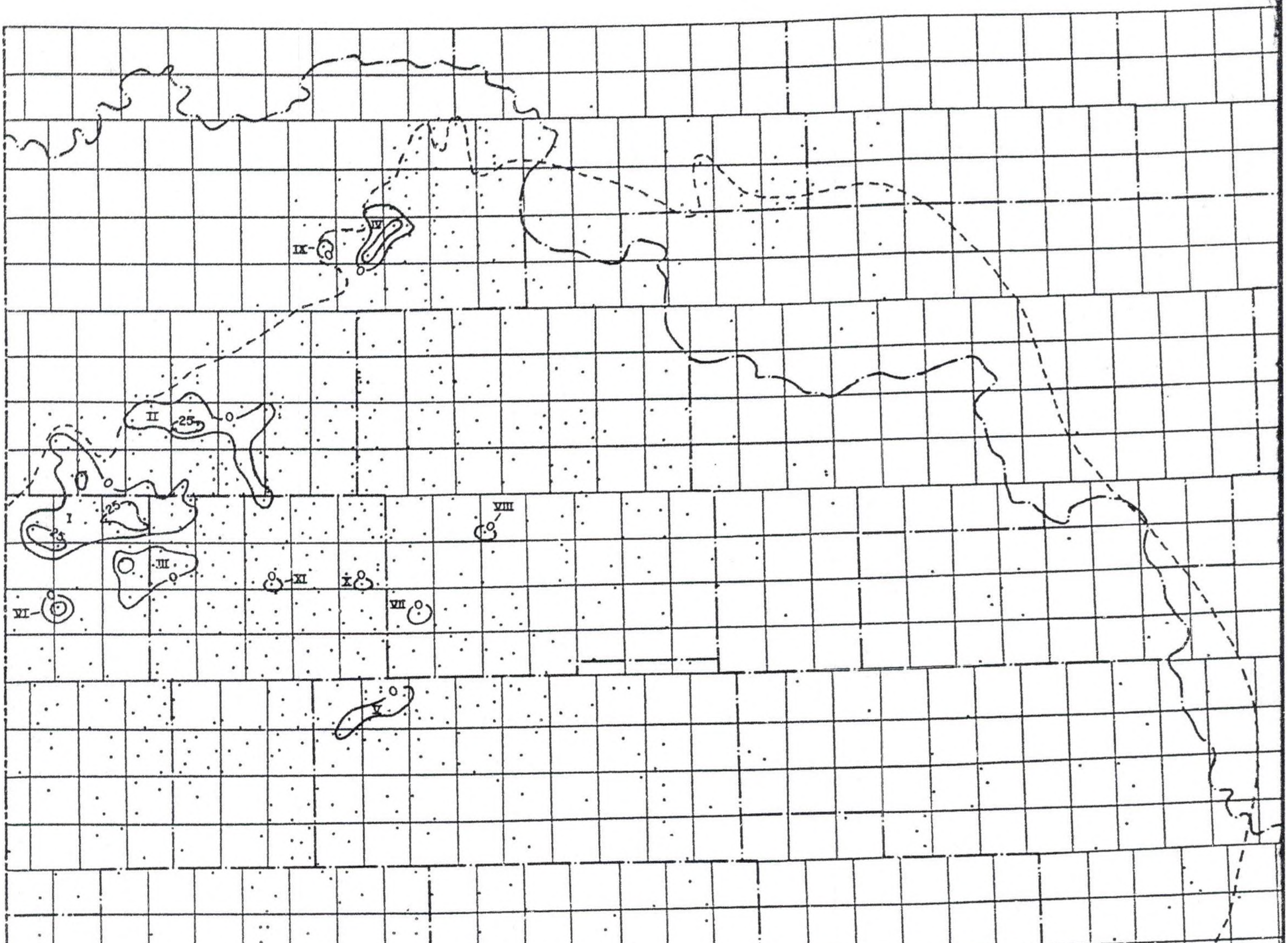

NDGS 8590
IKE LOVELADY
MOORE FEDERAL #1-28
SENW SEC. 28 ,T. 144 N. ,R. 103 W.
GOLDEN VALLEY COUNTY ,NORTH DAKOTA
K. B. 2260'
FORMATION
GR
FDC-CNL
GR
CALIPER
ØD
ØN
BROOM CREEK FM.
7400
NITROGEN ZONE
AMSDEN FM.
7500

Figure 28. Isopach map of nitrogen gas saturated Broom Creek Formation. Contour interval is 25 feet (8 meters). Roman numerals designate regions used in the tabulation of nitrogen reserves. Dashed line shows present extent of the Broom Creek Formation.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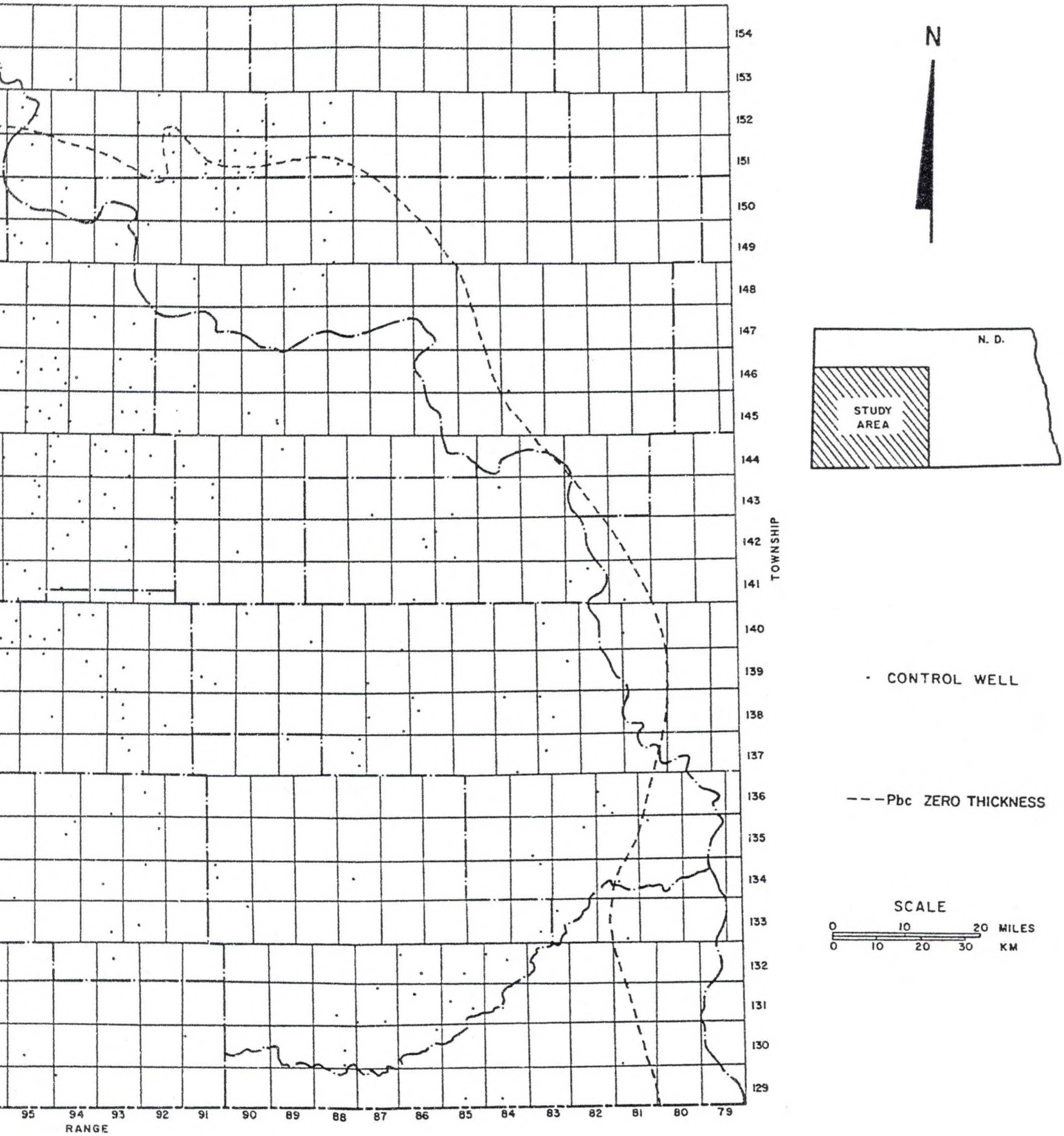
RANGE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RANGE
· CONTROL WELL
---Pbc ZERO THICKNESS
SCALE
0 10 20 MILES
0 10 20 30 KM

Lower portions of the overlying Opeche siltstone also appear to show some presence of nitrogen gas on wireline logs. It is possible that nitrogen migrated up into the Opeche Formation; however, the low permeability exhibited by the fine-grained siltstone severely limits the potential flow capacities and ultimate use as a gas reservoir.

Calculation of Nitrogen Reserves

An attempt was made to quantify the amount of nitrogen gas which was encountered in the study area. Areal extent of the eleven nitrogen-rich regions (Fig. 28) were determined by planimetering each area, and reserves were calculated for each region on a volumetric basis. Net thickness of reservoir was obtained by averaging thickness values of wells in each region. Some of the reservoir parameters (porosity, pressure, and water saturation) from Marchant's (1966) study were used in the volumetric calculation, as they appeared to be good approximate values for the study area. The reservoir parameters are listed in Table 1. This volumetric method of calculation resulted in a total estimated value of 2.3 trillion cubic feet (65 billion cubic meters) of nitrogen gas in place in the Broom Creek Formation. The nitrogen reserves for each region are calculated separately and also shown in Table 1. The amount of total nitrogen in place is a broad estimate which could be improved upon with increased well control.

Table 1. Calculated nitrogen reserves in the Broom Creek Formation.

Estimation of Nitrogen Reserves
Broom Creek Formation, North Dakota

Reservoir Data

Average Porosity (Ø)	13%
Initial Water Saturation (Sw)	40%
Reservoir Temperature	184 °F
Initial Reservoir Pressure	3200 psig
Average Depth	-4500'subsea
Initial Formation Volume Factor (B_g)	.00111 bbl/ ft^3

Formula for volumetric calculation of original gas in place:

$$OGIP = \frac{7758*(\emptyset)*(1-Sw)*(h)*[(Area)*640]}{B_g}$$

OGIP - original gas in place (cu. ft.)
h - average height of gas zone (feet)
Area - area with nitrogen gas (sq. miles)

Region	Area (sq. miles)	Avg. thickness (feet)	Gas in place (cu. ft.)
I	186	19	1.2×10^{12}
II	87	17	5.2×10^{11}
III	50	14	2.3×10^{11}
IV	30	17	1.8×10^{11}
V	23	10	8.0×10^{10}
VI	2	20	1.4×10^{10}
VII	2	25	1.7×10^{10}
VIII	2	10	7.9×10^{9}
IX	2	4	2.8×10^{9}
X	2	40	2.8×10^{10}
XI	2	13	9.1×10^{9}
Total	388		2.3×10^{12}

DISCUSSION

Synthesis of Well Log and Core Data

The depositional pattern of the Broom Creek Formation has many similarities to the Upper Minnelusa Formation in the Powder River basin of Wyoming. The Upper Minnelusa in Wyoming is informally broken into three eolian-marine depositional packages labeled "A", "B", and "C" (Fryberger, 1984). The three depositional packages or cycles do not correlate exactly with the Broom Creek Formation within the study area. The Broom Creek Formation in North Dakota appears to have more abbreviated or incomplete cycles than what is seen in equivalent strata in Wyoming. However, there is evidence for at least two major cycles in North Dakota with the preservation of two fairly widespread carbonate sections.

The Williston basin most likely was intermittently connected with the Powder River basin during Minnelusa time. Isopach maps of the Broom Creek Formation and the Minnelusa Group in North Dakota show distinct thinning in all directions from their thickest accumulations. The thinning, however, is not as great southward towards the South Dakota border. This agrees with previous authors' conclusions of a narrow seaway extending northward from the midcontinent (Fryberger, 1984, Peterson, 1980, Bates, 1955).

It is postulated that the Upper Wolfcampian sand, which was deposited in both the Powder River and Williston basins, came from the western edge of the paleocontinent with the

erosion of the Ancestral Rockies (Rascoe and Baars, 1972). Other sources of sand may have been the Canadian shield to the north, the Siouxia uplift to the east, and the Alberta shelf to the northwest (McKee and others, 1967, Peterson, 1980). From numerous dipmeter measurements in the Powder River basin (Fryberger, 1984), the prevailing paleowind direction was shown to be north to south (seaward). Some of the Wolfcampian sand eventually formed into dunes along the north and west side of the shallow Lusk embayment. It appears that eolian dunes were preferentially preserved on the western side of the study area, which did not receive as much active marine inundation as the eastern side. The Broom Creek sea was bounded on the east by a steeper flank of the basin where dunes were either nonexistent or completely reworked by periodic marine transgressions.

From this study, little can be determined of the wind direction associated with the formation of dunes. There is no oriented core or dipmeter surveys available in the study area. However, a persistent wind pattern is suggested by the fact that the cored eolian sections in both the Herman May #2 and Burlington Northern #1 wells appear to be the result of large dunes migrating and depositing laminae uniformly dipping in one direction. Primarily from these observations and lack of any more definitive data, it is postulated that wind patterns were similar in both the Williston and Powder River basins.

A map of the total sandstone percentage (Fig. 25)

within the Broom Creek Formation suggests that marine deposition predominated in the eastern portion of the study area. The sandstone percentage map clearly shows a trend of decreasing sandstone percentage to the east. The 75 percent boundary does not necessarily represent the exact line between marine predominance and eolian predominance. It is quite likely that the Broom Creek shoreline transgressed and regressed numerous times throughout the deposition of the Broom Creek Formation, and the strandline moved substantial distances laterally with small fluctuations in sea level. Three distinct reentrants of the 75 percent contour line might denote zones of greater carbonate buildups where bays or inlets preferentially formed during marine transgressive phases. The variability of sandstone percentage on a small scale could be the result of carbonate buildups or, in cases of high sandstone percentage, possible areas of thicker eolian sediments.

The discontinuous distribution of the dolostone beds appears to be similar to the Upper Minnelusa of Wyoming. However, dolostone beds in the Powder River basin cannot be traced into the Williston basin, as there is virtually no dolostone in the Wolfcampian sediments northeast of the Powder River basin into South Dakota (Ziebarth, 1972). It appears that carbonate deposition was similar for both basins, although it is discontinuous either from nondeposition or erosion.

A major dolostone bed was geographically widespread

across the middle portion of the study area, although not present in every well. This major dolostone bed is referred to as the "middle argillaceous zone" due to its distinctive gamma-ray response on wireline logs. The "middle argillaceous zone" is thought to contain a higher concentration of radioactive clays than surrounding beds. The high gamma-ray response usually, but not exclusively, coincides with the marine carbonate lithofacies. This is in contrast to the two sandstone lithofacies in the Broom Creek Formation, which usually manifest negligible response on the gamma-ray log. A good example of this "middle argillaceous zone" is shown in the resistivity log of the E.E. Miller No. 10-1 well, from 7825 to 7900 feet (Fig. 17).

These beds of high radioactivity are likely due to an influx of radioactive clays, which occurred intermittently throughout the deposition of the Broom Creek Formation. The argillaceous zones appear to coincide with only the marine deposits in the Broom Creek Formation. Equivalent strata in South Dakota and Wyoming do not appear to contain any major radioactive beds similar to the North Dakota deposits. It appears that these radioactive clays in the Broom Creek Formation were not deposited to the south of the study area. The origin of the radioactive clays is not known but may be a function of the close proximity of the study area to the cratonic shield, which might have been a source of radioactive material.

Steeply dipping, finely laminated sandstone

predominates in the Burlington Northern #1 and Herman May #2 well cores. It is postulated that these steeply dipping laminae represent eolian dune sedimentation, specifically foreset or slipface deposits. The inclined strata show variation between thicker nondistinct beds and thin distinct laminae. These sets of fine-grained laminae and coarser-grained beds may represent alternate ripple- and avalanche-produced strata. This type of sedimentation pattern is common for eolian dune, slipface deposits (Fryberger and others, 1983). The top of the core from the Burlington Northern #1 well is interpreted to be a reworked dune, showing no particular bedding structure compared to the distinct underlying foreset beds.

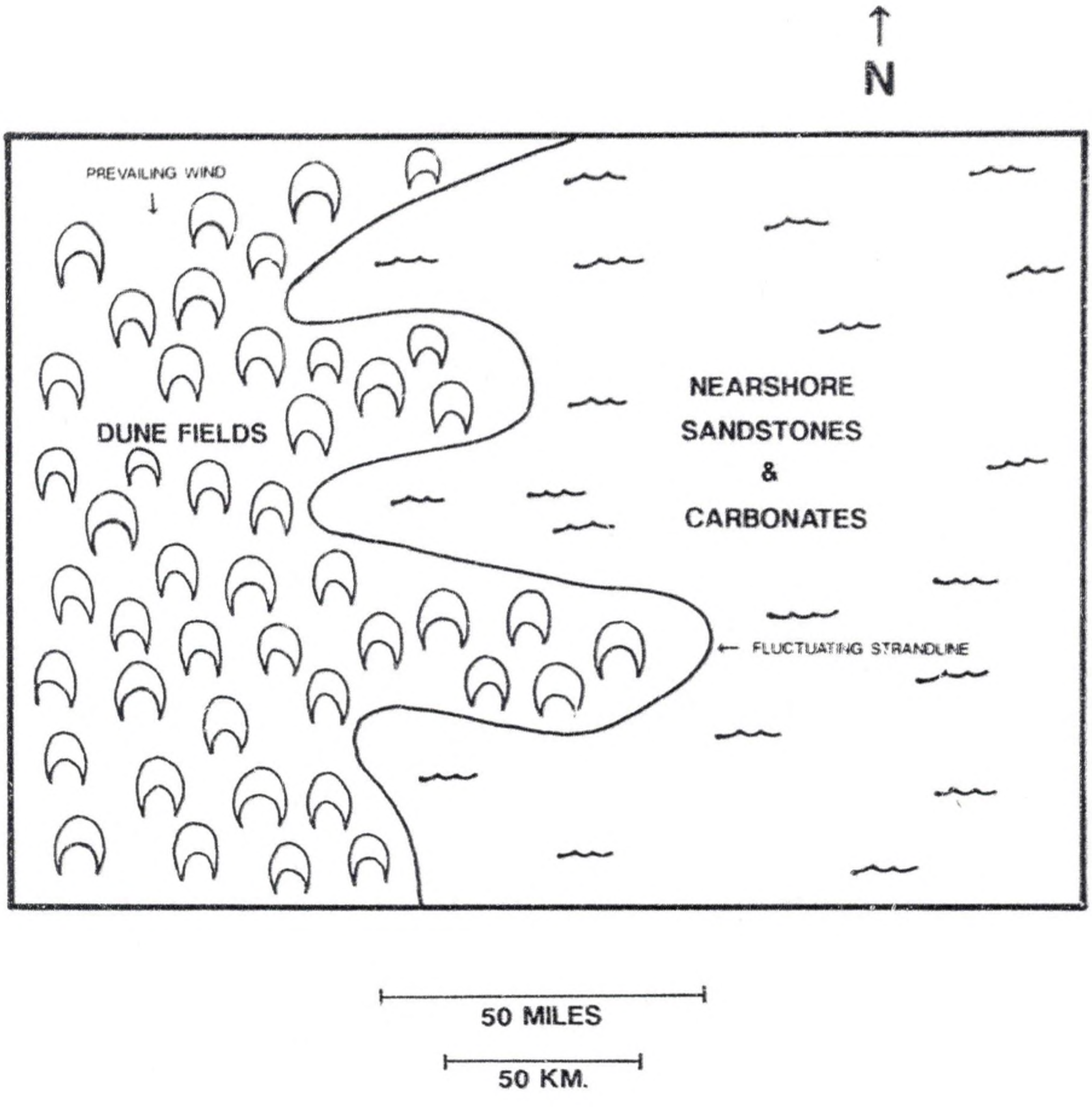
A single overturned bed occurs in the Burlington Northern #1 core. The overall structure is less than one foot thick (.3 meters) and is bounded below and above by steeply dipping laminae. The structure coincides with surrounding slipface sediments and is the only structure of its kind found in core. This overturned bed appears to be a slump structure related to the avalanching of moist, cohesive sand down the slipface of the dune. In moist sand, eolian, avalanche deposits are likely to consist of slumped, coherent blocks (Kocurek and Dott, 1981).

The general lithologic makeup of the eolian section of the Broom Creek Formation matches quite well with studies of the Upper Minnelusa of the Powder River basin (Fryberger, 1984). However, it appears that anhydrite is a more common

constituent in the Powder River basin sediments. The eolian sandstone lithofacies has distinct beds of unstained, white sandstone, which contrast with the surrounding beds of pink sandstone. In the unstained beds, it appears that anhydrite (originally gypsum) precipitated soon after deposition of the dune and can be considered a primary depositional feature. It is possible that detrital anhydrite (gypsum) was incorporated into the eolian sediments. Detrital anhydrite is common in modern eolian environments (Fryberger and others, 1983). However, the occurrence of anhydrite is minor throughout the complete Broom Creek eolian section. It is postulated that some of the original anhydrite has been removed by later stage dissolution.

The fine-grained texture of the marine carbonate lithofacies and lack of structure other than burrowing leads to an interpretation of low energy carbonate deposition consisting of lime mud forming in relatively quiet, shallow water. These carbonate beds interfingered with marine sandstone in the eastern portion of the study area and may have been deposited in bays or inlets in the west (Fig. 29). In many instances, these carbonate beds formed discontinuous lenses across most of the study area. The thicker carbonate beds represent times of more persistent marine inundation. Deposition of marine carbonate and marine sandstone at times was gradational, and resulted in the preservation of some carbonate beds containing substantial amounts of detrital material.

Figure 29. Idealized paleogeographic map of study area during Broom Creek time showing probable strandline with eolian sediments to the west and nearshore marine sediments to the east. Barchanoid dunes are depicted only for illustrative purposes. Schematic is approximate size of study area. Prevailing wind direction from Fryberger (1984).


N
PREVAILING WIND
DUNE FIELDS
NEARSHORE
SANDSTONES
&
CARBONATES
FLUCTUATING STRANDLINE
50 MILES
50 KM.

Overall, the nearshore marine sandstone lithofacies does not exhibit prominent sedimentary structures. However, the nearshore marine lithofacies in the ANG #1 Disposal well shows a distinct cementation change from the bottom of the cored section to the top. A friable massive sandstone grades upwards to an indurated laminated sandstone; the sequence is interpreted as a shallowing-upward marine succession. The deeper water sediments appear to have a larger percentage of clays. The cementation within the deeper water sediments is weakened by the increase of interstitial clays and this accounts for the friability. The subtle change in sedimentation is most likely a result of change in the energy of environments due to relatively small changes in water depth and proximity to shoreline.

Preservation of Eolian Dunes

Dune preservation is generally sparse in the geologic record. Reworking of eolian sediment by fluvial or marine systems has undoubtedly obliterated numerous eolian sections from the rock record (Walker and Harms, 1972). It is quite probable that a substantial part of the marine sandstone lithofacies in the Broom Creek Formation is reworked eolian dunes. The probability of preservation is a function of the rate of subsidence and energy of the inundating system. The occurrence of eolian sandstone in two of the four cored wells in the study area suggests that a substantial portion of the Broom Creek Formation in the western part of the

study area remains intact as original eolian dunes.

The preservation of the upper eolian section of the Broom Creek Formation was made possible by events which transpired after Broom Creek deposition. The basal Opeche Formation, above the contact with the Broom Creek Formation, consists of either a thin salt section or a very-fine-grained, massive siltstone. The presence of a basal Opeche salt is direct evidence that arid conditions prevailed after Broom Creek deposition and into Opeche time. The low-energy depositional environment in the Opeche Formation enabled dunes in the upper Broom Creek Formation to be preserved without much reworking by Opeche seas. These topographically high areas (possibly dunes) within the Broom Creek Formation existed as islands in the shallow Opeche salt pan. There is direct evidence, from log data, that the upper surface of the Broom Creek is quite variable, particularly in western part of the study area. Higher-standing areas in the upper Broom Creek section appear to have persisted after Broom Creek deposition ceased. These isolated higher-standing features, such as in the Jacob #1-1 well (Fig. 17), are possible evidence of sets of dunes preserved in the upper part of the section. The onset of Opeche deposition was of sufficiently low energy that at least some Broom Creek dunes were only partially reworked. Certain sections in the Burlington Northern and Herman May cores appear to be beds of marine sandstone, which are likely reworked eolian sediments (Figures 10 and 11).

The isopach map of the Broom Creek Formation (Fig. 21) shows substantial local variability. A primary reason for this variability is the irregular upper contact of the Broom Creek Formation. It appears that local erosion occurred during the hiatus between the deposition of the Broom Creek Formation and the Opeche Formation. The irregular upper Broom Creek surface may be the result of fluvial processes, although there is no direct evidence of that from data gathered in this study. Widespread stream-cut valleys in the upper Broom Creek section are not evident from logs or core in the study area. The regional distribution of the Broom Creek Formation does not appear to be greatly altered by erosion.

It is possible that, because of insufficient well density, detailed erosional trends cannot be recognized in the study area. The irregular reentrants of the isopach contours may denote paleodrainage patterns cut by streams which existed after Broom Creek deposition. It is possible that at the end of Broom Creek time, some dunes and interdune areas were not eroded or reworked, and were wholly or partially preserved. The resulting Broom Creek isopach pattern may reflect the irregular topography which existed at the end of Broom Creek deposition.

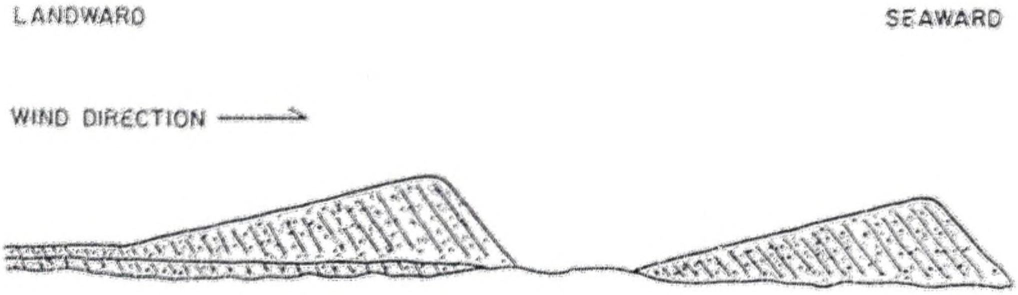
It cannot be determined whether the lower sandstone beds of the Broom Creek Formation in the western area are eolian or marine. All the core specimens studied were from the upper section of the Broom Creek Formation. Based on

the existence of two widespread carbonate beds, at least two major marine influxes occurred during the deposition of the Broom Creek. The occurrence of dolostone beds above sandstone beds in the Broom Creek Formation is evidence of marine inundation and possible reworking of eolian sediments. Due to the absence of cored lower section, it is difficult to determine if any eolian sandstone was preserved in the lower Broom Creek Formation. The lower section of the Broom Creek Formation is postulated to have been more heavily influenced by marine sedimentation than the upper Broom Creek. From logs, it appears that porosity in the sandstone beds is not as well developed in the lower portion of the Broom Creek Formation (Fig. 3). This is most likely due to marine sandstone predominance (more dolomite occluding porosity) in the lower section. The chance for preservation of eolian sediments in the lower section of the Broom Creek Formation appears diminished over that of the upper section.

Genetic Depositional Model

A genetic model is proposed for the deposition of an ideal eolian-marine cycle within the Broom Creek Formation (Fig. 30). The first phase of the model consists of eolian dunes migrating over a low-relief erosion surface. The initial phase of eolian sedimentation was followed by two depositional phases of marine inundation including partial reworking of eolian dune deposits into a nearshore marine

Figure 30. Proposed depositional model for the formation and preservation of eolian sediments in the Broom Creek Formation. Lateral scale is on the order of one to three miles (.6 to 1.8 km). Vertical scale is on the order of 30 to 100 feet (10 to 30 meters).



I. MIGRATION OF DUNES SEAWARD OVER LOW RELIEF EROSIONAL SURFACE.

II. MARINE TRANSGRESSION AND SUBSEQUENT PARTIAL REWORKING OF EOLIAN SANDS.

III. LAST STAGE OF MARINE INUNDATION WITH DEPOSITION OF CARBONATE MUD.

IV. MARINE REGRESSION, DIASTEM WITH MINOR EROSION.

sandstone and marine carbonate deposition. The last phase in the model consists of marine regression and accompanying diastem with minor erosion. A succeeding cycle begins with the onset of new dune migration. The initial Broom Creek sediments were deposited upon the disconformable Amsden contact, which shows minimal evidence of paleotopography in the subsurface of North Dakota. Subsequent Broom Creek cycles may have been deposited on surfaces with slightly more topography depending on the smoothing effect of marine reworking in the preceding cycle. From the model it can be seen that the resulting strata are laterally discontinuous and that many vertical combinations of lithofacies can occur.

Nitrogen Accumulation

Nitrogen is a common, minor constituent in most petroleum deposits. About one-fifth of all American crude is classified as high nitrogen, with more than .25 percent nitrogen, and many gas reservoirs in the midcontinent and Rocky Mountain region contain large amounts of nitrogen gas (Levorsen, 1967).

Nitrogen gas is commonly associated with red beds, such as the Broom Creek Formation. The occurrence of nitrogen gas in the Broom Creek Formation appears to be related to hydrocarbon generation and subsequent reaction of the nitrogen compounds with iron oxide. It has been postulated that oxidation of nitrogen bearing organic compounds by

ferric iron would yield nitrogen (Hunt, 1979). Nitrogen is also associated with the generation of methane gas and it is likely that nitrogen migrates farther than methane because of its smaller molecular size (Hunt, 1979).

The nitrogen gas within the Broom Creek Formation is postulated to have originated in either the Tyler or Amsden Formations. The Tyler Formation produces oil and associated natural gas in the Dickinson, North Dakota area (T. 145 N., R. 96 W.). The produced natural gas has low BTU content, which can be attributed to a high concentration of nitrogen. It appears that there is a relationship between the nitrogen gas in the Broom Creek Formation and the high content of nitrogen in the associated natural gas within the Tyler Formation. However, the accumulations in each respective formation occur in different geographical areas.

Similarities in source rock composition and thermal maturation between the Amsden Formation and the Tyler Formation indicate both horizons may have produced nitrogen, which migrated into the Broom Creek sandstones. The nitrogen accumulations in the Broom Creek Formation generally occur in the central portion of the Williston basin. Thermal maturity, which increases in the deeper central part of the basin, may be a factor in the distribution of nitrogen gas in the Broom Creek Formation.

The Broom Creek sandstones exhibit excellent reservoir qualities, with good porosity and permeability. Overall, the eolian sandstone lithofacies has slightly better

porosity than the marine sandstone lithofacies. Productivity of nitrogen should not be a problem insofar as reservoir quality is concerned. Gas saturation and net pay thickness would be key factors in the deliverability potential of large volumes of nitrogen gas.

Major structural features do not appear to be the primary cause of entrapment of nitrogen gas. The structure on top of the Broom Creek Formation (Fig. 16) did not delineate any definite structural closure for the nitrogen accumulations, and there is no evidence from log or core data of any major lateral facies changes or diagenetic changes which might serve as stratigraphic traps. The trapping mechanism of the gas is postulated to be subtle structural traps with the overlying Opeche siltstone and, to a lesser extent, the basal Opeche salt as the reservoir upper seal. Mapping on a smaller scale with increased well control may better define the trapping mechanism.

Some oil fields along the southern portion of the Nesson anticline use nitrogen from the upper sandstone beds in the Amsden Formation to operate artificial gas lift systems on a number of oil-producing wells. Most of these nitrogen gas wells have very high productive potentials (Marchant, 1966). Pressure from the nitrogen gas reservoir is sufficiently high that further compression of the gas is not necessary for utilization in the gas lift process. Chemical analysis of the gas produced from the Amsden Formation has shown that it is 96 percent nitrogen

(Marchant, 1966). The nitrogen accumulations within the Broom Creek Formation may have some future economic potential. Nitrogen could possibly serve the oil industry for use in gas lift systems in other oil producing areas of North Dakota. Economics would dictate the ultimate usage of the nitrogen for gas lift.

There are other uses of nitrogen which might lead to the exploitation of reserves in the Broom Creek Formation. A few examples of such uses are the manufacture of anhydrous ammonia for agricultural fertilizer, fracture stimulation of oil wells, nitrified cementing of oil wells, and a remote possibility of use in enhanced oil recovery. It is not the scope of this paper to elaborate on the prospects and economics of any product usage.

CONCLUSIONS

1. Three main lithofacies have been identified in the Broom Creek Formation: nearshore marine lithofacies, marine carbonate lithofacies, and eolian sandstone lithofacies.

2. Eolian strata occur in two well cores. Thick beds of steeply inclined laminae are interpreted as eolian dune, slipface deposits.

3. The fine-grained, burrowed dolostones were probably deposited in relatively quiet, shallow water. These carbonate beds interfinger with marine sandstone lithofacies in the eastern portion of the study area and may have been deposited over some eolian deposits in the west.

4. It is probable, from core and wireline logs, that eolian sedimentation predominated in the western portion of the study area and marine sedimentation predominated in the east.

5. The surface of the upper Broom Creek section is quite irregular due to preserved paleotopography associated with dune sets in the upper Broom Creek, and also to erosional processes which occurred post-Broom Creek - pre-Opeche time.

6. A four-phase genetic model is proposed for the deposition of an ideal eolian-marine cycle within the Broom Creek Formation. The first phase of the model consists of eolian dunes migrating over a low-relief erosion surface. The initial phase was followed by two phases of marine inundation, including partial reworking of eolian deposits

into a nearshore marine sandstone facies, and marine carbonate deposition. The last phase consists of regression and an accompanying diastem with minor erosion. A succeeding cycle begins with the onset of new dune migration.

7. The preservation of dunes in the upper section of the Broom Creek Formation is largely a function of the arid paleoclimate and low energy depositional conditions which prevailed after Broom Creek time. The overlying, basal Opeche Formation was deposited in a shallow salt pan. Some Broom Creek dunes existed as islands in this shallow salt pan and were eventually preserved without substantial reworking.

8. The depositional pattern of the Broom Creek Formation has many similarities to the Upper Minnelusa Formation in the Powder River basin of Wyoming. However, the Broom Creek Formation in North Dakota appears to have more abbreviated or incomplete eolian-marine cycles than equivalent strata in Wyoming.

9. The diagenetic history of the marine sandstone lithofacies consists of a number of early stage diagenetic events and a number of later stage events. The early stage diagenetic events were minor iron oxide precipitation, the formation of quartz overgrowths and subsequent partial cementing with quartz, dolomitization of all carbonate material including fusulinids, and minor gypsum precipitation. Later stage diagenetic events include

porosity reduction from compaction and pressure dissolution of quartz grains, minor replacement of dolomite with anhydrite, and minor dissolution of anhydrite.

10. The pervasive dolomitization of all the carbonate material in the Broom Creek Formation appears to be an early diagenetic feature. Dolomitization probably occurred as the result of reflux brines that formed during the deposition of the overlying Opeche evaporite beds.

11. The diagenetic history of the eolian sandstone lithofacies is less complex than the marine sandstone lithofacies. The early stage diagenetic events were gypsum precipitation (possibly syndepositional), iron oxide precipitation, and the formation of quartz overgrowths and subsequent quartz cementation. Later stage diagenetic events include porosity reduction from compaction and pressure dissolution of quartz grains, and minor dissolution of anhydrite.

12. Eleven separate areas of nitrogen gas accumulation in the Broom Creek Formation are estimated to contain a total of 2.3 trillion cubic feet (65 billion cubic meters) of gas in place.

APPENDIX A

CORE DESCRIPTIONS

The following core descriptions are from core curated at the Wilson M. Laird Core and Sample Library, Grand Forks, North Dakota. The descriptions are listed according to footage depth in descending order.

ANG Water Disposal #1
SE SW Sec. 24, T.145 N., R.88 W.
Mercer County, North Dakota

Depth	Description
5800-5826	Opeche Siltstone: red, fine-grained, moderately cemented; finely laminated; possible dewatering structures.
5826-5828.5	Anhydrite: red to pink, laminated to massive, well-cemented; interspersed chert fragments and large quartz grains.
5828.5-5830	Anhydrite and Quartzarenite: red, fine to medium grained, poorly sorted, well-cemented; small beds of anhydrite alternating with cross-bedded sandstone; some chert fragments.
5830-5830.5	Broom Creek Quartzarenite: red, fine to medium-grained, moderately well-sorted, well-cemented; massive.
5830.5-5834	Dolomudstone: red, fine grained, well-cemented; fossiliferous; crinoid columnals (2-3mm); fusulinids; shell fragments (brachiopod?); mostly massive; some finely laminated layers; anhydrite replacement of fossil material; some vuggy porosity.
5834-5837	Quartzarenite: pink, fine-grained, well-sorted, well-cemented; fossiliferous; numerous fusulinids; massive.
5837-5838	Quartzarenite: pink, fine-grained, well-sorted, well-cemented; nonfossiliferous; vertical fracture; massive.
5838-5840	Dolomudstone: pink, fine-grained, well-cemented; some fusulinids; vertical fracture; massive; some vuggy porosity.

5840-5848	Quartzarenite: pink, fine-grained, well-sorted, moderately well-cemented; numerous fusulinids; burrow structures?; very porous; massive; slightly calcareous.
5848-5852	Quartzarenite: pink, fine-grained, well-sorted, moderately well-cemented; unfossiliferous; some ripple cross lamination.
5852-5860	Quartzarenite: pink to light brown, well-sorted, friable; unfossiliferous; thinly laminated (2-3mm); slightly calcareous.

NDGS #658
Herman May #2
SE SE Sec. 9, T.139 N., R.100 W.
Billings County, North Dakota

Depth	Description
7662-7676	Opeche Siltstone: rusty red, fine-grained, moderately well-sorted; very hematitic; poorly cemented; no bedding structure.
7676-7677	Anhydrite: Pink to white, bedded; fractured; broken clasts.
7677-7679	Broom Creek Quartzarenite: red, fine to medium-grained, moderately well-sorted; well-cemented; few beds poorly sorted with some large chert fragments and large well-rounded quartz grains; low angle cross-bedding; overturned bedding?.
7679-7682	Quartzarenite: red, fine to medium-grained, well-sorted; massive; friable; noncalcareous; few rock partings along low angle planar bedding planes.
7682-7686	Quartzarenite: red, fine to medium-grained, well-sorted; moderately well-cemented; noncalcareous; steeply dipping parallel planar bedding.
7686-7691	Quartzarenite: red, fine to medium-grained, well-sorted; moderately well-cemented; noncalcareous; mostly massive with a few planar beds.
7691-7697	Quartzarenite: red, fine to medium-grained, well-sorted; moderately well-cemented; steeply dipping parallel planar bedding; few beds of white sandstone (no iron staining).
7697-7698	Quartzarenite: red, fine to medium-grained, well-sorted; moderately well-cemented; massive.
7698-7698.5	Quartzarenite: red, fine to medium-grained, well-sorted; moderately well-cemented; steeply dipping parallel planar bedding; white speckled appearance from uneven iron staining.
7698.5-7701	Quartzarenite: red, fine to medium-grained, well-sorted; moderately well-cemented;

	noncalcareous; steeply dipping parallel planar bedding; indistinct bedding planes.
7701-7701.1	Dolomitic quartzarenite: red, fine-grained, moderately well-cemented; level planar laminations; some chert fragments (3-5mm); few rounded glauconite grains, slightly calcareous.
7701.1-7702	Quartzarenite: pale red, fine to medium-grained, well-sorted; moderately well-cemented; planar level laminae (1-2mm thick); some white unstained interbeds.
7702-7704.5	Quartzarenite: pale red to white, fine to medium-grained, moderately well-sorted; moderately dipping parallel planar bedding; some beds poorly sorted with large quartz grains; some white unstained beds.
7704.5-7705	Quartzarenite: pale red to white, fine to medium-grained, moderately well-sorted; medium angle ripple cross lamination; alternating red and white laminae (stained and unstained, 1-2mm).
7705-7708	Quartzarenite: white with some red mottling, fine to medium-grained, well-sorted; some low angle parallel planar bedding.
7708-7711.5	Quartzarenite: white with few red flecks, fine to medium-grained, moderately well-sorted; low angle to level parallel planar laminae (1-3mm); some ripple cross laminae; bottom grades to dolomite; mottled appearance near base.
7711.5-7718	Dolomitic mudstone: red to gray, fine-grained, well-cemented; massive; alternating to thinly laminated shaly laminae; base is irregular surface (erosional) with shale parting; quartz grains interspersed in massive dolomite.

NDGS #5196
Burlington Northern #1
NE SE Sec. 1, T.141 N., R.100 W.
Billings County, North Dakota

Depth	Description
7879-7886	Broom Creek Quartzarenite: red, fine to medium-grained, moderately well-sorted; indistinct bedding; some beds (3-5cm) of dark friable sandstone; speckled appearance in some beds from differential iron staining.
7886-7897	Quartzarenite: red, fine to medium-grained, moderately well-sorted, poorly cemented; steeply dipping parallel planar bedding.
7897-7901	Quartzarenite: pink, fine to medium-grained, moderately well-sorted, friable; indistinct steeply dipping parallel planar bedding.
7901-7902	Quartzarenite: pink, fine to medium-grained, moderately well-sorted, moderately well-cemented; overturned bedding.
7902-7905	Quartzarenite: pink, fine to medium-grained, moderately well-sorted, moderately well-cemented; steeply dipping parallel planar bedding.
7905-7907	Quartzarenite: pink, fine to medium-grained, moderately well-sorted, moderately well-cemented; steeply dipping parallel planar bedding; truncated bedding.

NDGS #4989
John Gangl #1
SW NE Sec. 11, T.135 N., R.82 W.
Morton County, North Dakota

Depth	Description
3893-3894	Opeche Siltstone: red, fine-grained, well-sorted, well-cemented; some anhydrite nodules.
3894-3903	Broom Creek Dolomudstone: pink, fine-grained, well-cemented; massive; some moldic porosity; anhydrite nodules (1-3cm).
3903-3907	Quartzarenite: pink, fine-grained, well-sorted, moderately well-cemented; some ripple cross laminations; noncalcareous.
3907-3909	Dolomudstone: red, fine-grained, well-cemented; finely laminated; some nodules of anhydrite (1-10mm); stylolitic.

APPENDIX B

THIN SECTION DESCRIPTIONS

The following thin section descriptions were made from selected units in the ANG Water Disposal #1 core and the Herman May #2 core. The descriptions are listed according to footage depth in descending order.

ANG Water Disposal #1
SE SW Sec. 24, T.145 N., R.88 W.
Mercer County, North Dakota

Depth	Description
5826	Siltstone: quartz (97%), opaques (3%); fine-grained, well-sorted; finely laminated; quartz cement.
5830	Quartzarenite: quartz (84%), anhydrite (10%), porosity (5%), opaques (1%), chert (tr); fine to medium-grained, moderately well-sorted; vuggy porosity; subangular smaller grains, larger grains subrounded; anhydrite cement.
5830.5	Dolomudstone: dolomite (95%), opaques (3%), porosity (3%); fine-grained, rhombic dolomite; vuggy porosity.
5833	Dolomudstone: dolomite (85%), porosity (10%), anhydrite (3%), quartz (1%), opaques (1%); fine-grained; blocky anhydrite infilling vugs and replacing some dolomite; interspersed quartz grains; bryozoan fenestrae, crinoid columnals; intercrystalline and vuggy porosity.
5834	Quartzarenite: quartz (60%), dolomite (25%), porosity (10%), anhydrite (5%); fine-grained, well-sorted; subangular quartz grains; massive; some anhydrite infilling; some fusulinids; dolomite cement; intercrystalline and vuggy porosity.
5838	Dolomudstone: dolomite (75%), quartz (10%), porosity (10%), anhydrite (5%), opaques (tr); fine-grained; blocky anhydrite infilling fractures; interspersed subangular quartz grains; massive; intercrystalline and microvugular porosity.
5841	Quartzarenite: quartz (70%), dolomite (15%), porosity (15%), opaques (tr); fine-grained, well-

sorted; subangular quartz grains, suture grain contacts; massive; dolomite and quartz cement; intergranular and vuggy porosity.

5844 Quartzarenite: quartz (75%), porosity (20%), dolomite (5%); fine-grained, well-sorted; some fine-grained dolomite rhombs; some anhydrite infilling; massive; some fusulinids; dolomite cement; intercrystalline and vuggy porosity.

5847 Quartzarenite: quartz (75%), porosity (20%), dolomite (5%), opaques (tr); fine-grained, moderately well-sorted; faint laminations; dolomitized fusulinids; quartz cement; intergranular porosity.

5853 Quartzarenite: quartz (75%), porosity (15%), dolomite (10%), opaques (tr); fine-grained, moderately well-sorted; subangular quartz grains, suture grain contacts; laminated; dolomite follows bedding planes; dolomite and quartz cement; intergranular porosity.

5856 Quartzarenite: quartz (75%), porosity (20%), dolomite (5%), opaques (tr); fine-grained, well-sorted; subangular quartz grains, suture grain contacts; faint laminations; quartz cement; intergranular porosity.

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Depth	Description
7676	Siltstone: quartz (92%), opaques (5%), anhydrite (3%); fine-grained, angular quartz grains; some clusters of anhydrite replacing quartz; quartz cement; very little porosity.
7682	Quartzarenite: quartz (82%), porosity (15%), anhydrite (3%); Fine-grained, well-sorted; quartz overgrowths on grains; some anhydrite replacement of quartz; quartz cement; substantial porosity.
7685	Quartzarenite: quartz (80%), porosity (14%), anhydrite (5%), opaques (1%); Fine-grained, moderately well-sorted; quartz overgrowths on grains; quartz cement; substantial porosity.
7692	Quartzarenite: quartz (82%), porosity (15%), anhydrite (3%), opaques (tr); Fine-grained, moderately well-sorted; quartz overgrowths on grains; some bedding planes have anhydrite occluding porosity; quartz cement; substantial porosity.
7696	Quartzarenite: quartz (83%), porosity (15%), anhydrite (1%), opaques (1%); Fine-grained, well-sorted; quartz overgrowths on grains; some sutured grain contacts; some pods (2-3mm) of anhydrite occluding porosity; quartz cement; substantial porosity.
7698	Quartzarenite: quartz (90%), anhydrite (8%), porosity (2%); Fine to medium-grained, moderately well-sorted; no quartz overgrowths on grains; anhydrite cement; little porosity.
7705	Quartzarenite: quartz (85%), porosity (10%), anhydrite (5%), chert (tr); Medium to coarse-grained, moderately sorted; low angle bedding; alternating layers of coarse-grained sandstone with anhydrite cement and medium-grained sandstone with quartz cement; some large quartz grains suspended in anhydrite; good porosity in medium-grained layers.
7706	Quartzarenite: quartz (90%), porosity (5%), anhydrite (5%), chert (tr); Medium-grained, poorly sorted, grades into fine-grained, well-sorted

sandstone; fine-grained anhydrite dispersed throughout; quartz cement.

7708 Quartzarenite: quartz (85%), anhydrite (10%), porosity (5%); Fine to medium-grained, well-sorted; substantial anhydrite occluding pores; quartz overgrowths on grains; indistinct level bedding; quartz and anhydrite cement.

7710 Quartzarenite: quartz (85%), porosity (15%), anhydrite (5%), opaques (tr); Fine to medium-grained; poorly sorted medium-grained section, anhydrite filled; fine-grained section, no anhydrite; quartz and anhydrite cement.

7716 Dolostone: dolomite (95%), quartz (3%), opaques (tr); fine-grained; interspersed quartz grains; possible burrows.

7718 Dolostone: dolomite (97%), quartz (3%); fine-grained; grades to dolomite cemented sandstone.

APPENDIX C

Log Derived Stratigraphic Tops

The following list of stratigraphic tops are from wireline logs used in the study. Wells are listed according to Township, Range, and Section location. Each entry begins with the North Dakota Geological Survey well number followed by legal location (Township, Range, section, quarter-quarter), and kelly bushing elevation (KB). Abbreviations for listed tops are: Pm - Minnekahta, Po - Opeche, bsalt - basal Opeche salt, Pbc - Broom Creek, PPa - Amsden, PPt - Tyler, Mbs - Big Snowy. All depths are given in feet measured from kelly bushing elevation. All blank entries denote absence of strata.

Well	Twn	Rge	Sc	QQ	KB	Pm	Po	bsalt	Pbc	PPa	PPt	Mbs
7930	129	84	28	SWSW	2338				3985	4052	4470	4530
6654	129	85	27	SESE	2331	4067	4093			4125	4582	4652
8091	129	94	7	NESW	2648	5538	5575		5705	5823	6208	6303
6050	129	98	30	SWSW	2695	5845	5888		6030	6185	6467	6566
8847	129	99	27	SWSW	2658	5897	5934		6092	6212	6529	6629
9017	129	100	18	NESE	2792	6099	6143		6263	6378	6722	6776
10307	129	100	21	SENE	2782	6046	6084		6265	6412	6725	6780
11454	129	100	34	NESW	2788	5991	6032		6157	6280	6615	6667
5619	129	101	6	SWNW	2925	6154	6197		6275	6471	6789	6843
8627	129	101	16	SWNW	2800	6047	6088		6195	6343	6665	6724
7922	129	101	21	SWSE	2836	6035	6077		6155	6340	6659	6705
11218	129	102	7	NWSW	2989	6196	6240		6339	6478	6774	6810
5733	129	102	11	SESW	2832	6090	6129		6245	6375	6695	6755
5758	129	102	21	SWSE	2849	5993	6030		6104	6306	6620	6670
5287	129	102	31	SWSE	2965	6080	6118		6193	6372	6668	6713
6038	129	102	34	SENW	2870	5974	6015		6105	6280	6579	6630
8605	129	103	8	NENW	3006	6268	6309		6394	6537	6850	6906
8062	129	103	10	SESE	2923	6152	6203		6295	6432	6706	6765
11049	129	103	34	SESW	3058	6214	6260		6390	6458	6723	6800
4662	129	104	8	SESE	3252	6385	6429		6485	6637	6887	6974
7839	129	104	16	SWNW	3213	6334	6377		6516	6605	6847	6924
10121	129	104	19	SESW	3203	6192	6238		6257	6512	6751	6825
9201	129	104	26	SWNE	3069	6225	6270		6346	6513	6759	6826
10817	129	104	33	SWNW	3081	6166	6213		6307	6421	6687	6755
8774	129	105	12	NWSW	3132	6194	6236		6300	6472	6700	6772
8658	129	105	15	SESW	3181	6219	6260		6389	6488	6703	6780
10337	129	105	25	NENW	3145	6138	6177		6255	6420	6650	6727
10278	129	105	36	NESE	3201	6160	6202		6259	6430	6682	6755
6277	129	106	5	NWSE	2851	5432	5475		5583	5740	5960	6075
6113	129	106	9	NWSE	2887	5520	5562		5732	5807	6018	6125
6203	129	106	23	NWNE	3061	5787	5829		5950	6071	6295	6397
5567	129	106	36	SWSE	3008	5735	5779		5877	6050	6259	6347
6143	130	81	32	SWSW	2190				3533	3624	3955	4015
4969	130	86	1	SWSW	1995	3846	3855		3950	4102	4460	4530
5118	130	88	23	NWSW	2206	4145	4158		4337	4472	4811	4883
4951	130	88	35	NESE	2136	4031	4049		4190	4343	4672	4752
6322	130	91	7	NESW	2453	5048	5085		5212	5452	5790	5893
7642	130	95	28	NWSE	2804	5767	5818		5976	6137	6465	6554
4922	130	100	5	SESW	2944	6505	6546		6655	6765	7105	7173
4545	130	100	17	NWNE	2867	6330	6374		6462	6590	6988	7072
4952	130	100	32	SWSW	2958	6329	6375		6475	6620	6975	7038
9284	130	101	19	SWNE	2869	6213	6253		6325	6470	6855	6912
8573	130	102	5	SWSW	2952	6393	6438		6563	6650	6995	7067
11176	130	102	21	SESE	2977	6316	6354		6471	6570	6860	6936
7201	130	102	33	NESW	2871	6183	6226		6315	6447	6797	6844
11223	130	102	35	NESW	2975	6264	6310		6390	6545	6883	6945
5951	130	103	3	SWNE	3030	6503	6547		6675	6767	7095	7145
6119	130	103	6	SESE	3109	6489	6534		6580	6715	7080	7154
9439	130	103	17	SESE	3030	6386	6428		6534	6644	6953	7029
5910	130	103	24	NESE	2962	6351	6392		6515	6572	6896	6956
11255	130	103	27	NESW	2992	6383	6426		6537	6564	6895	6963
7809	130	103	32	SWSW	3038	6302	6341		6390	6590	6867	6940
8232	130	104	5	SESE	3167	6618	6667		6722	6875	7170	7250
11797	130	104	14	SESE	3195	6512	6554		6635	6753	7059	7140
5804	130	104	17	NENW	3064	6312	6359		6412	6583	6850	6934
9805	130	104	32	NESW	3122	6309	6353		6427	6570	6830	6890
8397	130	104	36	SENE	2516	6404	6446		6554	6620	6910	6971
9198	130	105	2	SWNE	3022	6275	6322		6435	6525	6810	6886
9345	130	105	30	SENE	2981	5965	6016		6147	6222	6460	6526
11656	130	106	6	SWSE	2936	5728	5773		5910	6027	6260	6328
12155	130	106	30	NWSW	2933	5559	5600		5775	5822	6061	6168
9664	130	107	3	NWSE	2966	5483	5523		5650	5762	5984	6062
11638	130	107	13	NESW	3005	5635	5674		5802	5938	6148	6240

Well	Twn	Rge	Sc	QQ	KB	Pm	Po	bsalt	Pbc	PPa	PPt	Mbs
3150	130	107	27	NESE	3001	5635	5673		5840	5921	6148	6245
4968	131	85	17	NENE	2105		4025		4044	4215	4570	4616
4100	131	85	23	NWNW	2014	3800	3827		3920	4060	4433	4490
4953	131	86	9	NWNW	2009		3987		4030	423[illegible]	4600	4667
4934	131	87	3	SESE	2174	4155	4183		4310	4477	4880	4939
4935	131	87	31	SESE	2451	4425	4445		4560	4770	5068	5125
4960	131	87	35	NENE	2374	4282	4295		4410	4655	4957	5015
5097	131	88	27	NENW	2531	4574	4586		4750	4860	5246	5305
7939	131	98	32	SESW	2805	6168	6217		6350	6512	6818	6929
9656	131	100	6	NWNE	2945	6625	6671		6805	6955	7273	7338
5904	131	103	34	NWNE	3043	6539	6587		6702	6795	7135	7205
8250	131	104	1	NENW	3161	6742	6787		6868	6993	7328	7405
7240	131	104	4	SWNE	3091	6623	6667		6739	6880	7190	7263
7331	131	104	13	NWNW	3207	6720	6765		6821	6993	7315	7373
4669	131	104	21	SWNE	3158	6600	6647		6762	6843	7135	7203
7635	131	104	22	SWNW	3237	6729	6773		6914	6953	7255	7305
8101	131	104	28	SESE	3139	65[illegible]8	6586		6663	6800	7100	7165
5070	131	105	15	NWNW	2960	6272	6316		6408	6518	6825	6888
11515	131	105	19	SENE	2904	6026	6075		6160	6282	6557	6627
11409	131	105	22	NENW	2942	6218	6267		6342	6468	6757	6825
8119	131	105	33	NWNW	3002	6115	6159		6240	6345	6640	6708
8365	131	106	4	NENW	2889	5965	6007		6157	6210	6463	6534
3798	131	106	32	NWSW	3037	5897	5940		6097	6185	6422	6485
10444	131	107	26	SWSW	3082	5760	5800		5958	6065	6300	6363
4966	132	84	7	SESE	2066				3946	4110	4460	4525
4111	132	84	15	SESE	1960				3800	3910	4323	4359
4967	132	85	27	NWNW	2145				4125	4284	4610	4640
6420	132	86	7	SWSW	2285	4325	4356		4455	4640	5050	5100
5572	132	86	27	NENW	2172	4070	4095		4230	4440	4750	4820
8206	132	93	16	NESW	2556	5567	5605		5743	6020	6360	6455
5888	132	104	15	NWSW	3167	6803	6847		6920	7058	7380	7465
5305	133	81	35	SWSW	1849					3410	3720	3784
5007	133	82	7	SWSW	1816				3602	3783	4100	4210
232	133	83	26	SWSW	1997				3793	3867	4176	4242
3636	133	90	1	SWNE	2350	5096	5135		5295	5478	5830	5885
6413	133	92	21	SESE	2508	5570	5612		5740	5940	6345	6412
7075	133	93	26	SWSE	2517	5725	5767		5895	6062	6485	6574
7819	133	97	23	SESE	2694	6262	6300		6390	6655	7030	7124
8010	133	97	25	NWNE	2677	6268	6312		6421	6629	6990	7088
5881	133	98	5	NENW	2776	6614	6658		6755	6915	7325	7400
5210	133	100	3	NENW	2975	6968	7011		7111	7235	7587	7675
7016	133	100	23	SESW	2879	6804	6845		6947	7057	7388	7465
4749	133	101	33	SWNW	2976	6835	6875		6940	7100	7510	7610
5933	133	102	9	SESW	2897	6833	6879		6985	7068	7403	7488
7826	133	102	17	NENE	2927	6863	6906		7008	7066	7405	7510
7383	133	103	28	NWSE	3005	6785	6829		6925	7055	7355	7465
7548	133	106	22	SENE	2828	6172	6209		6313	6413	6673	6755
5285	134	81	22	NESE	1721					3425	3685	3790
8630	134	83	2	SESW	2146				4050	4225	4560	4690
8549	134	87	16	SESE	2293	4605	4678		4745	4993	5387	5440
5496	134	90	5	SENW	2420	5334	5376		5537	5752	6097	6190
6586	134	90	17	NWNE	2456	5343	5385		5515	5753	6075	6140
8143	134	92	3	NENW	2442	5660	5705		5849	6092	6480	6552
7231	134	93	22	SESW	2367	5757	5803		5930	6217	6550	6622
5689	134	95	30	SWNW	2602	6260	6305		6422	6603	6980	7070
5668	134	95	34	SENW	2561	6067	6112		6215	6486	6805	6944
7965	134	96	31	NENE	2829	6570	6610		6734	6880	7263	7367
8928	134	96	33	NESW	2710	6358	6404		6494	6751	7125	7227
8375	134	98	7	NWSW	2828	6805	6851		6943	7148	7510	7605
10847	134	100	1	NENE	2806	6881	6922		7000	7230	7610	7690
9237	134	100	4	SESW	2916	7013	7053		7170	7352	7728	7808
7890	134	100	23	SENW	2955	6968	7009		7090	7310	7656	7736
6355	134	105	21	SWSE	2907	6633	6670		6738	6913	7193	7252

Well	Twn	Rge	Sc	QQ	KB	Pm	Po	bsalt	Pbc	PPa	PPt	Mbs
5221	135	80	5	NESW	2254					3950	4193	4265
464	135	82	11	NWNW	2134				3937	4121	4500	4540
3859	135	83	34	SENE	2124				4082	4252	4670	4725
4984	135	92	12	NWNE	2524	5805	5849		5965	6185	6550	6635
10602	135	94	1	SENW	2559	6103	6152		6260	6530	6955	7035
10484	135	94	14	SWSW	2604	6155	6202		6324	6535	6930	6993
10180	135	96	18	NWNE	2580	6485	6527		6627	6863	7290	7368
8312	135	96	35	NWSW	2544	6298	6342		6453	6684	7060	7128
5049	135	98	2	SESE	2655	6701	6742		6820	7093	7534	7628
11212	135	98	14	NENW	2727	6789	6828		6937	7151	7515	7561
7987	135	98	17	NWSE	2870	6951	6993		7096	7362	7710	7800
10069	135	98	31	SWSE	2870	6890	6930		7018	7245	7620	7700
1464	135	100	16	SWSW	2807	6980	7030		7147	7360	7713	7815
2805	135	101	9	SESE	2791	6981	7022		7082	7320	7715	7773
5929	135	101	10	SWSW	2788	6990	7033		7095	7335	7725	7790
5499	135	101	21	SWSW	2863	7037	7080		7147	7355	7740	7830
4280	135	103	18	NESW	2971	7140	7181		7299	7418	7766	7853
9209	135	106	14	SESW	2894	6616	6648		6770	6894	7200	7269
9883	135	106	26	SWSE	2692	6376	6410		6591	6632	6927	6992
5979	136	81	18	NWNW	1907				3815	3920	4247	4335
26	136	81	29	NENW	2005				3870	3985	4310	4370
5222	136	81	33	SENE	1930				3745	3800	4172	4238
5447	136	92	15	SESW	2429	5730	5765		5885	6210	6540	6676
5463	136	92	36	SENW	2526	5799	5840		5960	6224	6555	6695
5783	136	93	35	NWNE	2548	6011	6070		6184	6478	6818	6965
10522	136	95	31	SESW	2620	6453	6494		6592	6832	7172	7279
7876	136	96	14	NENW	2738	6713	6758		6855	7087	7430	7560
6961	136	96	19	NWSE	2715	6810	6855		6967	7167	7523	7652
6795	136	97	19	SENE	2692	6830	6873		6960	7215	7625	7715
9244	136	98	2	NWSE	2780	7015	7064		7176	7408	7787	7846
8629	136	98	34	SENE	2656	6743	6785		6875	7130	7530	7605
11615	136	99	5	SE/4	2707	7104	7145		7208	7468	7842	7945
7132	136	99	22	SWSE	2686	6940	6981		7074	7318	7674	7769
4907	136	99	30	NENE	2745	7085	7130		7220	7422	7788	7885
5448	136	100	2	SWSE	2791	7204	7250		7308	7512	7905	8002
5160	136	100	12	NWNW	2777	7174	7217		7311	7520	7870	NDE
4124	136	101	4	NWSE	2740	7030	7076		7185	7394	7786	7878
4164	136	101	17	SWNE	2783	7140	7184		7305	7483	7819	7910
6048	136	101	23	SWSW	2810	7097	7140		7200	7447	7838	7920
6412	136	101	34	NWNE	2751	7057	7100		7175	7402	7760	7850
6855	136	102	4	SENW	2659	7051	7096		7156	7387	7753	7830
9814	136	104	4	NWSE	2751	7044	7094		7253	7369	7723	7806
7983	136	105	6	NESE	2908	6938	6975		7183	7280	7620	7690
6319	136	105	22	NENW	2694	6779	6820		7001	7077	7395	7475
7784	136	106	23	NWSE	2937	6864	6900		7105	7160	7460	7547
5018	137	82	17	NESE	1736				3981	4095	4400	4480
3978	137	83	34	SENW	2281				4425	4600	4925	5000
8395	137	87	1	SWSE	2211		5011		5055	5363	5705	5790
7797	137	87	14	SESE	2281	4983	5008		5027	5405	5780	5870
5011	137	87	25	NESE	2190	4850	4878		5002	5260	5630	5730
7020	137	88	5	SENE	2342	5385	5429		5558	5783	6165	6242
8665	137	92	4	NESW	2339	5913	5960		6061	6335	6713	6786
4134	137	92	15	NWSE	2340	5863	5905		6020	6234	6610	6673
10430	137	92	36	NENW	2379	5838	5883		5987	6225	6567	6653
8837	137	95	17	SWSE	2685	6719	6760		6861	7152	7555	7660
5255	137	95	22	NESW	2717	6735	6795		6900	7163	7600	7700
5143	137	97	9	NENW	2688	7040	7083		7160	7462	7824	7905
5482	137	98	2	NWSW	2749	7187	7238		7340	7570	7955	8043
5717	137	99	9	SWSE	2703	7220	7263		7339	7623	7960	8074
6438	137	99	14	NESW	2749	7277	7315		7420	7605	7965	8070
4830	137	99	31	SWNW	2807	7215	7265		7427	7637	7974	8103
10827	137	100	1	NESW	2770	7249	7287		7461	7630	8015	NDE
8483	137	100	14	SESW	2839	7258	7310		7390	7637	8007	8150

Well	Twn	Rge	Sc	QQ	KB	Pm	Po	bsalt	Pbc	PPa	PPt	Mbs
2923	137	100	15	NWNW	2910	7380	7429		7530	7742	8088	8232
4802	137	100	25	SWSE	2835	7210	7262		7437	7635	8007	NDE
9905	137	100	27	NENE	2908	7332	7384		7543	7712	8100	NDE
11956	137	101	12	SESE	2931	7397	7449		7555	7752	8135	NDE
2357	137	102	20	NENW	2719	7250	7304		7415	7637	7955	8072
7842	137	103	28	SWSW	2728	7079	7128		7287	7450	7752	7872
6993	137	104	1	NWNW	2735	7135	7179		7352	7452	7740	7862
6361	137	104	9	NENE	2696	7059	7098		7233	7376	7665	7796
12227	137	106	22	SWNE	3067	6900	6936		7250	7297	7603	7705
8158	138	82	6	SWSE	1792				3942	4180	4465	4535
5019	138	82	21	NWNE	1896				4005	4182	4535	4575
5379	138	83	5	NWNE	1980				4275	4495	4860	4905
7770	138	85	6	NWSW	2076		4800		4832	5115	5385	5450
7691	138	85	19	SENW	2094		4772		4803	5014	5353	5457
7937	138	86	19	NENE	1965		4765		4843	5125	5430	5530
5016	138	86	36	SWSE	1930				4570	4909	5219	5317
9135	138	91	28	SENE	2361	5875	5921		6000	6313	6720	6788
6476	138	92	9	NESW	2507	6064	6108		6205	6512	6910	7003
8169	138	92	21	NENW	2372	5993	6037		6132	6480	6868	6937
6812	138	93	1	NWNW	2479	6387	6435		6566	6840	7270	7320
5203	138	94	23	NWNW	2554	6595	6635		6735	6960	7383	7472
10299	138	95	16	NENE	2392	6785	6815		6939	7210	7610	7700
10570	138	96	1	NWSE	2534	6854	6896		6990	7252	7675	7773
2496	138	97	18	SESE	2726	7239	7278		7379	7595	7987	8072
9684	138	97	34	NENW	2755	7177	7210		7315	7510	7908	7991
850	138	98	15	NWNW	2652	7198	7245		7353	7646	7985	8078
7007	138	98	26	SESE	2756	7338	7375		7443	7589	7985	8103
12078	138	99	7	NWSE	2675	7334	7376		7493	7700	8097	8195
6307	138	99	21	C/SE	2696	7252	7295		7453	7700	8060	8158
1536	138	99	25	SENW	2644	7195	7236		7344	7600	7955	8053
9347	138	100	10	SWNE	2798	7305	7343	7623	7697	7791	8155	8257
4377	138	100	19	SESW	2814	7340	7385		7565	7700	8060	8151
8582	138	100	24	NESE	2712	7307	7346		7470	7682	8065	8165
5120	138	100	31	NESE	2866	7357	7406		7579	7778	8116	8205
849	138	100	34	SESE	2828	7315	7377		7471	7721	8079	8160
11425	138	102	4	SENE	2446	6977	7026		7295	7459	7778	7881
7744	138	102	15	SWSE	2641	7200	7250		7374	7572	7940	8045
7972	138	103	5	SWSE	2542	6955	7002	7270	7306	7380	7690	7825
3695	138	103	11	SESW	2616	7109	7158		7343	7513	7830	7932
4490	138	103	29	SESW	2765	7095	7143		7325	7503	7805	7925
9097	138	104	16	SWNW	2777	7057	7095		7350	7480	7770	7905
5832	138	104	27	NWSE	2737	7115	7153		7363	7422	7739	7853
4130	138	105	9	SWNW	2867	7098	7137		7366	7460	7760	7907
2185	139	82	11	SWNE	1861				4045	4193	4513	4613
133	139	86	30	SWSW	2204		5075		5155	5460	5790	5900
10386	139	90	20	NENE	2483	5997	6043		6202	6401	6775	6853
1620	139	90	27	NESW	2426	5895	5945		6059	6272	6655	6730
6797	139	92	16	SESW	2494	6273	6316		6408	6716	7120	7215
9407	139	92	32	NESW	2391	6132	6167		6303	6587	6987	7073
9341	139	93	10	NESW	2535	6446	6492		6590	6950	7294	7373
9056	139	93	24	SENW	2436	6280	6323		6437	6666	7080	7183
5754	139	94	3	SESW	2450	6656	6699		6839	7080	7475	7552
10530	139	95	2	SENE	2429	6843	6878		7010	7210	7587	7705
7076	139	95	21	SENE	2453	6773	6813		6920	7181	7585	NDE
10417	139	96	6	NWNW	2486	7058	7095		7219	7421	7808	NDE
11385	139	96	23	SWNW	2460	6932	6973		7100	7286	7690	7840
7127	139	96	30	NWNE	2521	6970	7015		7170	7390	7785	7892
9611	139	96	33	NWNW	2576	7045	7055		7185	7385	7795	7910
6447	139	97	8	SWNW	2496	6965	7010		7173	7440	7843	8005
4311	139	97	20	NESW	2560	7055	7100	7310	7333	7498	7906	8025
5169	139	97	26	NWNE	2504	6987	7030		7129	7370	7772	7880
5405	139	98	2	SENE	2517	7110	7153		7343	7590	7988	NDE
4583	139	98	7	SENW	2573	7224	7275		7425	7710	8096	8220

Well	Twn	Rge	Sc	QQ	KB	Pm	Po	bsalt	Pbc	PPa	PPt	Mbs
12260	139	98	9	NWNW	2533	7175	7223		7400	7633	8040	NDE
6369	139	98	15	SESW	2544	7188	7230		7416	7595	7999	NDE
9315	139	99	1	NWNW	2540	7174	7220		7478	7723	8102	NDE
5489	139	99	3	SENE	2579	7310	7352		7510	7750	8149	NDE
10555	139	99	4	NENW	2660	7408	7453		7611	7830	8220	NDE
11753	139	99	7	NWSE	2669	7377	7415		7604	7831	8213	8303
5646	139	99	14	NWSE	2581	7228	7277		7548	7732	8097	NDE
11911	139	99	28	NENW	2675	7398	7443		7579	7782	8170	8270
3918	139	100	5	SENW	2863	7482	7529		7776	7997	8337	NDE
10857	139	100	11	SESE	2711	7424	7473		7711	7853	8257	8352
4020	139	100	17	NESE	2803	7431	7473		7683	7921	8259	8360
12001	139	100	19	SWNE	2792	7397	7438	7710	7730	7890	8244	8324
5819	139	100	27	SWSW	2715	7304	7344		7544	7750	8108	8198
5437	139	101	10	NESE	2627	7215	7254		7450	7604	7938	8044
4121	139	101	17	NESW	2550	7091	7132		7373	7568	7904	7999
10441	139	101	28	NENE	2599	7185	7230	7504	7533	7698	7998	8092
4076	139	101	31	SWNW	2671	7258	7303		7562	7735	8067	8169
3928	139	102	3	SESE	2418	6891	6936	7225	7265	7412	7727	7844
4268	139	102	8	NWNW	2496	6983	7026	7326	7368	7497	7798	7878
4024	139	102	13	SWSE	2378	6942	6987		7163	7369	7712	7833
10815	139	102	16	SESW	2545	7063	7111	7387	7432	7524	7865	7970
8304	139	102	26	NWSE	2554	7123	7173		7444	7560	7910	8003
9437	139	102	29	NENE	2315	6824	6870	7149	7167	7343	7647	NDE
7135	139	102	32	SENW	2398	6981	7031		7270	7417	7726	NDE
7461	139	103	9	SENE	2758	7168	7213	7498	7503	7645	7950	8082
4498	139	103	14	SESE	2718	7218	7266		7498	7643	7970	8092
10700	139	103	20	NWNE	2749	7185	7230		7499	7628	7913	8045
1907	139	103	35	NENE	2503	7045	7095		7309	7428	7754	7875
8356	139	104	2	NESW	2872	7325	7368	7670	7701	7805	8095	8270
4308	139	104	23	SENW	2766	7172	7215	7512	7534	7618	7945	8062
6774	139	104	31	SWSW	2746	7076	7112		7311	7422	7693	7877
6563	139	105	4	NWNE	2744	7204	7243		7520	7656	7935	8080
9148	139	105	16	NENE	2836	7260	7302		7550	7625	7900	8063
10518	139	106	35	SWNE	2890	7040	7077	7393	7412	7517	7772	7918
4685	140	80	19	SWSW	1865				4000	4055	4320	4413
8553	140	82	17	SENW	1994				4370	4555	4855	4950
5017	140	86	36	NWSW	2204		5020		5100	5376	5668	5798
7340	140	88	26	NWSE	2230	5380	5405		5530	5855	6215	6280
7818	140	89	5	NESE	2284	5813	5837		5978	6282	6635	6735
3515	140	93	9	NWNW	2292	6325	6368		6493	6790	7165	7280
5415	140	93	11	NWNW	2293	6350	6397		6545	6840	7187	7278
9475	140	94	24	NWNE	2320	6523	6565		6692	7015	7372	7462
6691	140	94	27	NESE	2395	6715	6763		6870	7110	7478	7575
1935	140	94	29	SENE	2417	6732	6775		6880	7130	7522	7620
7247	140	95	5	NESW	2455	6952	6995		7105	7427	7795	7910
12330	140	95	9	SENW	2423	6870	6909		7030	7353	7718	NDE
5361	140	95	13	SWNE	2486	6865	6908		7055	7290	7660	7785
6177	140	95	27	NWSE	2448	6875	6919		7068	7238	7630	NDE
8342	140	95	36	NWNW	2418	6745	6787		6900	7173	7613	7705
5820	140	96	1	SWSW	2426	6897	6940	7175	7210	7390	7810	NDE
11320	140	96	6	SESE	2483	6975	7022	7323	7360	7508	7908	NDE
7995	140	96	13	SWSW	2496	7057	7098		7240	7413	7820	NDE
10651	140	96	19	SWNE	2565	7062	7116		7394	7563	7950	NDE
7077	140	96	22	NWNW	2546	7112	7158		7310	7550	7907	NDE
11154	140	96	36	SENW	2510	6964	7010		7168	7403	7815	7925
5440	140	97	9	NWNE	2590	7100	7138	7483	7542	7745	8068	8245
11754	140	97	13	NWNW	2574	7210	7260		7412	7615	8000	NDE
12370	140	97	20	NWSW	2569	7140	7178	7432	7444	7640	8002	NDE
9759	140	97	27	SESW	2575	7070	7114		7330	7540	7945	NDE
7230	140	97	29	SWSE	2608	7055	7095	7375	7401	7584	7980	NDE
12037	140	97	36	SENW	2583	6983	7024	7288	7345	7515	7915	NDE
9670	140	98	4	SWSE	2663	7349	7391		7606	7838	8210	8363
10688	140	98	7	SESE	2622	7292	7341	7645	7670	7850	8190	8336

Well	Twn	Rge	Sc	QQ	KB	Pm	Po	bsalt	Pbc	PPa	PPt	Mbs
9422	140	98	9	SENE	2647	7264	7304		7568	7822	8180	8345
10664	140	98	12	NWSE	2656	7376	7414		7503	7754	8133	8293
10891	140	98	18	SWNE	2623	7289	7336	7617	7671	7797	8175	NDE
12328	140	98	22	NESE	2578	7220	7263		7482	7731	8070	8197
5416	140	98	25	NENE	2647	7119	7157	7468	7478	7690	8065	NDE
9418	140	98	29	SWSW	2543	7233	7283		7508	7707	8105	NDE
9786	140	99	3	SWNW	2724	7431	7477		7794	7962	8345	8468
11088	140	99	16	SESE	2631	7332	7378	7670	7704	7877	8238	NDE
10844	140	99	26	SESE	2612	7387	7431	7576	7593	7818	8178	NDE
10340	140	99	30	SWSE	2639	7325	7372		7652	7824	8203	8318
10356	140	99	33	SWNE	2606	7371	7412		7551	7770	8155	NDE
7508	140	100	2	NWNW	2767	7484	7532	7838	7872	8058	8415	8545
10267	140	100	7	NWNW	2509	7097	7142	7444	7466	7685	7975	8073
11778	140	100	16	SWNW	2749	7424	7470	7763	7823	7935	8295	8430
10949	140	100	25	SENW	2681	7355	7400		7660	7879	8265	8370
6000	140	100	28	NWNW	2799	7538	7580		7830	7970	8336	NDE
11938	140	100	35	NESW	2727	7424	7469	7747	7797	7930	8325	NDE
11501	140	101	30	NWSW	2636	7230	7273	7550	7573	7702	8038	8134
11570	140	101	33	SWSE	2536	7130	7174		7464	7635	7920	8027
5446	140	101	36	SWSW	2748	7391	7429		7685	7824	8165	NDE
11191	140	102	5	SWNW	2450	6960	7009	7319	7358	7445	7770	7899
11816	140	102	18	NWNW	2492	7009	7055	7340	7353	7459	7820	7968
4642	140	102	30	SWNW	2585	7094	7140		7411	7556	7895	8012
11464	140	102	36	SENE	2410	6973	7018		7343	7493	7808	7904
11688	140	103	1	SESW	2562	7082	7129		7414	7570	7878	8003
6331	140	103	10	SWSW	2662	7140	7186	7472	7494	7604	7920	8055
8657	140	103	13	SESW	2505	7037	7084		7355	7469	7825	8005
4339	140	103	20	SWSW	2652	7129	7174		7456	7612	7928	8057
5167	140	103	26	NWNE	2443	6983	7032		7248	7405	7755	7898
4760	140	103	33	NESE	2610	7102	7151		7410	7549	7900	8020
6325	140	103	36	NENE	2519	7067	7108		7287	7459	7805	7924
8713	140	104	6	SWNE	2919	7477	7516		7807	7930	8232	8390
7533	140	104	15	NENE	2760	7310	7350		7625	7762	8062	8193
9540	140	104	32	NESE	2820	7315	7356		7632	7763	8068	8242
9011	140	105	6	NENE	2739	7203	7240		7538	7642	7907	8059
470	140	105	15	NESE	2867	7343	7382		7681	7800	8093	8245
4467	140	105	21	SWNW	2765	7098	7238		7537	7652	7932	8070
11293	140	105	32	NWNW	2810	7178	7216		7493	7606	7892	8038
4389	141	80	33	SWNE	2126				4283	4347	4620	4727
95	141	81	3	SESW	1924				4305	4360	4685	4795
15	141	81	18	SESE	2037				4447	4517	4830	4937
2183	141	85	34	NWNW	2173				5143	5315	5665	5785
9074	141	91	28	NWNE	2034	5973	6019		6155	6420	6835	6952
10627	141	93	21	NESW	2263	6505	6522		6683	6917	7325	7430
505	141	94	6	SENE	2296	6685	6735	7040	7075	7278	7685	7788
5374	141	94	10	SENW	2172	6626	6666		6825	7030	7475	7570
5274	141	94	24	NESW	2255	6644	6680		6800	7145	7505	7635
5417	141	94	33	SENW	2256	6695	6735		6850	7120	7495	7615
9765	141	95	14	SWSW	2415	6782	6825	7155	7203	7380	7830	7925
6530	141	95	18	SENE	2595	7016	7060	7390	7445	7645	8045	8160
3970	141	95	21	SWNE	2606	7090	7132		7382	7585	8022	8140
6148	141	96	2	SWSW	2615	7222	7265		7477	7665	8140	8240
12011	141	96	4	NENW	2594	7185	7229		7585	7718	8155	8332
6997	141	96	15	SENE	2571	7094	7137	7470	7511	7736	8157	8295
5399	141	96	30	NENE	2605	7076	7120	7422	7438	7700	8040	8210
6396	141	97	7	NESW	2598	7263	7305	7636	7697	7848	8250	8400
8396	141	97	15	SENE	2546	7195	7243	7570	7598	7788	8176	8348
11612	141	97	30	NENE	2575	7234	7280	7570	7600	7800	8165	8343
11801	141	98	1	CSE4	2631	7427	7475		7723	7882	8275	8412
8990	141	98	6	NENE	2587	7399	7442	7678	7685	7905	8245	8380
8205	141	98	16	NWNE	2568	7263	7310	7618	7651	7850	8195	8342
11780	141	98	22	NWNW	2591	7351	7398		7635	7843	8200	8321
7996	141	98	33	NESE	2618	7257	7301	7622	7662	7870	8195	8332

Well	Twn	Rge	Sc	QQ	KB	Pm	Po	bsalt	Pbc	PPa	PPt	Mbs
3679	141	99	6	SWNW	2734	7513	7562	7871	7928	8098	8435	8535
10597	141	99	13	SENW	2615	7350	7394	7713	7740	7922	8275	8393
6788	141	99	16	SENW	2628	7362	7409	7722	7768	7925	8284	8400
9087	141	99	28	NESW	2720	7458	7500	7790	7835	7973	8335	8458
9070	141	99	31	NESW	2734	7446	7490	7802	7855	7980	8326	8440
9175	141	100	2	SWNW	2741	7350	7400	7716	7749	7900	8268	8395
7363	141	100	6	SWSE	2426	7160	7208		7460	7600	7920	8040
7120	141	100	16	NESE	2494	7134	7181		7503	7642	7999	8157
8741	141	100	26	NWNW	2557	7232	7280		7600	7750	8085	8209
7012	141	100	30	NENW	2470	7113	7158	7455	7487	7629	7930	8090
7562	141	100	33	NENW	2523	7107	7153	7460	7509	7662	7980	8117
7278	141	101	12	NESW	2547	7169	7217	7518	7557	7670	8000	8105
9514	141	101	16	SWSE	2484	7148	7195	7486	7518	7654	7965	8080
8385	141	101	26	SENE	2389	7019	7067	7364	7398	7570	7870	7977
9218	141	102	1	NESW	2493	7200	7248		7529	7663	7973	8150
7527	141	102	9	NESW	2467	7080	7128	7406	7412	7545	7876	8003
9120	141	102	20	NWSW	2555	7145	7190	7491	7500	7590	7920	8037
7061	141	102	29	NWSW	2607	7145	7190	7490	7518	7618	7948	8052
10398	141	102	34	NWSW	2554	7060	7110		7428	7557	7858	8018
8460	141	103	31	NWNE	2726	7297	7338		7631	7748	7998	8173
8127	141	104	8	SESW	2786	7334	7375		7648	7770	8045	8178
8746	141	104	23	NWSE	2850	7434	7478		7757	7896	8186	8328
6513	141	104	31	NENE	2841	7370	7409		7680	7811	8088	8232
8987	141	105	11	NWSE	2802	7326	7365	7675	7708	7773	8053	8195
9350	141	105	24	SENE	2838	7378	7417		7697	7817	8073	8226
5438	141	105	27	NENW	2710	7173	7211	7512	7555	7620	7878	8038
4941	142	84	7	NESW	2138				5110	5360	5676	5795
4937	142	84	34	SENW	2093				4947	5190	5475	5590
3277	142	85	14	NESE	2193				5164	5410	5787	5885
4940	142	85	24	SESW	2252				5213	5480	5761	5875
21	142	89	28	NWNE	2287	6040	6070		6230	6475	6760	6850
8675	142	90	6	NENW	2085	6108	6114		6240	6535	6920	6983
8115	142	92	24	NESW	2277	6337	6381		6479	6820	7261	7360
8243	142	92	36	SESE	2147	6230	6273		6432	6660	7087	7210
9096	142	93	1	SWNW	2061	6444	6463		6660	6880	7270	7411
10606	142	93	15	NWNW	2146	6562	6594		6745	6963	7420	7535
11183	142	93	29	NWNW	2142	6470	6507		6692	6914	7377	7500
6477	142	95	2	SESW	2287	6773	6823	7179	7234	7453	7880	7978
11857	142	95	14	NESE	2247	6670	6721	7071	7135	7352	7775	7912
7161	142	95	20	NWSE	2460	7035	7083	7377	7389	7618	8030	8173
5144	142	95	25	SWSW	2368	6765	6817	7165	7195	7425	7940	NDE
6829	142	95	28	SESE	2414	6883	6934	7258	7280	7510	7954	8060
10374	142	96	14	SENW	2421	7064	7113	7432	7465	7660	8072	8213
8896	142	96	17	SWSE	2460	7193	7240		7535	7740	8140	8270
8491	142	96	30	NESW	2635	7268	7305	7622	7652	7881	8251	8406
9126	142	96	33	SENW	2610	7236	7277		7607	7810	8213	8353
10115	142	97	5	NWNW	2500	7236	7282	7626	7679	7845	8189	8345
5621	142	97	23	NENW	2583	7332	7388		7645	7820	8212	8372
9568	142	97	29	NWSE	2626	7314	7357	7714	7752	7961	8348	8475
11782	142	98	3	NENW	2708	7552	7598		7913	8083	8440	8549
6470	142	98	15	SWSW	2708	7436	7483	7822	7873	8057	8407	8534
11432	142	98	18	NESW	2665	7447	7496	7816	7862	8050	8404	8510
10095	142	98	23	SESW	2646	7344	7390	7722	7754	7958	8304	8422
12253	142	98	30	SENE	2611	7432	7477	7788	7816	7998	8322	8452
9599	142	98	35	NENE	2599	7366	7407	7686	7738	7933	8308	8445
7618	142	99	3	NWNE	2728	7583	7627	7932	7993	8125	8436	8557
8947	142	99	7	SESE	2708	7550	7598	7908	7948	8057	8448	8570
10181	142	99	13	NESW	2743	7554	7600	7911	7931	8140	8495	8603
6744	142	99	22	NENW	2712	7545	7591	7881	7910	8083	8425	8545
9368	142	99	32	SENE	2644	7431	7478	7786	7842	8000	8333	8446
7951	142	100	2	SWNW	2761	7476	7525		7824	8003	8345	8480
7148	142	100	7	SWNE	2651	7474	7528		7813	7980	8360	8515
7354	142	100	14	SWSW	2752	7408	7456		7786	7975	8310	8450

Well	Twn	Rge	Sc	QQ	KB	Pm	Po	bsalt	Pbc	PPa	PPt	Mbs
6969	142	100	17	SWSW	2523	7194	7240	7540	7566	7683	8028	8124
7499	142	100	26	SWNW	2756	7440	7486		7803	7970	8298	8392
7361	142	100	29	SWNE	2757	7416	7465	7755	7792	7915	8252	8355
7514	142	100	33	NENE	2513	7180	7230		7534	7700	8024	8130
8075	142	101	8	NESE	2430	7136	7183	7473	7492	7618	7936	8042
8197	142	101	13	SENW	2412	7095	7142		7460	7610	7922	8005
8416	142	101	16	NENW	2392	7117	7165		7418	7608	7903	8014
7273	142	101	25	SWNE	2580	7208	7257	7573	7595	7695	8025	8150
8025	142	101	29	SESW	2432	7155	7203	7495	7516	7626	7943	8100
7840	142	101	34	SESW	2362	7037	7084	7395	7410	7520	7840	7965
9033	142	102	4	NESW	2470	7165	7210	7498	7509	7624	7945	8045
5842	142	102	7	SWNE	2414	7113	7156	7442	7462	7574	7885	8016
7419	142	102	17	NESW	2606	7287	7330	7615	7620	7747	8056	8227
7099	142	102	26	SESW	2263	6964	7014		7272	7460	7753	7872
8306	142	102	32	NWNE	2534	7208	7256		7506	7665	7915	8015
7255	142	103	3	SWSE	2595	7360	7403		7653	7757	8056	8230
2894	142	103	24	NENE	2688	7408	7449		7725	7840	8147	8285
8324	142	104	18	NWNE	2768	7421	7467		7747	7826	8095	8190
4466	142	104	22	SESE	2595	7261	7304		7555	7680	7974	8106
9211	142	104	35	SENW	2604	7222	7266		7548	7630	7931	8042
9115	142	105	5	NESE	2538	7169	7203	7474	7476	7530	7818	7942
8943	142	105	32	SENW	2660	7141	7177		7454	7533	7816	7962
4938	143	83	10	SWNW	1951				4547	4710	5130	5265
4939	143	84	33	NENE	2139				5025	5270	5650	5721
4942	143	86	34	SENE	2217	5448	5460		5575	5790	5965	6060
2826	143	90	1	SESW	2201		6234		6292	6593	6948	7045
6683	143	90	13	NWSW	2097	6075	6085		6205	6511	6859	7000
8863	143	91	13	SESE	2227	6350	6358		6505	6787	7150	7270
9106	143	92	16	NENW	2221	6547	6587		6732	7000	7380	7505
3044	143	92	27	NENE	2200	6410	6455		6558	6815	7290	7380
1787	143	93	23	NWNE	2248	6522	6566		6986	7163	7573	7690
9851	143	94	2	SENE	2232	6663	6706		7124	7318	7695	7830
8652	143	94	12	SENW	2205	6637	6680	7020	7047	7302	7676	7803
5155	143	94	13	SWSW	2133	6640	6685		6990	7235	7600	7735
6591	143	94	35	NWNW	2130	6481	6527		6878	7147	7547	7683
7994	143	95	8	NENE	2178	6797	6843	7203	7227	7497	7908	8020
8275	143	95	31	SENW	2214	6861	6908	7230	7287	7445	7853	8000
11915	143	96	27	NENE	2362	7107	7156		7500	7685	8098	8227
10368	143	97	3	NENW	2499	7318	7366		7705	7930	8300	8495
9505	143	97	13	NWNW	2543	7357	7402	7727	7762	7964	8365	8508
8857	143	97	17	SENW	2570	7366	7416	7727	7743	7952	8301	8450
9258	143	98	9	NESW	2695	7447	7492		7821	8018	8375	8490
10669	143	98	13	NESW	2611	7391	7436	7755	7780	7957	8355	8505
11427	143	98	20	SWSW	2674	7458	7503	7846	7893	8055	8429	8556
10355	143	98	24	NENW	2711	7486	7531		7870	8053	8438	8555
9529	143	98	34	SWNW	2713	7496	7539	7867	7915	8081	8450	8535
6667	143	98	36	NENW	2690	7444	7494	7835	7855	8063	8417	8540
7348	143	99	2	SWSW	2722	7627	7673	7978	8010	8115	8520	8625
6913	143	99	9	SENW	2747	7646	7692	7984	8010	8145	8542	8630
7520	143	99	21	NENE	2730	7611	7658	7970	8010	8158	8519	8617
8079	143	99	34	SESW	2747	7609	7654	7955	7975	8144	8504	8608
10134	143	100	1	SENW	2709	7500	7550	7865	7895	8055	8368	8470
6474	143	100	5	SENW	2418	7228	7276		7575	7643	8023	8130
9321	143	100	8	SESE	2714	7494	7543	7832	7845	7969	8325	8423
7526	143	100	18	NWNW	2759	7534	7578	7857	7865	7995	8342	8437
8242	143	100	23	NWNW	2590	7456	7505		7753	7915	8245	8345
6303	143	100	29	NESW	2642	7365	7415	7695	7715	7805	8173	8270
8951	143	100	34	NWNE	2746	7488	7537		7840	7983	8335	8441
7113	143	101	2	SWSW	2392	7211	7257		7564	7685	8027	8128
6013	143	101	5	NESW	2477	7095	7143	7445	7467	7567	7887	7994
6938	143	101	16	NESW	2502	7258	7306	7601	7630	7716	8065	8162
7690	143	101	19	SWSW	2373	7120	7162	7449	7462	7555	7910	8015
8465	143	101	27	SWNE	2741	7521	7566	7865	7885	7985	8324	8440

Well	Twn	Rge	Sc	QQ	KB	Pm	Po	bsalt	Pbc	PPa	PPt	Mbs
9329	143	101	30	NENE	2396	7143	7185	7466	7492	7587	7947	8053
10074	143	101	36	NWNW	2684	7417	7462	7760	7782	7887	8267	8375
7399	143	102	1	SWNW	2283	7117	7167		7419	7531	7846	7952
6957	143	102	5	NESE	2155	6994	7041		7297	7411	7735	7848
8487	143	102	13	SESE	2344	7120	7169		7407	7563	7893	7987
9340	143	102	15	NESE	2283	7090	7138		7396	7500	7833	7937
11109	143	102	18	NESE	2359	7165	7214		7463	7573	7910	7995
7984	143	102	25	SWNE	2342	7098	7141	7432	7438	7543	7900	7995
7451	143	102	31	SENW	2574	7299	7340		7608	7725	8037	8150
10475	143	102	34	NWNE	2181	6923	6969	7251	7266	7347	7668	7764
586	143	103	3	NWNE	2365	7178	7230		7476	7560	7870	8000
11165	143	103	16	NENE	2319	7135	7185		7425	7520	7845	7970
7768	143	103	23	SESW	2591	7355	7405		7646	7758	8100	8230
6986	143	103	25	SENW	2482	7240	7288		7535	7645	7953	8057
8653	143	104	6	NENE	2529	7305	7347		7616	7665	7967	8082
8959	143	104	34	SESW	2616	7360	7405		7636	7750	8075	8222
377	144	88	10	SWSW	2059	5725	5735		5875	6147	6465	6571
7616	144	90	29	SWNW	2080	6162	6197		6360	6612	6943	7050
5233	144	91	16	NESE	2121	6258	6300		6467	6745	7081	7203
7346	144	92	7	SENE	2261	6380	6430	6838	6895	7120	7515	7627
6244	144	92	13	NENW	2194	6383	6422		6643	6952	7310	7420
9080	144	92	16	SENW	2224	6480	6524		6840	7056	7420	7562
9027	144	92	31	SESW	2204	6355	6387	6779	6842	7070	7428	7592
8235	144	92	36	SESE	2258	6459	6500		6664	6928	7291	7408
8745	144	93	5	NENE	2257	6672	6713	7050	7098	7284	7683	7830
8536	144	93	7	SWSE	2251	6606	6647	7020	7064	7248	7645	7770
8613	144	93	20	SWSW	2412	6732	6776	7145	7184	7425	7782	7930
9226	144	94	14	NWSE	2279	6785	6829		7100	7277	7783	7912
892	144	94	19	NENW	2411	7020	7061	7440	7480	7693	8085	8235
8153	144	95	30	NESE	2343	7133	7173		7457	7685	8085	8235
8374	144	96	4	NENE	2435	7265	7313	7648	7682	7863	8312	8447
9502	144	96	13	NESE	2456	7232	7273		7634	7856	8250	8400
10437	144	96	16	NENW	2556	7352	7401	7747	7786	7963	8425	8552
10712	144	97	2	NENE	2543	7407	7456	7793	7836	8037	8442	8556
9272	144	97	5	NWSE	2490	7373	7415	7742	7769	7956	8314	8457
10976	144	97	25	SWSW	2309	7119	7170	7513	7545	7740	8135	8257
10450	144	97	29	SENW	2387	7216	7256	7542	7611	7791	8202	8333
10188	144	97	31	NENE	2407	7233	7276	7613	7645	7803	8212	8342
7297	144	98	1	NWSE	2488	7361	7404	7730	7761	7895	8318	8443
6228	144	98	3	NWSW	2532	7347	7396	7720	7749	7920	8285	8428
11023	144	98	5	NWSE	2572	7452	7499	7819	7850	8000	8377	8523
6095	144	98	10	NWSE	2583	7418	7463		7797	7982	8350	8488
8168	144	98	13	NENE	2513	7393	7435	7765	7816	7925	8348	8466
6472	144	98	16	NESW	2536	7395	7440	7765	7786	7933	8325	8455
10999	144	98	19	SESE	2555	7451	7495	7800	7823	7981	8363	8488
6209	144	98	26	NWNW	2494	7314	7356	7673	7695	7876	8260	8378
10168	144	98	35	SENE	2425	7257	7301	7637	7659	7818	8215	8325
9787	144	98	36	NWNW	2423	7255	7298		7636	7828	8205	8336
11288	144	99	3	NESW	2636	7553	7596	7920	7940	8084	8465	8601
8656	144	99	7	SWSE	2615	7586	7634		7910	8062	8428	8552
6090	144	99	16	SWSE	2717	7625	7673		7965	8128	8512	8638
11142	144	99	26	NESE	2633	7555	7600	7891	7920	8078	8439	8548
8558	144	99	29	NWSE	2675	7602	7648	7938	7942	8100	8478	8600
2788	144	99	33	NENE	2716	7648	7692	7995	8015	8185	8524	8631
9134	144	100	4	SWNE	2591	7575	7620	7892	7912	8013	8342	8455
9461	144	100	13	SESW	2680	7573	7623	7915	7936	8075	8430	8547
9880	144	100	17	SWNE	2600	7505	7553	7830	7873	7980	8303	8415
10593	144	100	27	SENE	2478	7352	7400	7682	7712	7830	8178	8292
7265	144	100	30	SWSW	2615	7438	7488	7781	7820	7910	8246	8355
4035	144	100	36	SESE	2597	7465	7515	7823	7852	8000	8352	8461
8155	144	101	6	NWNW	2211	7093	7140	7408	7443	7508	7838	7958
7600	144	101	11	SENW	2325	7177	7227	7495	7513	7645	7995	8110
10215	144	101	16	SWNW	2361	7176	7224	7494	7511	7620	7980	8095

Well	Twn	Rge	Sc	QQ	KB	Pm	Po	bsalt	Pbc	PPa	PPt	Mbs
9900	144	101	19	SWSE	2272	7070	7117	7400	7428	7501	7842	7952
9079	144	101	22	SWNE	2387	7191	7238	7516	7549	7620	7985	8097
9183	144	101	29	SWSW	2310	7093	7142	7418	7438	7558	7879	7987
9432	144	101	34	NWNW	2318	7130	7178	7471	7508	7582	7940	8047
9007	144	102	1	SENE	2233	7127	7175	7446	7453	7538	7885	7994
8609	144	102	3	SWSW	2234	7144	7186		7432	7505	7859	7975
9426	144	102	12	SWSE	2602	7487	7534	7796	7810	7880	8226	8340
8903	144	102	15	SENW	2200	7175	7225		7485	7568	7915	8030
8070	144	102	19	SESE	2300	7167	7213		7467	7540	7877	7985
8829	144	102	23	NESW	2184	7063	7112		7376	7455	7777	7886
10212	144	102	34	SWSW	2413	7234	7281	7563	7589	7681	7997	8100
10076	144	103	3	NESE	2257	7180	7225	7476	7490	7562	7878	7995
10985	144	103	7	SESW	2490	7358	7403	7653	7684	7718	8029	8145
9908	144	103	13	NWSE	2468	7386	7433		7686	7740	8090	8184
7667	144	103	18	NWSE	2436	7307	7350		7600	7665	7970	8088
7094	144	103	20	NWNW	2422	7305	7351		7626	7660	7965	8080
10238	144	103	24	SWNE	2364	7247	7293		7554	7646	7960	8070
8590	144	103	28	SENW	2260	7080	7127		7378	7480	7776	7886
6508	144	104	1	NWSW	2451	7351	7395		7653	7688	7998	8114
6972	144	104	3	SWNE	2515	7451	7493		7737	7777	8094	8210
6531	144	104	12	SESE	2527	7400	7443	7695	7736	7752	8062	8177
8986	144	104	23	SWNW	2622	7519	7563		7817	7832	8160	8281
6562	144	105	23	NENW	2579	7382	7418		7663	7699	7993	8143
9376	144	105	27	NENE	2496	7256	7295		7540	7571	7873	8015
4177	145	88	17	NESW	2203		6133		6312	6495	6825	6925
ANG#1	145	88	24	SESW	1946		5655		5830	6042	6390	6473
ANG#2	145	88	25	NENW	1948		5654		5800	6043	6362	6453
6674	145	90	34	NWNE	2085	6238	6272		6432	6695	7040	7135
2618	145	91	15	SWSE	2212	6572	6597		6754	6900	7297	7412
7978	145	91	17	NWSE	2223	6344	6373	6732	6793	6974	7350	7471
6492	145	91	35	NWNE	2133	6322	6360		6480	6800	7187	7295
8768	145	92	30	NWNW	2159	6524	6576	6942	6961	7160	7549	7693
11389	145	93	12	NWSW	2252	6690	6728	7122	7178	7330	7737	7858
10783	145	93	16	NESW	2247	6744	6786	7135	7180	7327	7736	7853
7412	145	93	18	SWNW	2218	6800	6842		7158	7340	7734	7838
9601	145	93	22	NWSE	2183	6643	6684		7045	7219	7650	7801
7469	145	93	30	NENW	2170	6719	6761	7097	7165	7307	7726	7830
7707	145	93	35	NESW	2257	6674	6718		7082	7305	7705	7825
6828	145	94	8	NENE	2337	6963	7006	7423	7465	7685	8075	8202
9065	145	94	30	NWNW	2272	6996	7068	7405	7437	7665	8074	8208
6348	145	95	1	NENE	2359	7105	7145	7483	7511	7725	8125	8252
7584	145	95	8	NENW	2322	7120	7160	7497	7521	7768	8160	8300
10542	145	95	30	NENE	2349	7265	7309		7628	7820	8243	8375
11048	145	96	3	NENW	2561	7457	7499	7847	7873	8077	8443	8585
8431	145	96	21	SWSW	2573	7454	7508	7856	7882	8060	8472	8622
9597	145	96	27	NWSE	2416	7267	7310	7656	7678	7889	8273	8415
6251	145	97	6	SWSW	2574	7440	7486	7795	7835	7956	8318	8460
8586	145	97	10	NWNW	2584	7463	7506	7835	7858	8020	8382	8531
9189	145	97	17	SWSE	2676	7413	7457	7790	7813	7972	8350	8507
8277	145	97	27	SESE	2504	7373	7417	7755	7770	7960	8335	8486
6034	145	97	32	NWNW	2518	7334	7382	7705	7720	7890	8295	8430
4829	145	98	4	SESW	2615	7617	7655	7945	8005	8085	8455	8595
8726	145	98	12	SESE	2510	7360	7403	7721	7752	7865	8275	8397
6122	145	98	24	NWNE	2570	7405	7447	7763	7790	7937	8315	8450
10394	145	98	29	SWSW	2656	7595	7637	7930	7982	8090	8450	8586
6208	145	98	36	NENE	2587	7445	7493	7782	7820	7985	8365	8505
2821	145	99	3	NWNE	2681	7725	7760		8050	8182	8568	8710
9806	145	99	6	NWSW	2497	7545	7585	7879	7900	7977	8367	8472
10925	145	99	16	SESW	2484	7493	7537	7850	7860	7973	8357	8467
7564	145	99	19	SESW	2467	7480	7527	7793	7820	7927	8270	8397
6959	145	99	30	SESW	2493	7466	7513		7800	7919	8234	8357
7608	145	99	31	NENW	2570	7540	7585		7864	8005	8330	8449
8013	145	100	1	SENE	2442	7512	7551	7836	7850	7929	8300	8420

Well	Twn	Rge	Sc	QQ	KB	Pm	Po	bsalt	Pbc	PPa	PPt	Mbs
12169	145	100	7	SWSE	2324	7204	7248	7532	7575	7663	7957	8085
11275	145	100	10	NWSW	2282	7328	7369	7645	7665	7756	8110	8226
8782	145	100	17	SWNW	2346	7276	7320	7603	7645	7701	8025	8155
9005	145	100	21	SWSE	2361	7397	7440	7715	7750	7845	8200	8327
7518	145	100	29	SENW	2535	7474	7525	7800	7860	7945	8287	8410
9569	145	100	34	SESE	2585	7575	7619	7887	7900	7995	8322	8433
7525	145	101	1	SESE	2443	7394	7438	7716	7750	7775	8120	8255
6550	145	101	10	SESE	2320	7271	7315	7582	7598	7651	7998	8128
6403	145	101	13	NWNE	2390	7275	7320	7613	7657	7746	8040	8166
6132	145	101	16	SESE	2391	7321	7366	7643	7668	7710	8070	8188
9865	145	101	24	NESE	2463	7362	7408	7690	7716	7825	8152	8268
12042	145	101	29	SESE	2124	7047	7095	7353	7397	7425	7774	7898
11307	145	101	31	SESE	2407	7343	7390		7655	7690	8050	8170
8733	145	101	34	SESW	2214	7113	7161	7435	7478	7513	7867	7986
12016	145	101	36	NWSE	2274	7122	7169	7456	7486	7570	7922	8046
8667	145	102	5	NENW	2440	7446	7485	7751	7779	7790	8130	8258
9227	145	102	15	SESE	2298	7277	7318		7605	7621	7965	8095
11309	145	102	19	SWSE	2655	7634	7677	7926	7950	7972	8305	8421
8400	145	102	27	NWSW	2205	7175	7216		7513	7530	7867	7983
6308	145	103	7	NWNW	2491	7437	7474		7707	7728	8060	8188
6666	145	103	10	NWNE	2586	7589	7628			7868	8220	8300
7218	145	103	17	NWSW	2604	7550	7583		7821	7838	8178	8299
6014	145	103	19	NENE	2590	7526	7565		7797	7830	8145	8268
7579	145	104	24	SENE	2664	7603	7640	7886	7894	7933	8242	8362
3645	145	105	24	SESE	2379	7199	7232			7457	7783	7930
1516	146	82	32	SESW	2022					4857	5070	5143
3492	146	90	25	SWSE	2309	6459	6486		6670	6868	7208	7322
9633	146	91	8	SENE	2216		6493	6876	6906	7085	7467	7584
10068	146	91	12	NENE	2145	6529	6537		6710	6913	7238	7373
9627	146	91	19	NENW	2124	6337	6358	6753	6803	6970	7364	7460
5532	146	91	33	NENE	2146	6420	6458		6710	6910	7276	7410
11611	146	92	20	SWSW	2327	6720	6760	7160	7209	7378	7800	7903
9044	146	93	11	SENW	2270	6838	6877		7168	7338	7735	7808
7885	146	93	14	SESE	2406	6974	7016		7297	7498	7875	7984
5396	146	93	16	NESW	2383	6934	6975		7327	7532	7902	8020
9397	146	93	25	SWSE	2334	6755	6797	7163	7178	7378	7800	7908
8455	146	94	12	SWSE	2315	6911	6948	7297	7333	7537	7909	8045
6182	146	94	21	NENW	2186	6897	6941	7312	7355	7560	7912	8056
6448	146	94	24	NWNW	2256	6912	6954		7313	7502	7867	7995
9402	146	95	15	SWNW	2337	7142	7180	7566	7587	7772	8160	8296
11388	146	95	19	SWSE	2349	7170	7211	7592	7629	7822	8210	8360
9213	146	95	31	NENE	2337	7177	7220	7568	7602	7792	8185	8325
6887	146	95	35	SWNE	2324	7049	7090	7471	7494	7735	8055	8250
7420	146	96	4	SESW	2754	7670	7710	8065	8099	8232	8595	8763
10735	146	96	11	SWNW	2680	7505	7545	7903	7927	8112	8441	8605
2615	146	96	20	NENE	3039	7964	8002	8355	8379	8544	8922	9087
6284	146	96	31	SWSW	3055	7970	8013	8360	8380	8580	8945	9100
6302	146	97	4	NWSW	2526	7521	7560		7883	7981	8354	8507
6335	146	97	8	SWSE	2509	7435	7476	7802	7830	7955	8352	8495
6205	146	97	29	NWNW	2325	7151	7205	7535	7574	7696	8090	8226
10554	146	97	33	NWSE	2486	7344	7386	7713	7752	7886	8296	8430
9669	146	98	1	SWNE	2502	7462	7501	7832	7857	7910	8290	8430
8535	146	98	3	SENE	2552	7600	7640	7937	7952	8070	8450	8600
9394	146	98	15	SENW	2589	7643	7688		8003	8076	8468	8600
9138	146	98	22	SWSE	2378	7383	7424	7726	7773	7858	8255	8383
8805	146	98	29	NWSW	2568	7586	7628	7950	8002	8073	8465	8603
6324	146	98	36	SESE	2262	7192	7234	7545	7581	7697	8095	8230
11291	146	99	4	NENW	2593	7677	7723	7997	8023	8108	8457	8593
8160	146	99	6	NWSW	2223	7348	7389		7656	7734	8115	8225
8220	146	99	9	NESW	2520	7564	7606		7905	7975	8357	8475
10094	146	99	9	NWNW	2559	7635	7679	7955	7988	8064	8407	8555
8881	146	99	12	SWSE	2561	7603	7645	7953	7984	8060	8460	8581
11865	146	99	20	NESE	2654	7717	7762	8041	8068	8146	8483	8618

Well	Twn	Rge	Sc	QQ	KB	Pm	Po	bsalt	Pbc	PPa	PPt	Mbs
11105	146	99	24	SWSE	2659	7670	7714	8025	8047	8170	8549	8671
10750	146	99	33	NWSE	2538	7624	7667	7935	7949	8080	8468	8591
8604	146	100	3	NENW	2123	7230	7270		7520	7594	7942	8075
7496	146	100	16	SESW	2621	7656	7694	7970	7984	8050	8394	8521
12070	146	100	29	NESE	2424	7476	7516	7760	7785	7834	8190	8303
6698	146	100	33	SENW	2536	7511	7553	7822	7835	7897	8250	8376
11384	146	101	4	NWSE	2122	7158	7197	7475	7515	7534	7897	8009
8219	146	101	10	SESE	2443	7475	7515	7782	7820	7848	8199	8333
8199	146	101	12	SWSE	2412	7515	7557		7810	7849	8200	8338
8668	146	101	15	SWSE	2453	7447	7488	7763	7793	7820	8185	8305
8568	146	101	19	SENE	2196	7228	7265	7523	7558	7587	7931	8059
7512	146	101	22	SENE	2616	7608	7648	7920	7965	7987	8340	8477
9186	146	101	26	SWSW	2318	7305	7349	7620	7635	7785	8023	8159
10458	146	101	34	SWSE	2234	7223	7268		7538	7663	7949	8085
8762	146	102	3	SENE	2164	7236	7275	7513	7524	7548	7906	8023
12249	146	102	17	NENW	2360	7426	7466		7722	7732	8065	8200
8485	146	102	21	SESW	2255	7278	7317	7570	7590	7605	7952	8076
9252	146	102	25	SWNE	2293	7323	7360	7620	7644	7670	8015	8142
8481	146	103	7	NWSE	2415	7413	7451			7658	7990	8124
7217	146	103	10	SWSE	2299	7357	7392			7607	7957	8086
8872	146	104	9	NENE	2333	7310	7343			7561	7880	8035
8287	146	104	18	NWSE	2450	7405	7436			7655	7968	8113
7590	146	104	27	NESE	2541	7496	7529		7743	7755	8084	8212
6966	146	104	36	SESW	2502	7462	7495		7722	7734	8052	8195
9191	147	91	15	NENW	2198		6496	6820	6862	7023	7429	7536
7745	147	92	10	NENE	2048	6503	6543		6878	7018	7428	7536
8709	147	93	8	NESW	2283	6806	6844		7260	7440	7778	7920
10072	147	93	14	NENE	2238	6772	6813		7192	7350	7725	7896
11839	147	94	3	SESW	2231	6887	6928	7303	7360	7523	7855	8022
7959	147	95	19	NWNW	2544	7459	7500		7815	7970	8338	8495
7576	147	95	23	NWSE	2379	7256	7297	7662	7695	7856	8208	8318
9269	147	95	33	SENW	2421	7269	7310	7671	7710	7881	8243	8386
9103	147	96	10	SESE	2193	7024	7065	7420	7491	7640	7980	8145
11365	147	96	11	NENE	2284	7088	7130	7493	7565	7717	8055	8215
8107	147	96	23	SWNE	2538	7392	7434	7795	7822	7968	8330	8483
6967	147	96	34	NENE	2915	7772	7813		8181	8356	8728	8880
9167	147	97	7	SWSW	2136	7088	7128		7490	7564	7943	8095
8544	147	97	18	NESW	2003	6977	7019	7336	7350	7442	7825	7978
9062	147	97	19	NWNE	2389	7052	7094	7420	7453	7548	7943	8072
8739	147	97	20	SWNE	2025	6991	7030		7387	7486	7875	8032
8545	147	97	30	NESW	2491	7460	7500	7810	7839	7932	8319	8451
9086	147	97	34	E2NW	2515	7469	7508	7841	7868	7988	8372	8530
8196	147	98	21	SENW	2168	7240	7283	7587	7613	7673	8079	8203
11412	147	98	32	NENW	2562	7619	7662	7965	8016	8063	8440	8585
8443	147	99	29	NWSW	2312	7443	7484	7755	7792	7852	8217	8315
7337	147	99	33	NENE	2589	7674	7718	8011	8031	8133	8473	8615
10183	147	101	6	SWSW	2263	7403	7441			7680	8037	8163
6987	147	101	15	SWNE	2099	7230	7266		7525	7557	7903	8030
10308	147	101	18	NESE	2099	7185	7221			7482	7860	7981
6718	147	101	22	SWNE	2196	7289	7328		7578	7590	7960	8090
9276	147	101	33	SENE	2042	7087	7125	7395	7418	7458	7802	7930
10425	147	102	13	SENW	2269	7369	7404			7654	8003	8137
7850	147	102	27	NESW	2222	7315	7350			7592	7958	8078
12095	147	102	29	NESE	2420	7500	7535			7767	8110	8250
10199	148	87	12	NENE	2030				5634	5808	6150	6220
8802	148	87	20	NWNE	2007		5790		5869	5986	6325	6415
5352	148	89	30	SENW	2058		6225		6424	6563	6907	7030
9941	148	90	12	NESE	2072		6316		6452	6583	6905	7016
9707	148	92	4	SWNE	2306	6772	6794	7175	7231	7326	7707	7860
8061	148	93	19	NENW	2225	6812	6852	7245	7303	7415	7765	7930
9710	148	94	7	NESE	2393	7101	7139	7527	7570	7740	8068	8234
6582	148	95	8	NESW	2378	7158	7197	7562	7641	7780	8110	8274
2352	148	95	18	SENW	2441	7218	7258	7664	7682	7819	8168	8328

Well	Twn	Rge	Sc	QQ	KB	Pm	Po	bsalt	Pbc	PPa	PPt	Mbs
6457	148	96	2	SESW	2100	6876	6915	7247	7300	7383	7768	7926
8448	148	96	16	NENE	2394	7198	7237	7574	7624	7710	8080	8249
10749	148	96	22	SWSE	2044	6790	6830	7182	7240	7363	7695	7865
9462	148	96	34	SWNW	2183	6975	7018	7367	7420	7564	7890	8051
10346	148	97	6	SWSW	2378	7406	7446	7767	7796	7863	8210	8391
9266	148	97	17	SWSE	2408	7418	7457	7767	7794	7865	8242	8410
4725	148	97	24	SWSE	2373	7315	7355		7752	7850	8200	8370
11875	148	97	28	SENW	2021	7010	7052	7379	7425	7484	7828	7991
9802	148	98	14	NWNE	2559	7630	7670		7997	8056	8403	8576
8780	148	98	29	NENW	2427	7602	7641	7940	7990	8048	8390	8555
6597	148	98	36	NENW	2206	7223	7264	7572	7634	7686	8081	8238
10293	148	99	5	NWNE	[illegible]	7603	7637			7925	8248	8440
9066	148	99	12	SENW	[illegible]	7668	7712		8020	8035	8400	8520
8887	148	99	25	NWNW	2515	7722	7763		8063	8100	8477	8625
9470	148	100	7	NENE	2236	7493	7526			7784	8122	8270
10324	148	100	17	NWNE	2313	7562	7594			7853	8215	8363
7700	148	100	31	SENE	2402	7560	7598			7856	8262	8395
7173	148	101	25	SENW	2253	8212	8295			8510	8820	8873
5126	149	86	16	NWSW	2227				5795	5923	6260	6330
10409	149	86	34	NESE	2099				5680	5798	6125	6186
1194	149	90	5	NWNE	1989		6350		6602	6718	7098	7222
793	149	91	22	SENW	2102	6505	6535		6890	6998	7393	7510
7214	149	92	33	SESE	2363	6825	6851	7250	7302	7389	7762	7905
8095	149	93	17	SWNW	2330	6968	7007	7405	7463	7567	7906	8076
9040	149	93	21	SWNW	2241	6853	6893	7296	7345	7423	7806	7970
607	149	93	24	SWNE	2149	6737	6770	7162	7225	7320	7683	7847
9722	149	94	16	SWNW	2417	7113	7151	7539	7596	7720	8043	8224
9037	149	94	21	SESE	2335	7030	7068	7453	7511	7663	7970	8130
9676	149	95	3	NWSE	2384	7064	7100	7470	7522	7646	7940	8130
5936	149	95	29	NWNE	2294	7056	7094	7455	7490	7623	7960	8127
10977	149	96	1	SESW	2376	7067	7102	7442	7491	7606	7935	8105
11624	149	96	13	NWSE	2507	7216	7255		7620	7685	8067	8246
10633	149	96	19	NWNW	2048	6951	6989	7308	7350	7396	7765	7945
8471	149	96	22	NENW	2406	7285	7325		7650	7693	8073	8262
11913	149	96	25	NWSE	2520	7253	7291	7643	7674	7755	8120	8297
7531	149	97	12	SWNW	2191	7045	7082		7400	7430	7793	7990
9378	149	97	19	SENW	2189	7328	7365			7710	8060	8265
11442	149	97	26	NWSE	1997	6978	7015	7335	7375	7421	7777	7965
9456	149	98	11	NWNW	2244	7490	7525			7837	8173	8379
7219	149	99	33	SWNW	2227	7507	7544			7830	8135	8330
10537	150	85	6	SESE	2208				5683	5730	5910	5992
8310	150	86	27	SESE	2162				5720	5767	6070	6152
8373	150	88	9	NWNW	2094					6177	6535	6670
5826	150	88	29	SESE	1999		6040		6117	6188	6520	6682
6766	150	89	12	NWNW	2019		6121			6230	6589	6747
9512	150	89	25	NENW	1982		6086		6218	6247	6582	6753
7783	150	90	1	SENW	2212		6539		6631	6660	7020	7200
2695	150	92	9	NENW	2115	6700	6720	7088	7133	7182	7525	7743
7457	150	92	20	NWNE	2146	6733	6763	7117	7145	7215	7590	7740
4113	150	93	4	SENW	2198	6883	6918	7300		7365	7750	7958
11680	150	94	19	NESW	2202	6843	6882		7307	7422	7680	7908
8179	150	94	23	NWSE	2220	7070	7106		7510	7614	7936	8120
3731	150	94	33	NWSW	2334	7026	7064	7454	7516	7634	7938	8120
11643	150	95	6	SWNE	2390	6864	6905		7271	7312	7625	7843
10247	150	95	10	NESW	2360	6842	6883		7315	7421	7684	7895
9562	150	95	18	NENE	2327	6860	6900		7321	7392	7673	7893
11295	150	95	21	CSW	2332	6867	6907		7326	7449	7703	7911
5934	150	95	23	NESW	2247	6805	6847	7245	7290	7415	7680	7895
9519	150	96	3	NWSE	2391	6984	7027	7398	7407	7473	7760	7966
8758	150	96	5	SWSE	2338	6982	7020		7403	7434	7728	7934
7886	150	96	15	SWNE	2300	6894	6945		7365	7432	7735	7938
10525	150	96	20	NESW	2303	6972	7012		7403	7456	7750	7980
10782	150	96	34	NESW	2364	7050	7088	7432	7463	7543	7815	8072

Well	Twn	Rge	Sc	QQ	KB	Pm	Po	bsalt	Pbc	PPa	PPt	Mbs
7743	150	97	3	NWSE	2244	7005	7043			7428	7745	7966
11383	150	97	15	NWSE	2167	7051	7092		7408	7450	7749	7946
9024	150	97	20	SWNW	2123	7268	7308		7658	7680	7974	8184
8933	150	97	26	SWSW	2301	7113	7152		7499	7530	7850	8067
10997	150	98	2	NESW	2038	7305	7342			7655	7942	8165
8747	150	98	4	SWSW	2054	7413	7451			7763	8040	8257
7704	150	98	23	NESE	2022	7230	7267		7580	7593	7900	8115
5096	151	86	23	SWSW	2150				5745	5765	5967	6063
8177	151	87	18	SESE	2146					5950	6235	6420
5481	151	88	8	NESE	2138					6175	6502	6695
11086	151	88	14	NWNE	2112					6080	6327	6470
5273	151	88	26	NESW	2167				6165	6185	6478	6602
12199	151	88	28	NESW	2135				6215	6251	6550	6680
10519	151	89	22	SESE	2106		6220		6345	6363	6674	6834
6780	151	89	24	SENE	2133		6210			6280	6610	6761
8447	151	89	34	NWNE	2139		6278		6380	6452	6733	6920
4392	151	90	13	NENW	2115		6381		6507	6523	6840	6984
4386	151	90	28	SESE	2216		6550	6694		6702	7115	7305
5257	151	90	34	NWSW	2223		6575			6740	7130	7315
3686	151	93	10	NENE	2159	6935	6945		7350	7367	7722	7898
7366	151	94	6	NENW	2175	6675	6708			7184	7480	7720
4594	151	94	10	NWNW	1956	6566	6591		7035	7053	7370	7600
9987	151	94	19	NWNE	2178	6766	6803		7260	7302	7568	7781
3832	151	94	29	SWSW	2301	6870	6908		7394	7440	7795	7955
10149	151	95	8	NESW	2544	6969	7002		7420	7471	7700	7905
3056	151	95	13	NWNW	2107	6648	6683		7153	7185	7503	7737
9192	151	95	19	SENE	2436	6865	6897		7312	7350	7590	7820
8005	151	95	29	NESW	2341	6847	6882		7272	7303	7589	7804
10488	151	96	2	NENE	2409	6877	6912		7346	7455	7663	7900
10050	151	96	3	SESW	2504	6775	6810		7255	7310	7497	7740
11401	151	96	5	NESW	2227	6769	6803			7188	7448	7686
11204	151	96	17	SENW	2296	6853	6885		7287	7324	7553	7790
8124	151	96	22	SENW	2381	6900	6935		7373	7460	7669	7904
8873	151	96	27	NWSE	2373	6941	6976		7369	7430	7684	7912
3279	151	96	29	NWSW	2398	6985	7020		7383	7393	7703	7920
9363	151	97	7	NENE	2284	7276	7310			7673	7940	8165
7008	151	97	11	NWNW	2291	7026	7060			7430	7730	7955
10805	151	97	19	NWNE	2157	7207	7241			7575	7894	8115
1765	151	97	35	NWNW	2430	7197	7235		7583	7587	7845	8120
9263	151	98	20	NESW	2059	7385	7424			7764	8004	8220
9036	152	86	10	NWNW	2110					5705	5720	5893
5105	152	86	28	NWNW	2120					5755	5802	6060
12264	152	87	29	SENW	2103					5860	6132	6255
10994	152	88	24	NWSE	2098					5927	6120	6321
9142	152	88	33	NWNW	2112					6110	6405	6550
8071	152	90	3	NENW	1967		6220			6375	6635	6800
4747	152	90	30	NWNW	1881		6240			6423	6795	6967
9055	152	90	35	NWSE	2001		6290		6393	6410	6722	6906
4061	152	93	16	NWNW	2020		6793			7205	7482	7712
11681	152	93	23	SENW	2127		6834			7228	7585	7805
1432	152	94	6	NWSE	2130	6674	6708			7145	7395	7620
8908	152	94	8	SENE	2060	6820	6853			7271	7595	7820
11686	152	94	17	NESE	2183	6743	6775			7192	7507	7732
8446	152	94	28	NENE	2206	6782	6815			7255	7580	7790
12019	152	94	33	SENE	2155	6765	6798			7235	7563	7767
8100	152	95	3	SENE	2308	6734	6762		7183	7232	7458	7690
2030	152	95	6	SESE	2326	6675	6708			7115	7330	7600
12214	152	95	17	NWSW	2368	6775	6810			7238	7482	7702
9539	152	95	32	NESW	2436	6843	6874		7300	7355	7577	7810
10636	152	96	3	SENE	2343	6585	6616			7030	7212	7472
8266	152	96	13	NWNW	2441	6767	6799		7236	7260	7513	7728
11620	152	96	20	NENE	2432	6830	6862			7240	7440	7715
9081	152	96	23	NESE	2391	6800	6832		7237	7283	7465	7700

Well	Twn	Rge	Sc	QQ	KB	Pm	Po	bsalt	Pbc	PPa	PPt	Mbs
11228	152	96	27	SWSW	2312	6718	6750			7195	7440	7681
3317	153	92	25	NWNE	2308		6914			7200	7485	7660
6547	153	95	34	NESW	2288	6548	6577			6987	7247	7445

APPENDIX D

Broom Creek Lithology and Nitrogen Occurrence Derived from Wireline Logs

Broom Creek Formation lithology determinations and nitrogen occurrences derived from wireline logs used in this study are listed in order according to Township, Range, and Section location. The first line of each entry begins with the North Dakota Geological Survey well number followed by legal location (township, range, section, quarter-quarter), kelly bushing elevation (KB), and the net pay thickness of nitrogen. The following one or two lines break the Broom Creek Formation into distinct lithologic beds by listing log depths with intervening lithology. Abbreviations for lithologies include: Ss - Sandstone, D - Dolostone, Tr - Transitional, Sh - Shale, An - Anhydrite. The absence of the Broom Creek Formation is noted by "ABS". All depths and thicknesses are given in feet.

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 7930 129  84 28 SWSW  KB:2338   NITROGEN:
      3985 Ss 4001 D  4010 Ss 4052

 6654 129  85 27 SESE  KB:2331   NITROGEN:
       ABS

 6091 129  94  7 NESW  KB:2648   NITROGEN:
      5705 Ss 5742 Tr 5769 Ss 5797 D  5809 Ss 5823

 6050 129  98 30 SWSW  KB:2695   NITROGEN:
      6030 Ss 6045 D  6050 Ss 6125 D  6160 Ss 6185

 8847 129  99 27 SWSW  KB:2658   NITROGEN:
      6092 Ss 6120 D  6128 Ss 6212

 9017 129 100 18 NESE  KB:2792   NITROGEN:
      6263 Ss 6310 D  6322 Ss 6336 D  6341 Ss 6378

10307 129 100 21 SENE  KB:2782   NITROGEN:
      6265 Ss 6315 D  6355 Ss 6390 D  6400 Ss 6412

11454 129 100 34 NESW  KB:2788   NITROGEN:
      6157 Tr 6167 Ss 6240 D  6250 Ss 6280

 5619 129 101  6 SWNW  KB:2925   NITROGEN:
      6275 Tr 6285 Ss 6297 D  6305 Ss 6430 D  6445 Ss 6471

 8627 129 101 16 SWNW  KB:2800   NITROGEN:
      6195 Ss 6263 D  6280 Ss 6300 D  6313 Ss 6343

 7922 129 101 21 SWSE  KB:2836   NITROGEN:
      6155 Ss 6304 D  6322 Ss 6340

11218 129 102  7 NWSW  KB:2989   NITROGEN:
      6339 Ss 6362 D  6373 Ss 6445 D  6455 Ss 6478

 5733 129 102 11 SESW  KB:2832   NITROGEN:
      6245 Tr 6260 Ss 6295 D  6305 Tr 6330 Ss 6348 D  6363 Ss 6375

 5758 129 102 21 SWSE  KB:2849   NITROGEN:
      6104 Tr 6115 Ss 6123 D  6130 Ss 6255 D  6265 Ss 6280 D  6293 Ss
      6306

 5287 129 102 31 SWSE  KB:2965   NITROGEN:
      6193 Tr 6198 Ss 6213 D  6221 Ss 6228 D  6250 Ss 6336 D  6359 Ss
      6372
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6038 129 102 34 SENW KB:2870 NITROGEN:
6105 Tr 6115 Ss 6135 D 6155 Ss 6223 D 6260 Ss 6280

8605 129 103 8 NENW KB:3006 NITROGEN:
6394 Ss 6408 D 6420 Ss 6473 D 6483 Ss 6495 D 6505 Ss 6537

8062 129 103 10 SESE KB:2923 NITROGEN:
6295 Tr 6304 Ss 6319 D 6342 Ss 6383 D 6393 Ss 6432

11049 129 103 34 SESW KB:3058 NITROGEN:
6390 Ss 6411 D 6431 Ss 6443 D 6448 Ss 6458

4662 129 104 8 SESE KB:3252 NITROGEN:
6485 Tr 6493 Ss 6518 D 6547 Ss 6610 D 6621 Ss 6637

7839 129 104 16 SWNW KB:3213 NITROGEN:
6516 Ss 6557 D 6563 Ss 6583 D 6590 Ss 6605

10121 129 104 19 SESW KB:3203 NITROGEN:
6257 Ss 6260 D 6300 Ss 6325 D 6332 Ss 6365 D 6376 Ss 6453 D
6460 Ss 6470 D 6473 Ss 6512

9201 129 104 26 SWNE KB:3069 NITROGEN:
6346 Tr 6361 Ss 6395 D 6404 Ss 6446 D 6462 Ss 6495 D 6499 Ss
6513

10817 129 104 33 SWNW KB:3081 NITROGEN:
6307 Ss 6346 D 6350 Ss 6393 D 6398 Ss 6421

8774 129 105 12 NWSW KB:3132 NITROGEN:
6300 Tr 6303 D 6330 Ss 6395 D 6423 Ss 6472

8658 129 105 15 SESW KB:3181 NITROGEN:
6389 Ss 6416 D 6420 Ss 6426 D 6437 Ss 6460 D 6465 Ss 6488

10337 129 105 25 NENW KB:3145 NITROGEN:
6255 Tr 6270 Ss 6362 D 6380 Ss 6420

10278 129 105 36 NESE KB:3201 NITROGEN:
6259 Tr 6273 Ss 6393 D 6405 Ss 6430

6277 129 106 5 NWSE KB:2851 NITROGEN:
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6113 129 106 9 NWSE KB:2887 NITROGEN:
5732 Ss 5764 D 5775 Ss 5807

6203 129 106 23 NWNE KB:3061 NITROGEN:
5950 Ss 6037 D 6050 Ss 6071

5567 129 106 36 SWSE KB:3008 NITROGEN:
5877 Ss 5998 D 6010 Ss 6050

6143 130 81 32 SWSW KB:2190 NITROGEN:
3533 Tr 3549 Ss 3624

4969 130 86 1 SWSW KB:1995 NITROGEN:
3950 Ss 3975 Sh 3996 D 4027 Ss 4070 D 4090 Ss 4102

5118 130 88 23 NWSW KB:2206 NITROGEN:
4337 D 4350 Sh 4365 D 4375 Sh 4407 D 4435 Ss 4472

4951 130 88 35 NESE KB:2'36 NITROGEN:
4190 D 4196 Ss 4205 D 4220 Sh 4240 D 4295 Ss 4343

6322 130 91 7 NESW KB:2453 NITROGEN:
5212 D 5260 Sh 5284 Tr 5295 An 5310 Ss 5320 D 5330 Ss 5350 D
5360 Ss 5395 D 5425 Ss 5452

7642 130 95 28 NWSE KB:2804 NITROGEN:
5976 Tr 6003 An 6010 Ss 6060 D 6080 Ss 6100 D 6108 Ss 6137

4922 130 100 5 SESW KB:2944 NITROGEN:
6655 Ss 6673 D 6676 Ss 6702 D 6723 Ss 6765

4545 130 100 17 NWNE KB:2867 NITROGEN:
6462 Ss 6470 D 6524 Ss 6540 D 6565 Ss 6590

4952 130 100 32 SWSW KB:2958 NITROGEN:
6475 Tr 6500 Ss 6545 D 6565 Ss 6578 D 6583 Ss 6620

9284 130 101 19 SWNE KB:2869 NITROGEN:
6325 Ss 6345 D 6350 Ss 6392 D 6400 Ss 6428 D 6433 Ss 6470

8573 130 102 5 SWSW KB:2952 NITROGEN:
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11176 130 102 21 SESE KB:2977 NITROGEN:
6471 Ss 6495 D 6508 Ss 6521 D 6530 Ss 6570

7201 130 102 33 NESW KB:2871 NITROGEN:
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11223 130 102 35 NESW KB:2975 NITROGEN:
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6675 Ss 6713 D 6728 Ss 6767

6119 130 103 6 SESE KB:3109 NITROGEN:
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9439 130 103 17 SESE KB:3030 NITROGEN:
6534 Ss 6600 D 6615 Ss 6644

5910 130 103 24 NESE KB:2962 NITROGEN:
6515 Ss 6531 D 6545 Ss 6572

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6537 Ss 6547 D 6559 Ss 6564

7809 130 103 32 SWSW KB:3038 NITROGEN:
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6509 D 6513 Ss 6525 D 6532 Ss 6590

8232 130 104 5 SESE KB:3167 NITROGEN:
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11797 130 104 14 SESE KB:3195 NITROGEN:
6635 Tr 6642 Ss 6735 D 6746 Ss 6753

5804 130 104 17 NENW KB:3064 NITROGEN:
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8397 130 104 36 SENE KB:2516 NITROGEN:
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9198 130 105 2 SWNE KB:3022 NITROGEN:
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9345 130 105 30 SENE KB:2981 NITROGEN:
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11656 130 106 6 SWSE KB:2936 NITROGEN:
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5775 Ss 5800 D 5810 Ss 5822

9664 130 107 3 NWSE KB:2966 NITROGEN:
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11638 130 107 13 NESW KB:3005 NITROGEN:
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4953 131 86 9 NWNW KB:2009 NITROGEN:
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4934 131 87 3 SESE KB:2174 NITROGEN:
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4620 D 4637 Ss 4655

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5904 131 103 34 NWNE KB:3043 NITROGEN:
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4095 Ss 4110

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ABS

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232 133 83 26 SWSW KB:1997 NITROGEN:
3793 Ss 3815 D 3827 Ss 3867

3636 133 90 1 SWNE KB:2350 NITROGEN:
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7075 133 93 26 SWSE KB:2517 NITROGEN:
5895 Ss 6030 D 6045 Ss 6062

7819 133 97 23 SESE KB:2694 NITROGEN:
6390 Tr 6400 Ss 6452 D 6460 Ss 6605 D 6631 Ss 6655

8010 133 97 25 NWNE KB:2677 NITROGEN:
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5881 133 98 5 NENW KB:2776 NITROGEN:
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7016 133 100 23 SESW KB:2879 NITROGEN:
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5933 133 102 9 SESW KB:2897 NITROGEN:
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7826 133 102 17 NENE KB:2927 NITROGEN:
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7548 133 106 22 SENE KB:2828 NITROGEN:
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5285 134 81 22 NESE KB:1721 NITROGEN:
ABS

8630 134 83 2 SESW KB:2146 NITROGEN:
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8549 134 87 16 SESE KB:2293 NITROGEN:
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5496 134 90 5 SENW KB:2420 NITROGEN:
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6586 134 90 17 NWNE KB:2456 NITROGEN:
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8143 134 92 3 NENW KB:2442 NITROGEN:
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7231 134 93 22 SESW KB:2367 NITROGEN:
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6463 Ss 6486

7965 134 96 31 NENE KB:2829 NITROGEN:
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8928 134 96 33 NESW KB:2710 NITROGEN:
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8375 134 98 7 NWSW KB:2828 NITROGEN:
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7113 D 7132 Ss 7148

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7258 Ss 7268 D 7285 Ss 7310

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ABS

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3859 135 83 34 SENE KB:2124 NITROGEN:
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6515 Ss 6530

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7093

11212 135 98 14 NENW KB:2727 NITROGEN:
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7070 Ss 7083 D 7097 Ss 7120 D 7129 Ss 7151

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7283 Ss 7335 D 7352 Ss 7362

10069 135 98 31 SWSE KB:2870 NITROGEN:
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7339 Ss 7355

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7299 Ss 7334 D 7380 Ss 7418

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9883 135 106 26 SWSE KB:2692 NITROGEN:
6591 Ss 6605 D 6618 Ss 6632

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3815 Ss 3920

26 136 81 29 NENW KB:2005 NITROGEN:
3870 Ss 3985

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7876 136 96 14 NENW KB:2738 NITROGEN:
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6967 Tr 6978 Ss 7102 D 7110 Ss 7128 D 7142 Ss 7167

6795 136 97 19 SENE KB:2692 NITROGEN:
6960 Tr 6970 Ss 7015 D 7033 Ss 7163 D 7197 Ss 7215

9244 136 98 2 NWSE KB:2780 NITROGEN:
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7363 D 7379 Ss 7408

8629 136 98 34 SENE KB:2656 NITROGEN:
6875 Ss 6922 D 6937 Ss 6995 D 7000 Ss 7082 D 7095 Ss 7130

11615 136 99 5 SE/4 KB:2707 NITROGEN:
7208 D 7218 Ss 7292 D 7312 Ss 7348 D 7352 Ss 7368 D 7378 Ss
7415 D 7440 Ss 7468

7132 136 99 22 SWSE KB:2686 NITROGEN:
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7266 Ss 7318

4907 136 99 30 NENE KB:2745 NITROGEN:
7220 Ss 7278 D 7298 Ss 7346 D 7384 Ss 7422

5448 136 100 2 SWSE KB:2791 NITROGEN:
7308 Tr 7330 Ss 7403 D 7412 Ss 7436 D 7448 Ss 7472 D 7481 Ss
7512

5160 136 100 12 NWNW KB:2777 NITROGEN:
7311 Ss 7328 Tr 7348 Ss 7358 D 7376 Ss 7450 D 7480 Ss 7520

4124 136 101 4 NWSE KB:2740 NITROGEN:
7185 Tr 7205 Ss 7304 D 7315 Ss 7362 D 7370 Ss 7394

4164 136 101 17 SWNE KB:2783 NITROGEN:
7305 Ss 7336 D 7345 Ss 7393 D 7415 Ss 7483

6048 136 101 23 SWSW KB:2810 NITROGEN:
7200 Tr 7210 Ss 7253 D 7259 Ss 7269 D 7282 Ss 7425 D 7432 Ss
7447

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ABS

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