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Petroleum potential of the Tilston interval (Mississippian) of central North Dakota

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PETROLEUM POTENTIAL OF THE TILSTON INTERVAL

(MISSISSIPPIAN) OF CENTRAL NORTH DAKOTA

by
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This thesis submitted by John P. Himebaugh in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

(Chairman)

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.

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Department Geology

Degree Master of Science

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Date 4-26-79

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ABSTRACT

The Tilston interval sediments were deposited on the eastern flank of the Williston basin of North Dakota, Manitoba and Saskatchewan. The interval (Osagian) is composed of a basal carbonate and upper anhydrite in the predominantly carbonate Mississippian Madison Formation. The interval consists of four major facies (subtidal, shoal, tidal flat and supratidal anhydrite), and two geographically restricted facies (lagoonal and clastic) and represents a regressive sequence.

Tilston deposition began with the subtidal facies, deposited on a broad, shallow shelf. As the sea regressed this was followed by deposition of the shoal facies. Further regression resulted in the deposition of the tidal flat facies. The final regressive stage of the Tilston is marked by the deposition of the widespread supratidal anhydrites and a local clastic facies. The western extent of the regression occurs at approximately 102° west longitude. This area is also interpreted to be the position of the shelf break at the end of Tilston deposition.

Possibility for additional Tilston production outside of known producing areas is indicated by: (1) the Tilston production in Canada and from the North Souris field near the international border in Bottineau County, North Dakota, (2) the scattered shows throughout the study area, (3) the porous zones or facies in the interval, (4) the impermeable anhydrite cap, and (5) the association with an angular unconformity on the subcrop portion of the interval.

The assessment of the petroleum potential of the Tilston interval revealed four potential types of hydrocarbon traps. The first two types, paleogeomorphic and wedge-out, are located at the subcrop portion of the Tilston interval. The third type of trap is due to a combination of a porous zone capped by anhydrite. The fourth type, a stratigraphic trap, is the result of updip porosity change.

INTRODUCTION

General Statement

The Tilston interval is composed of carbonates and evaporites within the predominantly carbonate Mississippian Madison Formation. Sando (1978) determined that the Tilston is of Osagian age. The Tilston interval is not exposed, and is known only in the subsurface of the eastern flank of the Williston basin. The Tilston has been identified and correlated through central North Dakota, Manitoba, and Saskatchewan, and has been postulated to occur in South Dakota (Porter, 1955; McCabe, 1949; Porter and Fuller, 1959; Ballard, 1963; Procter and Macauley, 1968).

Purpose

The first Madison oil recovered in North Dakota was from the Tilston interval of Morton County in 1951 (Scott, 1973). Since that time, there have been scattered shows from the Tilston throughout the eastern flank of the Williston basin in North Dakota, but production has been limited to the North Souris field in northern Bottineau County, North Dakota (Figure 1). The purpose of this study is to determine the depositional environment of the Tilston interval and to evaluate its petroleum potential.

Area of Study

The Tilston interval is found throughout the eastern margin of the Williston basin of Saskatchewan, Manitoba, North Dakota (Porter,

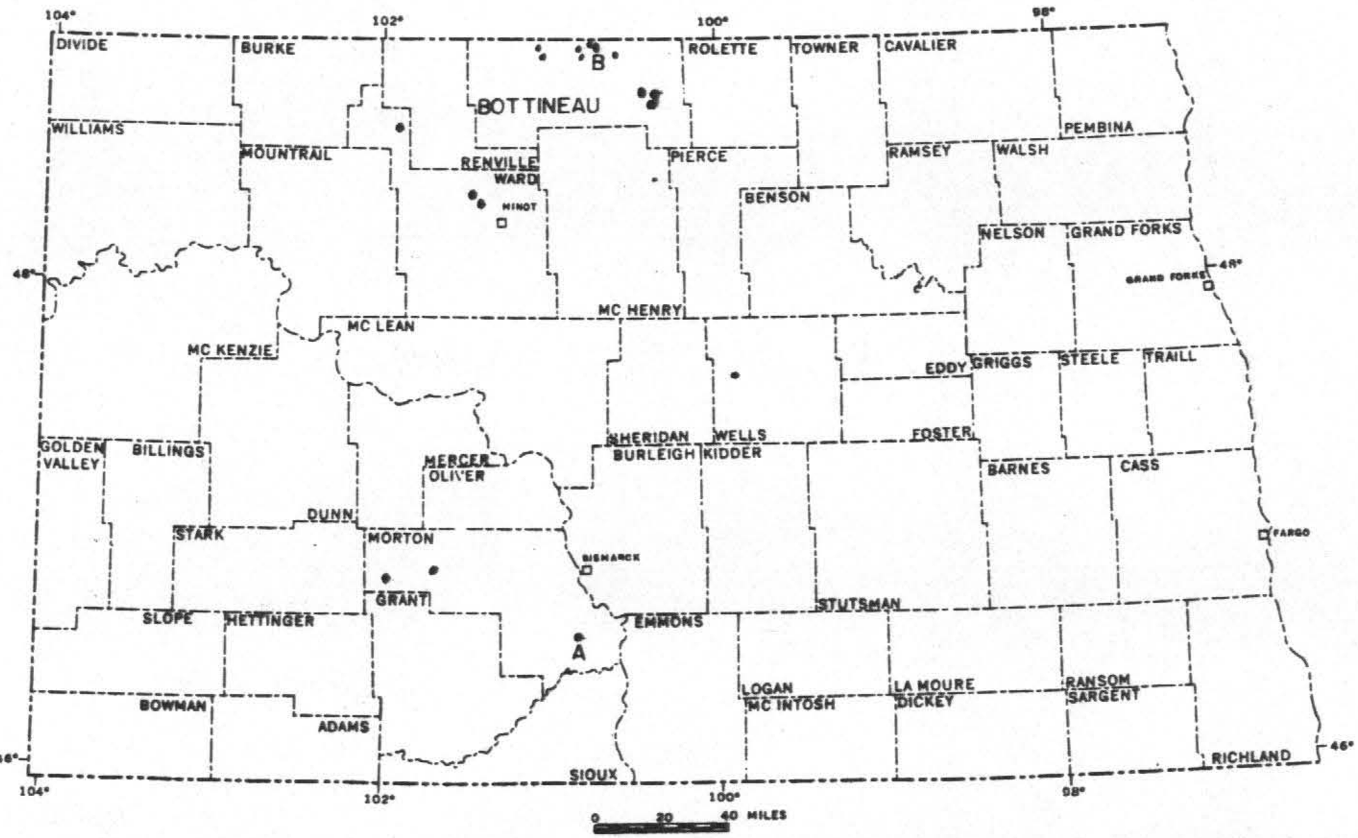


Fig. 1. "Shows" of hydrocarbon from the Tilston interval. Point "A" is the location of the first hydrocarbons recovered from the Madison in North Dakota, from the Phillips Petroleum Co.-Phillips, Carter and Dakota well no. 1. Point "B" is the location of the North Dakota Souris Field.

1955; Fuller, 1956; McCabe, 1959; Ballard, 1963; Carlson and Anderson, 1966; and Kent, 1974), and possibly in northern South Dakota (Procter and Maccauley, 1968). However, for the purpose of this paper, discussion of the Tilston interval will be limited to its occurrence in North Dakota. The area of study comprises 21,000 square miles in the central portion of North Dakota (Figure 2). The study area is bordered on the north by Canada and on the south by South Dakota. The eastern boundary is the erosional subcrop of the Tilston interval (Figure 2). The western boundary is defined as the area in which the Tilston and overlying Frobisher-Alida interval (Figure 3) are not differentiable due to the loss of the anhydrite marker, the T-2 unit, of the Tilston. This occurs at approximately 102° west longitude.

Regional Setting

The Tilston interval is found in the subsurface along the eastern flank of the intracratonic Williston Basin. The maximum sediment thickness of the Williston Basin is located near Williston, North Dakota (Carlson and Anderson, 1966). The Tilston interval attains its maximum thickness of 300 feet in Bottineau County (Figure 4). Thomas (1954) has called this same area the depocenter for early Madison deposition.

Structural features over the pre-Tilston surface are very subtle. Isostructural contour mapping of the study primarily reflected only the bowl-shape of the eastern margin of the Williston Basin (Figure 5). Slightly compressed contour lines in the eastern portion of the study area may indicate a basin "hinge line" at the start of Tilston deposition.

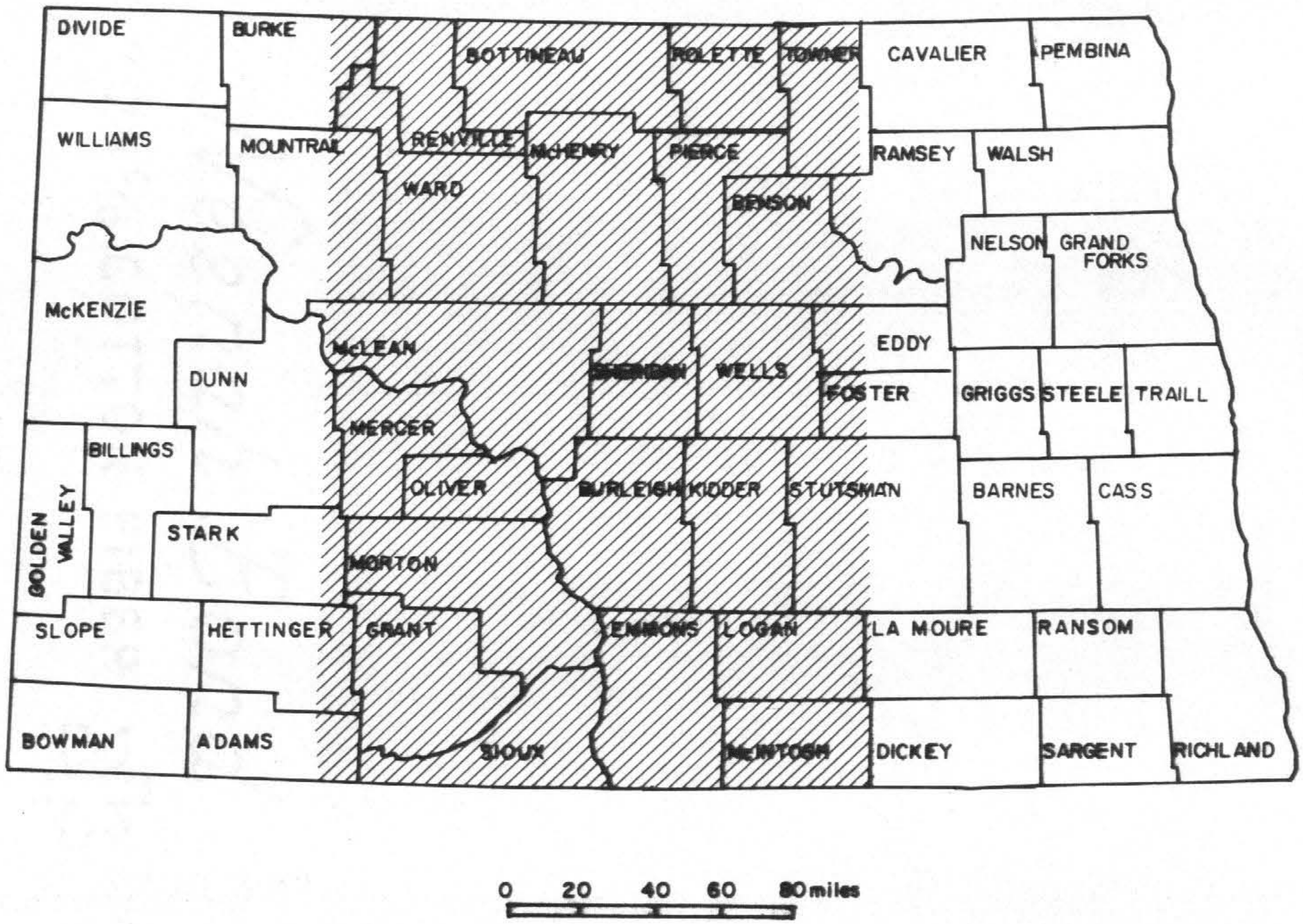


Fig. 2. Location of study area.

Fig. 3. Typical gamma ray, spontaneous potential and resistivity logs for the Madison Formation, central North Dakota. From the Sam G. Harris-J. H. Anderson et al. well no. 1, T157N, R85W, S21, SWSW, Ward County, NDGS Well no. 392. See, also, Figure 8.

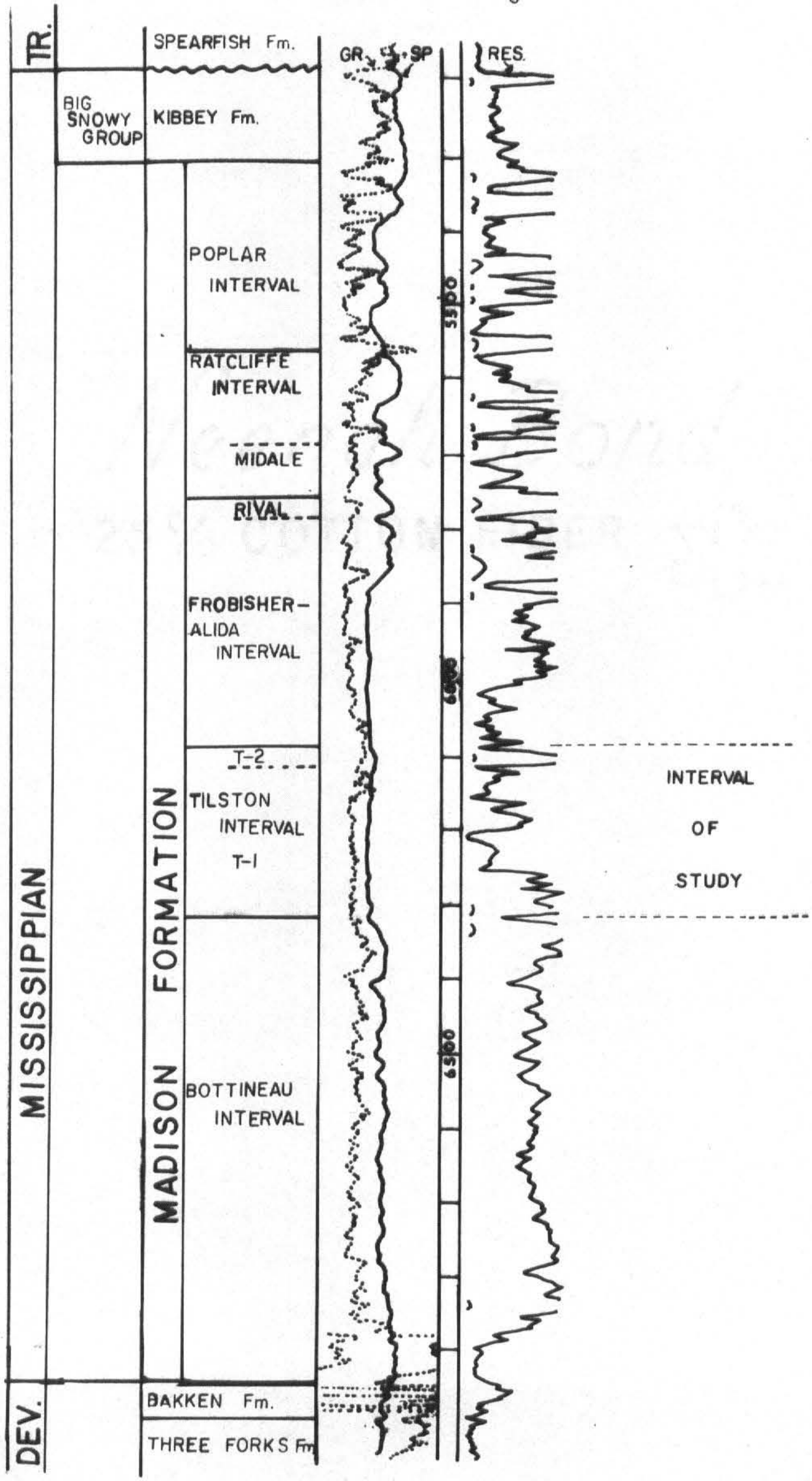

TR.
SPEARFISH Fm.
GR
SP
RES.
BIG SNOWY GROUP
KIBBEY Fm.
MISSISSIPPIAN
MADISON FORMATION
POPLAR INTERVAL
RATCLIFFE INTERVAL
MIDALE
RIVAL
FROBISHER-ALIDA INTERVAL
T-2
TILSTON INTERVAL
T-I
INTERVAL OF STUDY
BOTTINEAU INTERVAL
DEV.
BAKKEN Fm.
THREE FORKS Fm

Fig. 4. Isopachous map of the Tilston interval, central North Dakota.

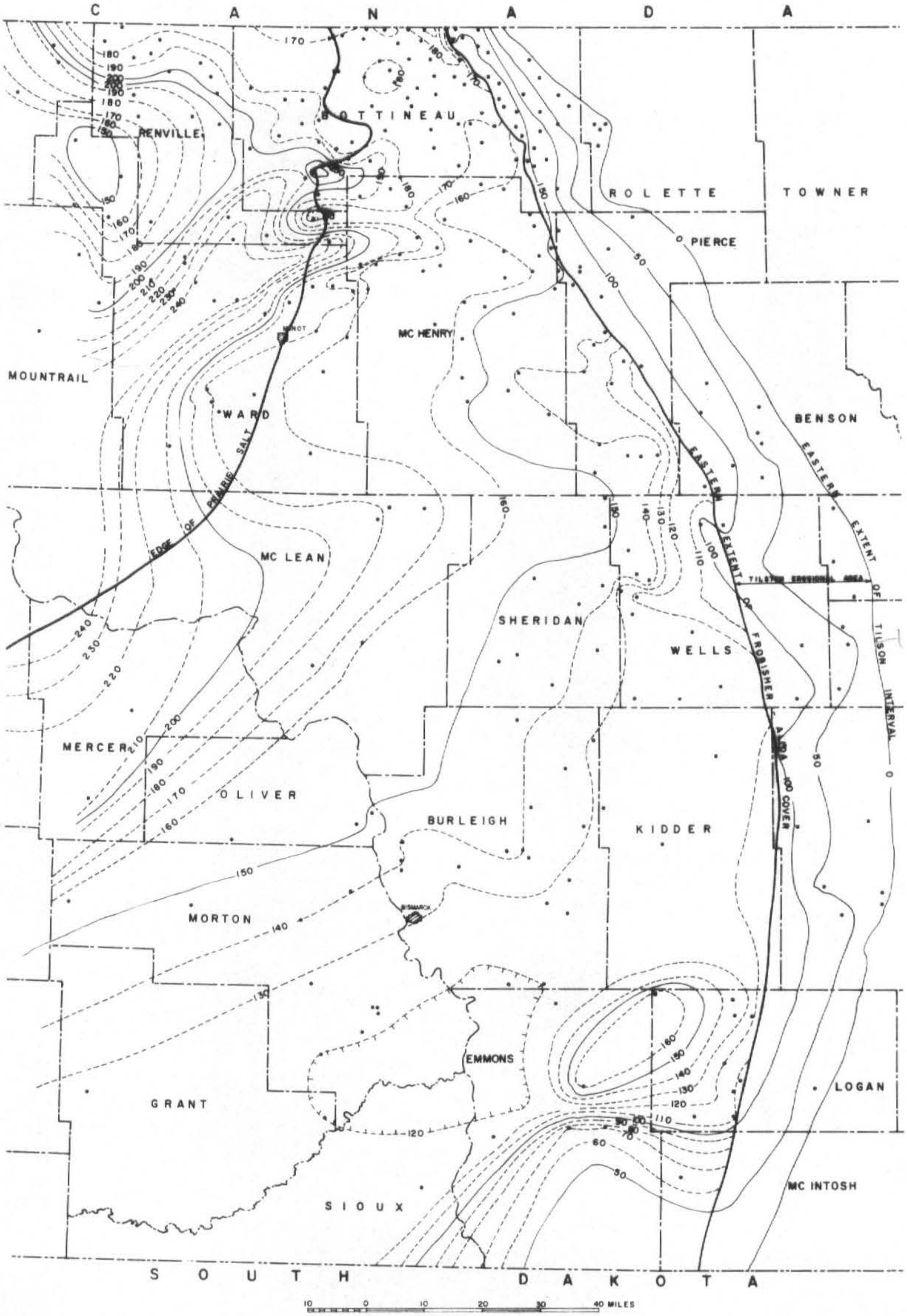
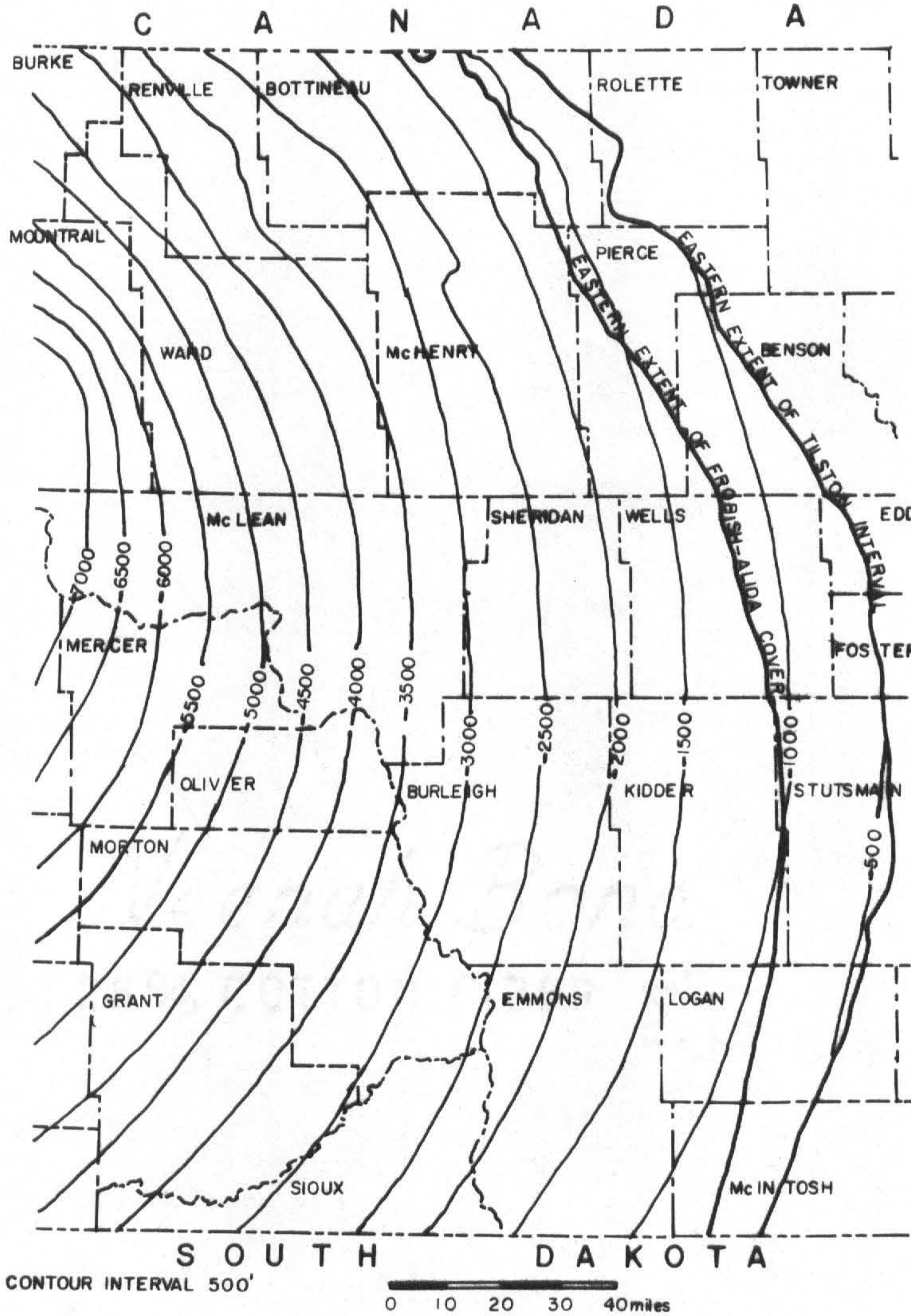

C A N A D A
S O U T H D A K O T A
RENVILLE
BOTTINEAU
ROLETTE
TOWNER
PIERCE
MC HENRY
MOUNTRAIL
WARD
BENSON
MC LEAN
SHERIDAN
WELLS
MERCER
OLIVER
BURLEIGH
KIDDER
MORTON
GRANT
EMMONS
LOGAN
SIOUX
MC INTOSH
MINOT
BISMARCK
EDGE OF PRAIRIE SALT
EASTERN EXTENT OF FROBISHER - ALIDA
100 COVER
EASTERN EXTENT OF TILSTON INTERVAL
TILSTON EROSIONAL AREA
10 0 10 20 30 40 MILES

Fig. 5. Isostructural map of the base of the Tilston interval, central North Dakota.


C A N A D A
BURKE
RENVILLE
BOTTINEAU
ROLETTE
TOWNER
MOUNTRAIL
PIERCE
WARD
McHENRY
BENSON
McLEAN
SHERIDAN
WELLS
EDDY
MERCER
FOSTER
OLIVER
BURLEIGH
KIDDER
STUTSMAN
MORTON
GRANT
EMMONS
LOGAN
SIOUX
McINTOSH
EASTERN EXTENT OF TILSTON INTERVAL
EASTERN EXTENT OF FROBISHER-ALIDA COVER
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
S O U T H D A K O T A
CONTOUR INTERVAL 500'
0 10 20 30 40 miles

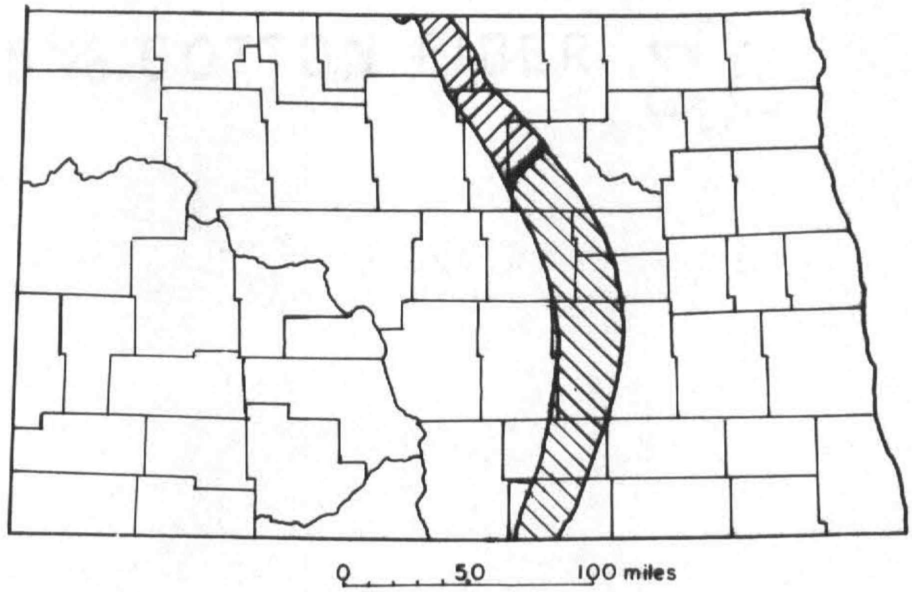
The Tilston interval generally is thickest in the northern portion of the study area. An exception is in northeastern Emmons County where an anomalous thickening occurs. In the northwestern part of Ward County the Tilston is anomalously thin and the Tilston interval thins slightly over the "Burleigh High," Burleigh County, described by Ballard (1963).

At the subcrop of the Tilston interval (Figure 6) pre-Mesozoic uplift and erosion created an erosional surface on which subsequent deposition of Mesozoic sediments created an angular unconformity. Erosion at that time also resulted in the formation of cuestas or "high" areas at the subcrop.

Stratigraphy

The Tilston interval rocks conformably overlie Bottineau interval rocks. The Tilston is conformably overlain by Frobisher-Alida rocks except in the eastern portion of the study area where erosion has removed the Frobisher-Alida interval and the Tilston is unconformably overlain by Mesozoic strata. Along this erosional edge Triassic sediment overlies the Tilston in the northern third of the subcrop, and Jurassic sediment overlies the Tilston in the southern two-thirds of the subcrop (Figure 6).

The term "Tilston" was first used by the Saskatchewan Geological Society (1956). Smith (1960) proposed the subdivision of the Madison into five intervals and two subintervals (Figure 7). This terminology has been informally accepted by the North Dakota Geological Survey. The writer has accepted the terminology proposed by Smith, and, in addition, has informally subdivided the Tilston



TRIASSIC COVER

JURASSIC COVER

Fig. 6. Age and areal extent of Mesozoic rocks overlying the subcrop portion of the Tilston interval.

PEALE, 1893	COLLIER & CATHCART, 1922	SLOSS & MORITZ, 1951	THOMAS, 1954	SASKATCHEWAN GEOLOGICAL SOCIETY, 1956	SMITH, 1960	THIS REPORT	
		CHARLES FORMATION	CHARLES FORMATION	POPLAR BEDS	POPLAR INTERVAL	POPLAR INTERVAL	MADISON FORMATION
				RATCLIFFE BEDS	RATCLIFFE INTERVAL	RATCLIFFE INTERVAL	
				MIDALE BEDS	MIDALE SUBINTERVAL	MIDALE SUBINTERVAL	
					RIVAL SUBINTERVAL	RIVAL SUBINTERVAL	
MADISON FORMATION	MISSION CANYON FORMATION	MISSION CANYON FORMATION	MC-5	FROBISHER-ALIDA BEDS	FROBISHER-ALIDA INTERVAL	FROBISHER-ALIDA INTERVAL	
			MC-4				
			MC-3				
			MC-2	TILSTON BEDS	TILSTON INTERVAL	TILSTON INTERVAL T-2	
			MC-1			T-1	
	LODGEPOLE FORMATION	LODGEPOLE FORMATION	LODGEPOLE FORMATION	SOURIS VALLEY BEDS	BOTTINEAU INTERVAL	BOTTINEAU INTERVAL	

Fig. 7. Stratigraphic nomenclature applied to the Madison Formation in North Dakota.

interval into two units. These two informal units within the Tilston interval will be referred to throughout this paper as the basal (T-1) and the upper (T-2) units (Figure 8).

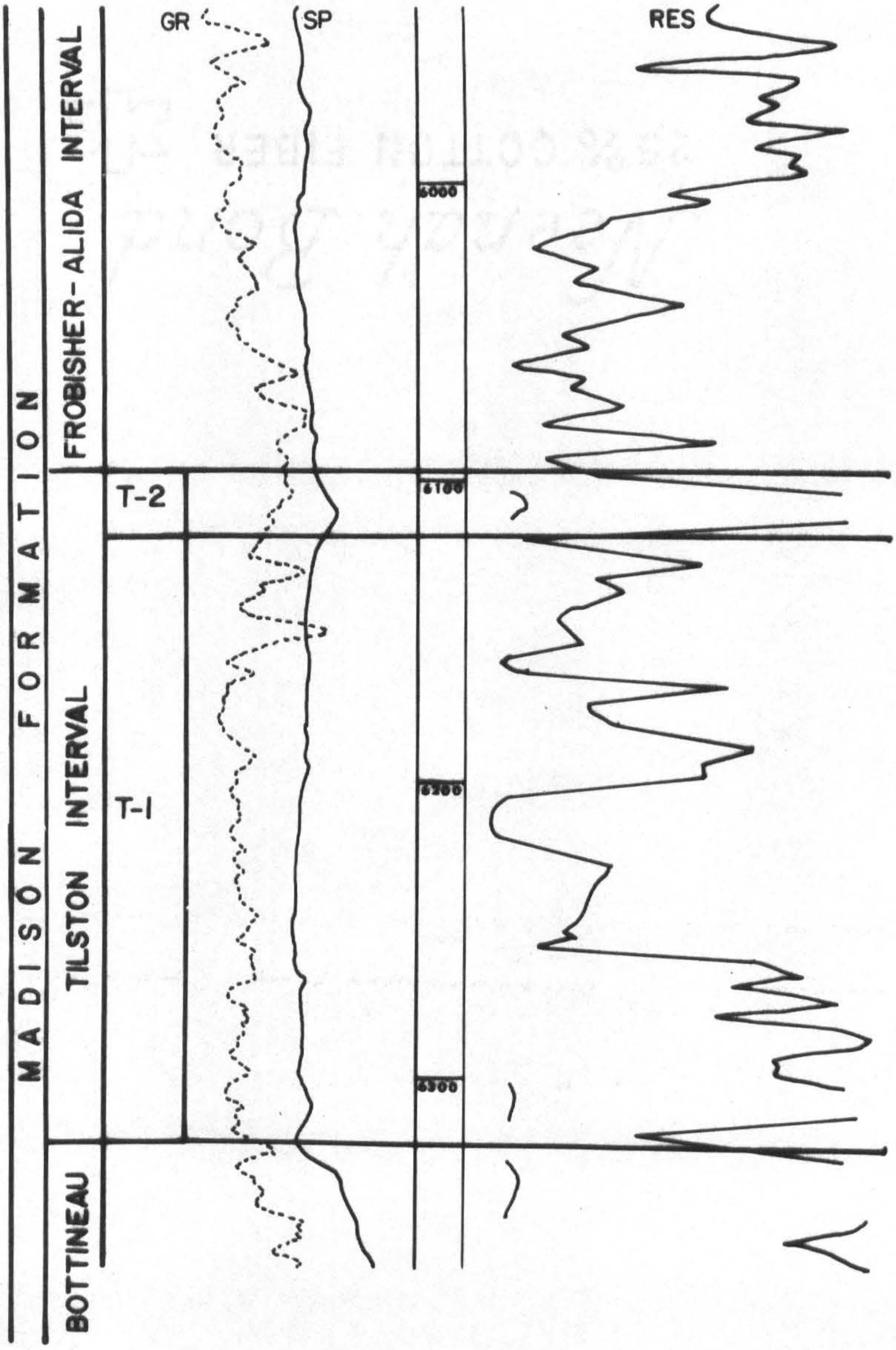
Methods

For the purpose of this paper, the author studied the Tilston interval by using mechanical logs on file at the North Dakota Geological Survey in Grand Forks, North Dakota. Core and sample well-cuttings from wells drilled in North Dakota, which are on file with the North Dakota Geological Survey and which were available in the North Dakota Geological Survey Core and Sample Library in Grand Forks, North Dakota, were also studied.

Cores were examined by using a hand lens, acetate peels, and petrographic thin sections. Cuttings studied were from the Tilston interval plus approximately forty to fifty feet of samples both above and below the Tilston. The samples were examined with reflected light binocular microscope. Some grain-mount thin sections were made from representative chips from occasional five-to-ten foot intervals. Alizarin Red Stain (Friedman, 1959) and ten percent hydrochloric acid were used to differentiate calcite from dolomite. Carbonates were described using Dunham's (1962) classification, which is based on fabric and grains of the carbonate rock.

Isopachous and isostructural maps were drawn from mechanical log data. The wells used and the author's unit boundary log picks are listed in the appendices. Mechanical log curves were used to project lithologies when core or samples either were not available or were not helpful. Mechanical logs were also used to assess the

Fig. 8. Typical gamma ray, spontaneous potential and resistivity logs for the Tilston interval, central North Dakota. From the Sam G. Harris-J. H. Anderson et al. well no. 1, T157N, R85W, S21, SWSW, Ward County, NDGS Well no. 392.


MADISON FORMATION
FROBISHER-ALIDA INTERVAL
TILSTON INTERVAL
BOTTINEAU
T-2
T-1
GR
SP
RES
6000
6100
6200
6300

the porosity or lack of porosity of the Tilston interval in the process of evaluating its petroleum potential.

Review of Nomenclature

The Madison Limestone was first named by Peale (1893) for Lower Carboniferous limestones exposed in the Madison Range of the Three Forks area in Montana (Figure 7). Peale divided the Madison into three units, which are, in ascending order: laminated limestone; massive limestone; and jaspery limestone. Weed (1899) extended Peale's terminolgoy to apply to rocks exposed in the Little Belt Mountains in Montana.

Collier and Cathcart (1922), working in the northern flank of the Little Rocky Mountains of north-central Montana, elevated the Madison to group status by naming two formations. These formations are the lower Lodgepole, which consists of 800 feet of thin-bedded limestone and shale, and the Mission Canyon, which consists of 500 feet of massive white limestone. Sloss and Hamblin (1942), supporting Collier and Cathcart's subdivision of the Madison Group, extended the distribution of the group to include all of Montana and northern Wyoming.

Seager (1942), working with subsurface sediments in eastern Montana, recognized a series of interbedded limestone, dolomite and anhydrite. To these rocks he applied the term "Charles member," referring to the sediments between the Madison Group and the Big Snowy Group (Figure 3). Seager concluded that the Charles Member should be considered a part of the Big Snowy Group based on the porosity development of the upper portion of the Madison Group. Sloss and Moritz (1951), however, recognized a similarity between Seager's Charles member and the sediments exposed in southwest

Montana. Sloss and Moritz therefore suggested that the Charles member belonged in the Madison Group rather than the Big Snowy Group (Figure 1). Since Sloss and Moritz's publication, the Charles member has been included as the uppermost formation of the Madison group (Nordquist, 1953; Anderson, 1954).

Thomas (1954), working in the northeast portion of the Williston basin of Saskatchewan, Manitoba, and northern North Dakota, subdivided the Mission Canyon Formation into five informal units. These units are, in ascending order, the MC-1 through MC-5. The MC-1 and MC-2 correspond to the Tilston interval of later authors.

Porter (1955) discussed the facies problems of the Madison Group relating the western migration of the basin depocenter with the concurrent uplift of the eastern basin margins. This combination of tectonics resulted in continual deposition in the basin center, with gradual westward regression and subaerial exposure of Madison strata in the northeast. Superimposed on this gradual regression are minor epeirogenic fluctuations, creating the "cyclic deposition" of the Mission Canyon and older strata.

In his study of the Madison of Saskatchewan and Manitoba, Porter noted four vertical lithofacies. The lowermost lithofacies is the Lodgepole, which he describes as a "dark, bioclastic-impoverished, sulfide-discolored, in part slightly siliceous and slightly argillaceous limestone." Above the Lodgepole is the Mission Canyon facies, described by Porter as a "clean bioclastic, porous limestone." The third lithofacies is between the Mission Canyon and the Charles, described by Porter as a "light-colored, pseudo-oolitic algal limestone." The uppermost lithofacies is the evaporitic lithofacies of the Charles.

Anderson and Nelson (1956) also subdivided the Mission Canyon as follows: Lower Mission Canyon; Middle Anhydride; and uppermost, Upper Mission Canyon. The lower Mission Canyon and the Middle Anhydrite are equivalent to Thomas' MC-1 and MC-2 respectively. The Lower Mission Canyon and Middle Anhydrite are also the Tilston T-1 and T-2 of this paper, respectively.

In 1956, Fuller proposed the original name, the "Madison Limestone" of Peale (1893). Fuller then subdivided it into an upper and lower Madison Limestone. The upper unit corresponds to the Mission Canyon and the Lower Madison Limestone corresponds to the Lodgepole. The Charles Formation was renamed the Charles Evaporite by Fuller. Porter also noted a facies relationship between the Upper Madison Limestone and the Charles Evaporite.

Fuller (1956) further proposed a subdivision of the Upper Madison Limestone based on Thomas' subdivisions, which, except for the MC-1 and MC-2 were derived from producing areas in Canada. They are, in ascending order: MC-1; MC-2; Forget-Nottingham Limestone; Hastings-Frobisher beds; Midale beds; and uppermost Ratcliffe beds. The uppermost Ratcliffe beds are overlain by the Charles Evaporite.

In an attempt to regionalize the Mississippian terminology, the Saskatchewan Geological Society appointed a Names and Correlation Committee (Saskatchewan Geological Society, 1956), which was to propose a system of nomenclature that could be applied to the Williston Basin of Saskatchewan, Manitoba, Montana and North Dakota. In their publication, the committee recommended changes only for the Madison. The committee divided the Madison into six beds. The committee used the term "beds" so as not to confuse the units with formations. The beds were based on Fuller's (1956) mechanical log marker concept. The committee named the beds, in ascending order: Souris Valley; Tilston; Frobisher-Alida; Midale; Ratcliffe; and uppermost Poplar. This was the first use of the name "Tilston." The committee applied the name "Tilston" to sediments between 3,470 and 3,622 of the Gordon White number 1 well, Lsd. 5, Sec. 14, Twp.1, R.29W, first Mer., of the Tilston oilfield in Manitoba, Canada. These units, as proposed by the Names and Correlations Committee of the Saskatchewan Geological Society, were found to be useful in North Dakota and, for a time, were adopted by the North Dakota State Geological Survey.

As more wells were drilled in North Dakota, it became increasingly difficult to utilize the markers of the Saskatchewan Geological Society. In 1960, the North Dakota Geological Society established a committee, under the Chairmanship of M. H. Smith, to propose a nomenclature for the Madison of North Dakota. The committee subsequently published an abstract containing their recommendations (Smith, 1960). The committee proposed changing the Lodgepole, Mission Canyon and Charles Formations to facies, and further subdividing these facies into five intervals and two subintervals. The committee elected to use the term "interval," which is a marker-defined unit, rather than the term "bed," which is a para-time rock term. The nomenclature was based on marker units within the Midale and Ratcliffe beds, which, unfortunately, did not correlate with the markers used by the Saskatchewan Geological Society (Carlson and Anderson, 1966).

The intervals established by the committee of the North Dakota Geological Society are, in ascending order: Bottineau, Tilston, Frobisher-Alida (containing the Rival subinterval); Ratcliffe (containing the Midale subinterval); and uppermost Popular interval (Figure 3). The first illustration of these intervals, including the Canadian nomenclature, was published by Anderson and others (1960), Figure 3. In 1966, Carlson and Anderson returned the Madison to Formation status within North Dakota.

The North Dakota Geological Survey has informally adopted Smith's recommendations. This paper will also use Smith's nomenclature. The author has also informally subdivided the Tilston interval into two units, basal T-1 (Thomas' MC-1) and upper T-2 (Thomas' MC-2). T-1 and T-2 are used by the author to better conform with current usage (Figure 7).

STRATIGRAPHY

Mechanical Log Characteristics

Mechanical logs consisting of spontaneous potential, resistivity, gamma ray and neutron logs were used to determine thickness, lithology and correlation of the Tilston interval, and to assess petroleum potential (Figure 8). The base of the Tilston T-1 (top of the Bottineau interval) is marked by a decreasing resistivity, a negative-going self potential, and a decrease in the radioactivity of the gamma ray log. The top of the T-1 (the base of the T-2) is marked by an increasing resistivity and a positive-going self potential. The top of the Tilston T-2 (the base of the Frobisher-Alida) is marked by a decreasing resistivity and a negative-going self potential.

Throughout the Tilston T-1 unit, the self potential is basically a "quiet" curve. The resistivity curve of the T-1 was most useful in delineating the porosity of the lithology. The gamma ray log was useful primarily in Logan County, North Dakota, and in the western boundary of the study area where the shale or silt content increased and the anhydrites of the T-2 unit changed to a shale facies.

Underlying Unit

The Tilston interval conformably overlies the Flossie Lake subinterval of the Bottineau interval (Heck, 1978). Throughout the study area, the Flossie lake subinterval consists of interbedded mudstone, packstone and grainstone deposited in an open shelf, shallow marine environment (Heck, 1979).

Tilston Interval

The Tilston interval is composed of carbonates and evaporites. For the purposes of this report, the Tilston has been subdivided into two informal units, or subintervals. This subdivision, first proposed by Thomas (1954), is based on mechanical log curves, and does not represent lithologically homogenous units.

The lower unit, T-1, is composed almost entirely of "clean" carbonates. However, the argillaceous content does increase near the contact with the underlying Bottineau interval. The limestones range from oolitic and skeletal grainstone, to mudstone. The T-1 unit varies in thickness from 0 feet on the erosional edge to 300 feet in Bottineau County, North Dakota.

The uppermost unit, T-2, is composed mainly of anhydrite, interbedded anhydrite-dolomitic mudstone, and dolomitic mudstone. The average thickness of the T-2 unit is thirty feet, but varies from 0 feet on the erosional edge to 50 feet in the western portion of the study area.

The Tilston interval may be subdivided into four laterally extensive major facies and two geographically restricted facies. The four major facies include a basal subtidal facies, shoal facies, tidal flat facies, and supratidal facies. The two geographically restricted facies consist of a lagoonal facies and a clastic facies. The latter two facies are found only in the southeastern corner of the study area in Logan County, North Dakota, and will be discussed in greater detail in a later section.

Overlying Unit

The Tilston interval normally is conformably overlain by the Frobisher-Alida interval, except where it has been removed by pre-Mesozoic erosion. At the subcrop, where the Frobisher-Alida has been removed, the Tilston is overlain by Mesozoic-age sediments. In the northern one-third of the subcrop, the Triassic Spearfish Formation overlies the Tilston, and sediments of Jurassic age overlie the remaining southern two-thirds of the subcrop area.

The Frobisher-Alida interval is composed predominantly of shallow marine carbonates (Gerhard et al., 1978). They have proposed that the diagenetic fabric of the carbonates of this interval indicate an intertidal to supratidal diagenetic environment.

FACIES ANALYSIS

General Statement

For the purposes of this report, the Tilston interval has been subdivided into six facies by the author. These facies subdivisions are based primarily on well cuttings, core analysis and electrical logs. A series of three west-east cross-sections (Figures 9, 10, 11, 12) illustrate the relationships of these facies.

The names applied to these facies are based on their characteristic lithology and interpreted environment of deposition. Dunham's (1962) classification of carbonate rocks was used to describe the fabric of the various lithologies of the facies of the Tilston interval. Appendix B lists the well cutting and core descriptions.

Subtidal Facies

Location

The basal facies of the Tilston interval is typically the subtidal facies. This facies overlies the Flossie Lake subinterval of the Bottineau interval (Heck, 1978). The subtidal facies has a thickness ranging from 0 to 277 feet and is best developed in the northern portion of the study area (Figure 4). Unfortunately, very few core samples are available from this facies.

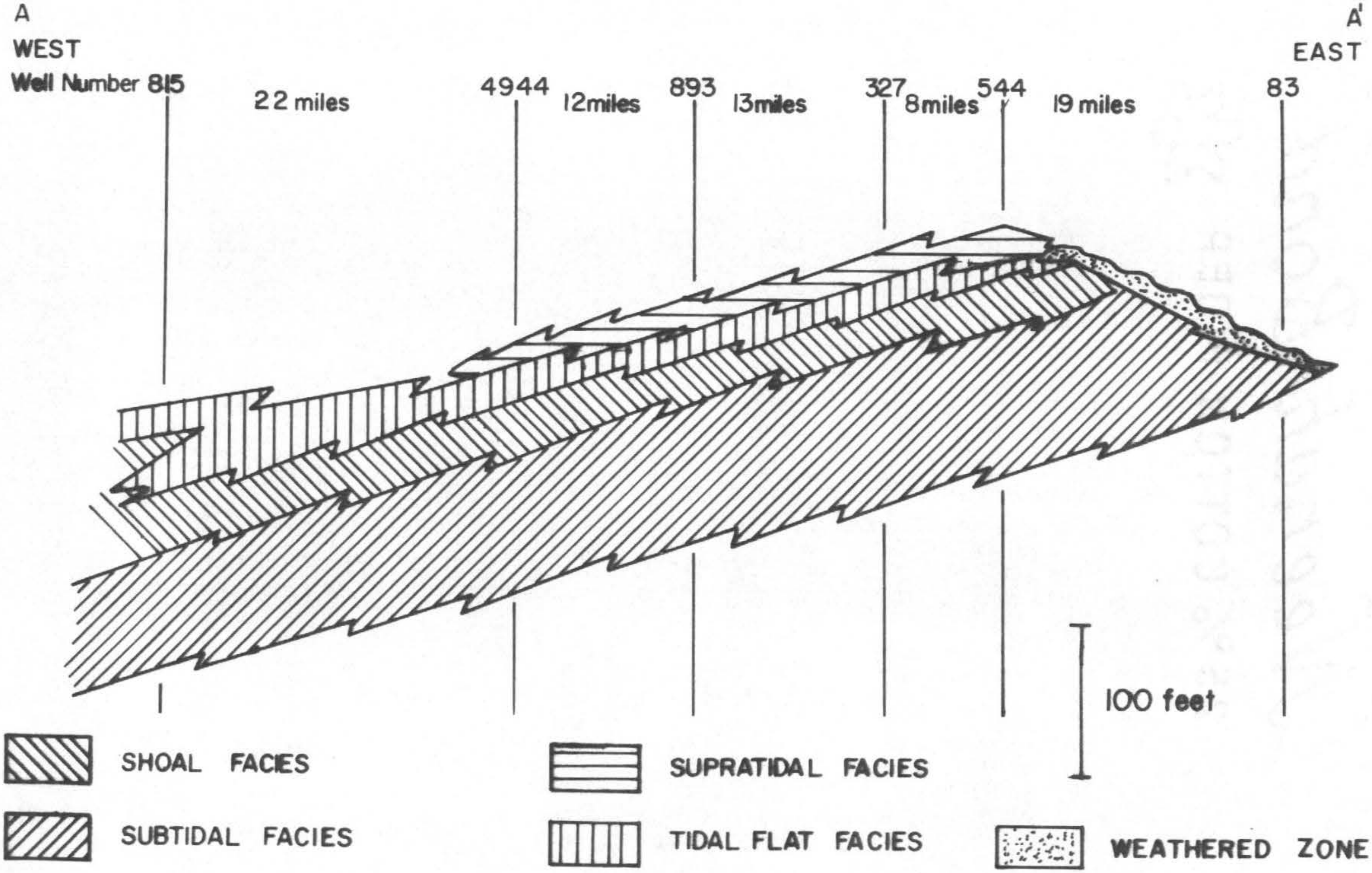
Lithology and Fauna

The subtidal facies is composed predominantly of wackestone and packstone. Some mudstone and skeletal and oolitic grainstones

Fig. 9. Index map for facies cross-sections in central North Dakota.


SASKATCHEWAN
MANITOBA
A
A'
BOTTINEAU
ROLETTE
TOWNER
RENVILLE
WARD
McHENRY
PIERCE
BENSON
McLEAN
SHERIDAN
WELLS
EDDY
B
B'
FOSTER
MERCER
OLIVER
BURLEIGH
KIDDER
STUTSMAN
MORTON
C
C'
GRANT
SIOUX
EMMONS
LOGAN
McINTOSH
SOUTH DAKOTA
0
50
100 MILES

Fig. 10. Facies cross-section A-A' through the northern portion of the study area.



A
WEST
Well Number 815
22 miles
4944
12miles
893
13miles
327
8miles
544
19 miles
A'
EAST
83
100 feet
SHOAL FACIES
SUBTIDAL FACIES
SUPRATIDAL FACIES
TIDAL FLAT FACIES
WEATHERED ZONE

Fig. 11. Facies cross-section B-B' through the central portion of the study area.

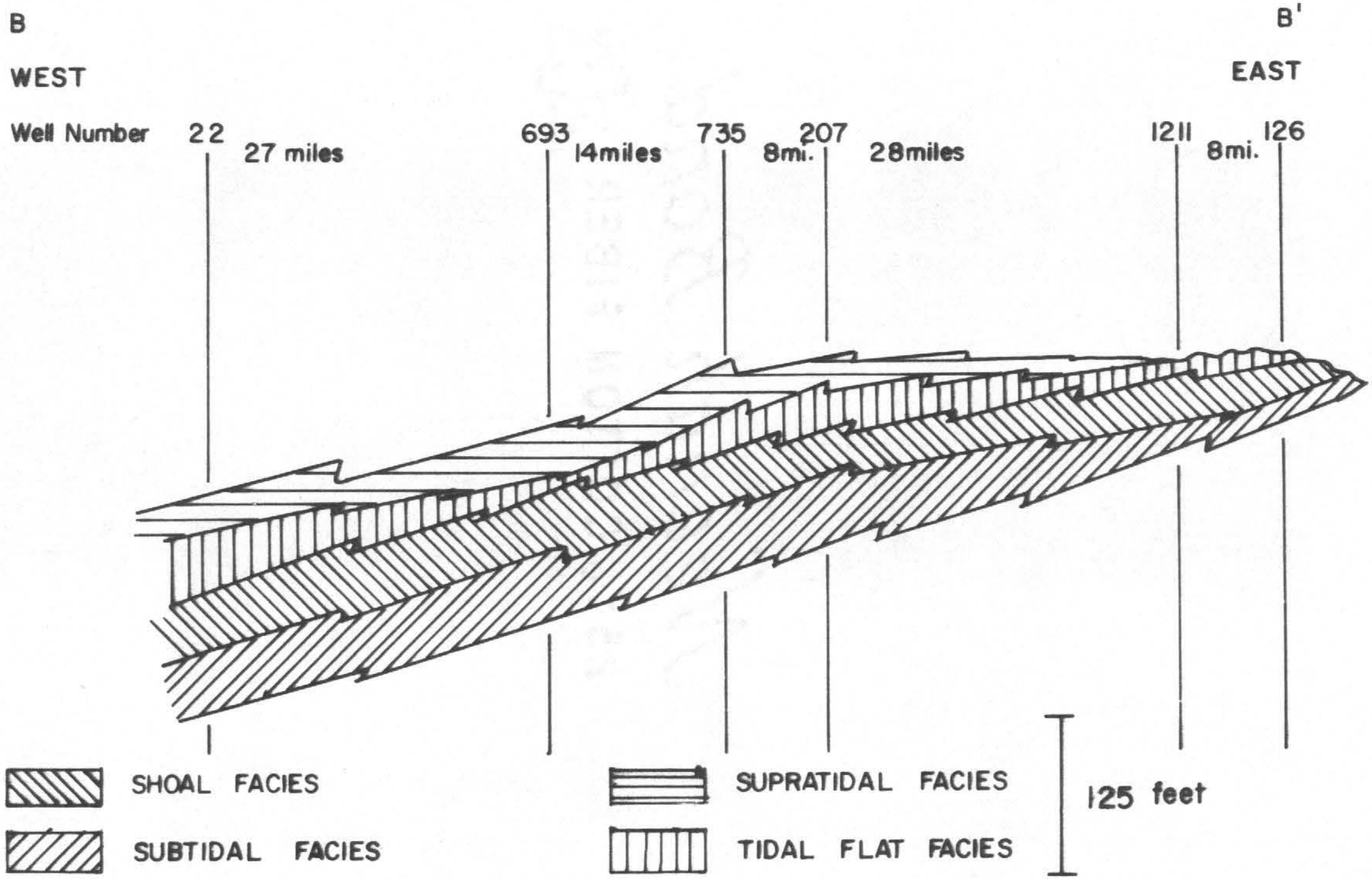
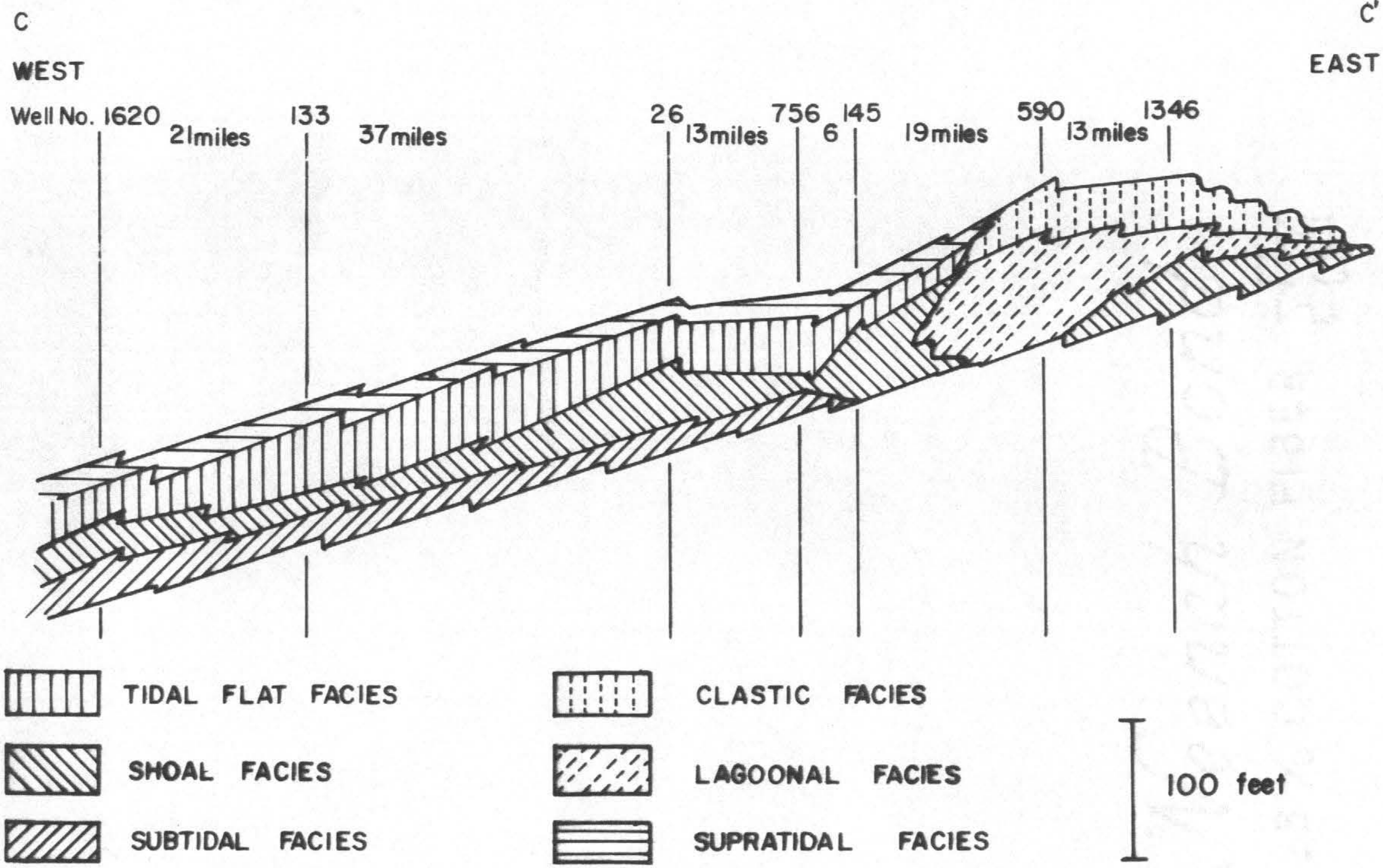

B
WEST
B'
EAST
Well Number
22
27 miles
693
14miles
735
8mi.
207
28miles
1211
8mi.
126
SHOAL FACIES
SUBTIDAL FACIES
SUPRATIDAL FACIES
TIDAL FLAT FACIES
125 feet

Fig. 12. Facies cross-section C-C' through the southern portion of the study area.


C
C'
WEST
EAST
Well No. 1620
21miles
133
37miles
26
13miles
756
6
145
19miles
590
13 miles
1346
TIDAL FLAT FACIES
CLASTIC FACIES
SHOAL FACIES
LAGOONAL FACIES
100 feet
SUBTIDAL FACIES
SUPRATIDAL FACIES

are found within the facies. The skeletal allochems consist of crinoid fragments, brachiopods, rugose coral and bryozoans. Micritized grains were also found within this facies. Crinoid fragments are the most abundant allochems. Some whole rugose corals and brachiopods are found within the facies, particularly in the lower portion. The skeletal allochems occasionally are abraded.

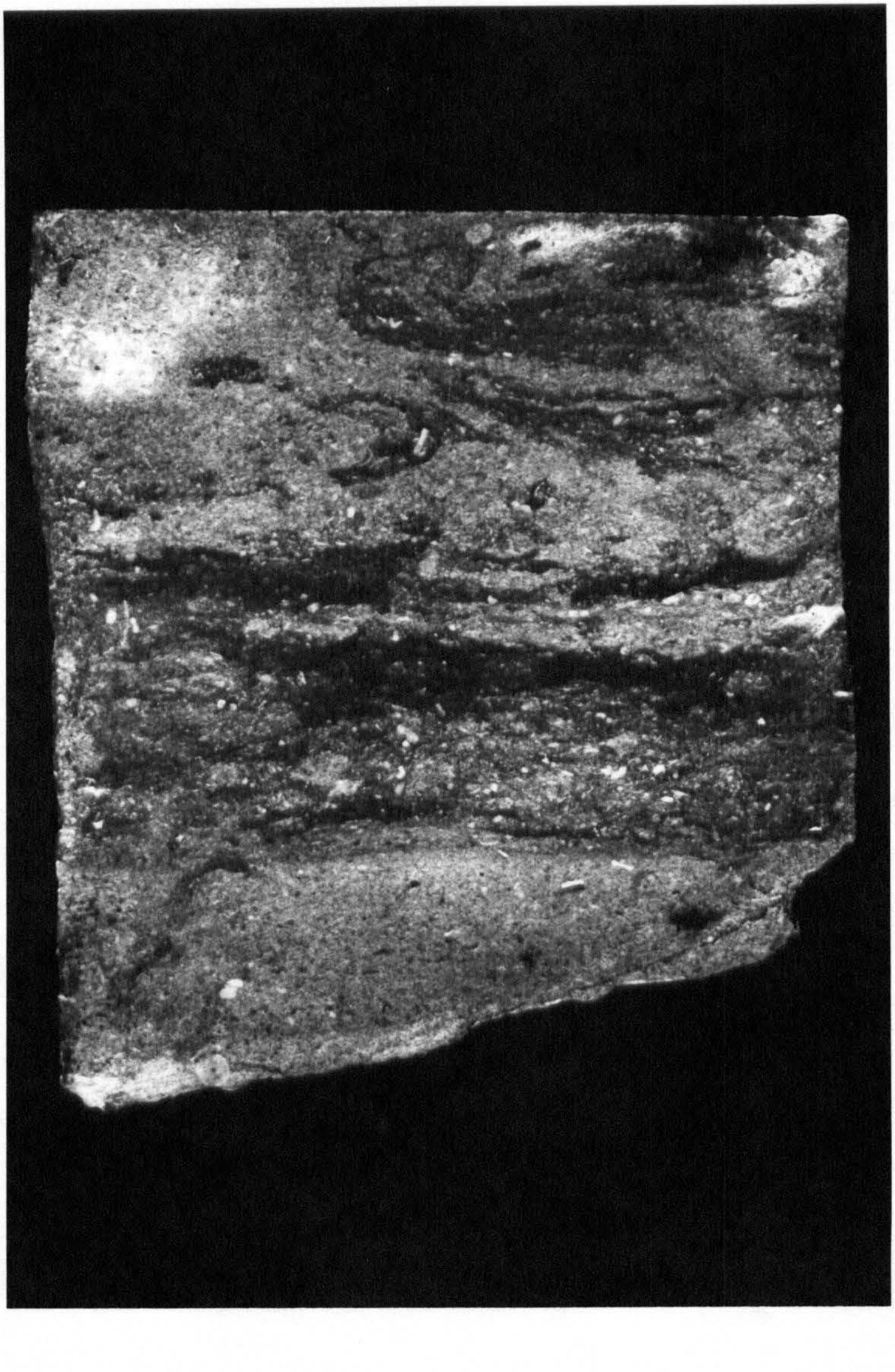
The matrix of the subtidal facies consists primarily of micrite. Subsequent diagenesis has partially dolomitized much of this micrite matrix. The argillaceous content of the facies increases near the contact with the underlying Bottineau interval (Figure 13).

Environmental Interpretation

Based on the whole rugose corals and brachiopods in a mud matrix, the subtidal facies is interpreted to have been deposited in a very shallow, low energy, open marine shelf environment. The presence of bioturbation, large amounts of crinoid, rugose coral and brachiopod debris indicates the shallow water depth. The predominate wackestone and packstone fabric also indicates shallow water deposition (Wilson, 1975, p. 65; Milner, 1976; Handford, 1978).

The presence of occasional grainstones, oolites and mudstones are the result of local variations in the environment. These variations may be the result of: water depth caused by bottom topography; biologic production or bioturbation; sedimentation rates; chemical changes caused by variation in water depth or bottom topography or both. The high clay concentration found only at the base of this facies is the result of a decrease in clasic input that had continued from Bottineau interval sedimentation (Heck, 1979) to early Tilston sedimentation.

Fig. 13. Core slab of argillaceous wackestone near the base of the Tilston interval. Width of core slab is 3.5 inches.



Shoal Facies

Location

The shoal facies is stratigraphically above and interfingers with the subtidal facies. It ranges from 0 to 80 feet thick. The best developed shoal facies is found in the central portion of the study area, where the oolites and grainstones are thickest and most abundant (Figure 11). There are no core samples available from the shoal facies, and the lithologies were determined from well cuttings. Fuller (1956) and McCabe (1959) have described oolitic shoals at this same stratigraphic level in Manitoba and Saskatchewan.

Lithology and Fauna

The shoal facies is predominantly composed of grainstone, both skeletal and oolitic. Some mudstone, wackestone, and packstone are also present in this facies. In thin sections, the grains occasionally show evidence of banding or superficial coatings. A spherical grain grainstones with a clear dolomite cement and packstones with high spherical moldic porosity were considered to have been oolitic packstones.

The skeletal allochems in the skeletal grainstones are abraded and show evidence of rounding. Again, as with the oolitic grainstones, the grains are cemented with a clear primary dolomite cement. The predominate skeletal allochem is crinoidal. Lesser amounts of brachiopod and rugose coral allochems are present.

Environmental Interpretation

The shoal facies is interpreted to have been deposited in normal marine shallow water. Modern oolites from Bahama have been found to be forming in less than six feet of water (Purdy, 1963). Also Newell and others (1960) have concluded that optimum oolite growth occurs in a heated, shallow water turbulent environment that has normal marine water or current movement through the shoal. If this analog can be applied to the Tilston oolites, then they, too, indicate an agitated environment with a water depth of six feet or less.

The presence of grainstones and mudstones within the facies indicates fluctuations in water depth, sedimentation rates, or chemical environment.

The few mudstones which occur may be interpreted as a supratidal or tidal flat deposits caused by emergence due to a further drop in sea level or by sediment accumulation. Handford (1978) has found supratidal mudstones capping oolitic shoals in the Mississippian of the Cumberland Plateau. Alternately, the mudstones may represent an interfingering relationship of the tidal flat facies with the shoal facies. It is also possible that the mudstones may be a lagoonal deposit, such as those found landward of modern shoals (Wilson, 1975, Figure II-4).

Tidal Flat Facies

Location

The tidal flat facies is located stratigraphically above and shoreward of the shoal facies and ranges from 0 to 65 feet thick. The thickest and best developed sediment of the tidal flat facies is found in the southern portion of the study area (Figure 12).

Lithology and Fauna

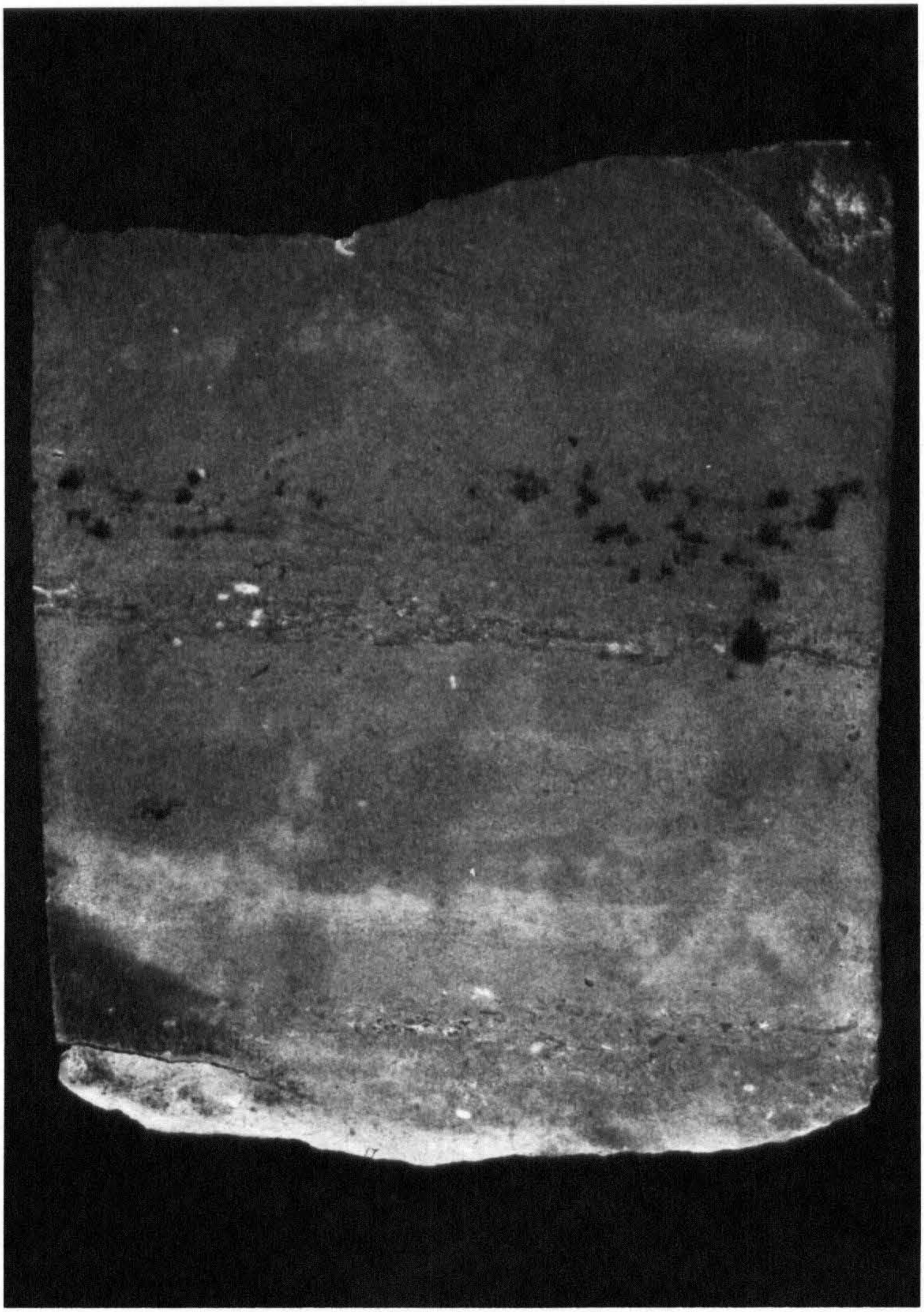
The tidal flat facies is composed primarily of mudstone. Core samples from this facies reveal a high percentage of anhydrite, particularly near the upper portions. A few wackestones and packstones, and, rarely, grainstones are also found within the tidal flat facies. The mudstones are usually fine-grained and are commonly bioturbated. These mudstones also exhibit desiccation cracks, especially in the upper portions of the facies.

Core from NDGS Well No. 961, located in Bottineau County, North Dakota, from a depth of 3017 feet, shows a cyclical and gradational pattern from a grainstone to a mudstone (Figure 14). Later cycles, however, are not as well-defined. The sediments in this cyclic section show evidence of bioturbation as well as mechanically abraded skeletal allochems.

Anhydrite is found throughout the tidal flat facies. It is present as an infilling in desiccation cracks and solution porosity, and also as nodules. The anhydrite is abundant in the upper portions of the facies where it commonly appears as nodules and, occasionally, interbedded with dolomitic mudstone.

The tidal flat facies contains a few skeletal allochems consisting primarily of abraded crinoid fragments. Brachiopods are also found on bedding planes, and exhibit evidence of abrasion. Some broken fragments of rugose coral are also found within this facies. Ostracods are common in this portion of the Tilston interval.

Fig. 14. Core slab of cyclical and gradational pattern from a grainstone to a mudstone. Width of core slab is 3.5 inches.



Environmental Interpretation

This facies is interpreted as having been deposited in a tidal flat environment as based on the occurrence of fine-grained dolomitic mudstone, the presence of anhydrite, and the sparsity of skeletal allochems, and also on its stratigraphic position between the shoal facies and supratidal facies.

The cyclic pattern discussed in the previous section indicates the slightly fluctuating environment. The grainstones indicate an environment, such as a beach or bar, with sufficient energy to remove the fine-grained sediments (Gerhard, In Press). Fluctuations of sea level, or possibly bar migration, created conditions conducive to deposition of finer grained sediments. Biologic activity probably aided in the formation of the gradational cycles.

Alternately this cyclic pattern may also have been developed within a tidal pond. During periods of very high tides or storms the sediments were suspended, or the muds were winnowed out, resulting in a grainstone or packstone. As the water receded, tidal ponds were formed in depressed areas and later bioturbation, or settling rates or both resulted in the formation of the gradational texture. This latter interpretation, however, does not appear as likely since, during the length of time the tidal pond was in existence, the burrowing or browsing organisms should have caused the entire sequence to become homogenous.

The presence of anhydrite within this facies suggests some restriction of normal marine circulation. Wilson (1975, p. 68-69) has applied some of the characteristic features of this environment to the restricted marine, protected environment, such as tidal ponds, pools, flats and channels. Laporte (1967) has also described the intertidal environment having calcarenites contained within mudstone. Roehl (1967) has described graded bedding from the Andros Island, Bahama, as follows: ". . . (T)he gradual reduction of shelf flow and current velocity results in the deposition of graded bedding." Butler (1969), working in the Arabian Trucial Coast, as well as Kahle and Floyd (1971), have also noted the dolomitic mudstone and anhydrite association in a tidal flat environment.

Supratidal Anhydrite Facies

Location

The supratidal anhydrite facies is located stratigraphically above and lateral to the tidal flat facies and is the uppermost facies of the Tilston interval. The T-2 unit consists primarily of this facies and the upper portion of the tidal flat facies. The supratidal anhydrite facies ranges in thickness from 0 to 40 feet thick.

Lithology and Fauna

This facies is composed primarily of anhydrite with increasing carbonate mudstone in the lower portions of the facies. The anhydrites occur in three main forms. The most abundant is "chicken wire" anhydrite. These anhydrites are almost pure, with the only carbonate being a fine-grained dolomitic mudstone, causing the chicken wire texture. The second most abundant form is anhydrite interbedded with fine-grained dolomitic mudstone. The third form of anhydrite occurs as infilling burrows, solution pores, and desiccation features. There appears to be a gradation from the burrow and desiccation infilling to laminated anhydrites and carbonates to almost pure anhydrites.

Skeletal allochems are rare within the supratidal anhydrite facies, occurring only in the basal portion. The most common skeletal allochems are crinoidal debris and rare brachiopods. Occasionally ostracods are abundant, usually in areas of increased argillaceous content. The ostracods probably lived in tidal ponds or pools.

Environmental Interpretation

The supratidal anhydrite facies is interpreted to have been deposited in a sabhka-type environment. The presence of nodular anhydrite has been found to be a common occurrence in the modern sabhka environments of the Persian Gulf (DeGroot, 1973) and the Trucial Coast, Arabian Gulf (Butler, 1969). Roehl (1967) has interpreted the nodular anhydrite to have developed within a supratidal environment. Although the laminated anhydrite may indicate a subtidal origin (King, 1947) the association with nodular anhydrite, dolomitic mudstone, and desiccation features gives credence to origin in a supratidal environment. The sparsity of skeletal allochems and the small amount of carbonate found within these facies are also indicative of this environment (Wilson, 1975, p. 27).

Geographically Restricted Facies

The two geographically restricted facies, lagoonal and clastic facies, are restricted to the extreme southeastern portion of the study area. The anhydrites of the T-2 unit are not present in this area and the clastic facies overlies the lagoonal facies (Figure 12).

Lagoonal Facies

Location

The lagoonal facies is located laterally within the shoal facies in Logan County, North Dakota (Figure 12). This facies bisects the shoal facies in NDGS Well No. 590. In this well, the entire Tilston section below the clastic facies is composed of the lagoonal facies. To the east, the lagoonal facies is found to lie stratigraphically above the shoal facies and below the clastic facies.

Lithology and Fauna

The lagoonal facies is composed entirely of mudstone. Few skeletal allochems are found, and, when present, are mainly crinoidal allochems. If core becomes available, however, it may reveal a more varied lithology and more abundant skeletal allochems.

Environmental Interpretation

This facies is interpreted to have been deposited in a shallow, subtidal, protected lagoonal environment. It is associated with oolites both shoreward and seaward suggesting that this facies was deposited within an oolitic shoal area. The shoals provided the protection from wave or current energy, thus enabling the formation of a lagoon. The homogenous mudstone found within the lagoonal facies is indicative of a lower energy, protected environment (Wilson, 1975, p. 68; Purdy, 1963).

Clastic Facies

Location

The clastic facies is restricted to Logan County, North Dakota and appears to be stratigraphically equivalent to the supratidal anhydrite facies. The clastic facies overlies the lagoonal facies, and in turn is overlain by Frobisher-Alida rocks, except at the erosional subcrop (Figure 12).

Lithology and Fauna

The clastic facies is composed predominantly of iron-stained sand, silt and clay. A few carbonate chips were also found within this facies which are commonly stained red, pink, or maroon, and consist of mudstone or wackestone. Due to the lack of core, it could not be determined if these carbonate chips were from the Tilston or the Frobisher-Alida interval.

Environmental Interpretation

The clastic facies is interpreted to have been deposited nearshore in a fluvial or deltaic environment. The red bed type staining and lithology indicate a nearshore environment (Todd, 1976). If the carbonate chips are from this section, their presence may indicate an interfingering facies relationship between the clastics and the carbonates. At times of higher water level, the environment was conducive to carbonate deposition; during periods of lower sea level, the clastic sand, silt, and clay were deposited.

Because the clastic facies was found in adjacent wells, all of which were overlain by Frobisher-Alida sediments, the author is assuming that the clastics are of Tilston age. However, because the clastics occur at the top of the section, it is possible that they could be a basal facies of the Frobisher-Alida. McCabe (1959) has also noted a clastic facies of the supratidal facies in Manitoba.

In the extreme southeastern portion of the study area, at NDGS Well No. 1835, Logan County, there is documented evidence of karst development (Carlson, 1958; Ballard, 1963). The clastics from NDGS Well No. 1346 were initially thought to be caused by weathering and subsequent deposition of iron stained clastics, such as were found in Well No. 1835. However, the mechanical logs show normal curves both above and below the clastic facies in the Tilston and Frobisher-Alida intervals. The clastics can also be correlated through surrounding wells, both by mechanical logs and samples, and are found at the same stratigraphic level.

PALEOGEOGRAPHY

The sediments of the Tilston interval have a two-fold distribution pattern. The sediments thin and environmentally shallow from west to east, and also from north to south. The west to east shallowing is evident from the facies distribution. During early Tilston deposition, the western portion of the study area was a shallow subtidal environment, with a shoal environment to the east. Near the shoreline was the tidal flat environment, and the sabhka environment was to the east of the tidal flat environment.

The second, less obvious, shallowing was from north to south. In the northern portion of the subtidal facies, the thickest and deepest water facies of the Tilston interval is found. The subtidal facies thins to the south. The shoal facies is best developed in the central portion of the study area and the tidal flat facies is thickest in the southern portion. The clastic facies is also found in the southern portion of the study area. Fuller (1956) and McCabe (1959) have also noted this thinning and shallowing in the Canadian portions of the Williston basin.

The north to south shallowing is interpreted to be the result of the fact that the Tilston depocenter was located in Bottineau County, North Dakota. The deepest area, penetrated by the Blanche Thompson NDGS Well No. 38 in Bottineau County, was proposed to have been the result of salt solution (Anderson, 1958; Anderson and Hunt, 1964; Carlson and Anderson, 1966). This greater water depth was too deep to allow major shoal development and resulted in the deposition of thicker subtidal sediments.

The Tilston rocks are thickest throughout the northern portion and thin to the south and to the east (Figure 4). This thickening near the international border has also been noted by Porter (1955) in Saskatchewan, where the sediments thin to the north. This same series of facies has been described by Thomas (1954), Fuller (1956), McCabe (1959) and Thames (1959) for the MC-1 (T-2 of this report) and MC-2 (T-2) beds of Saskatchewan and Manitoba. Kent (1974) noted the same facies distribution in western Saskatchewan, except the supratidal anhydrite facies was not deposited.

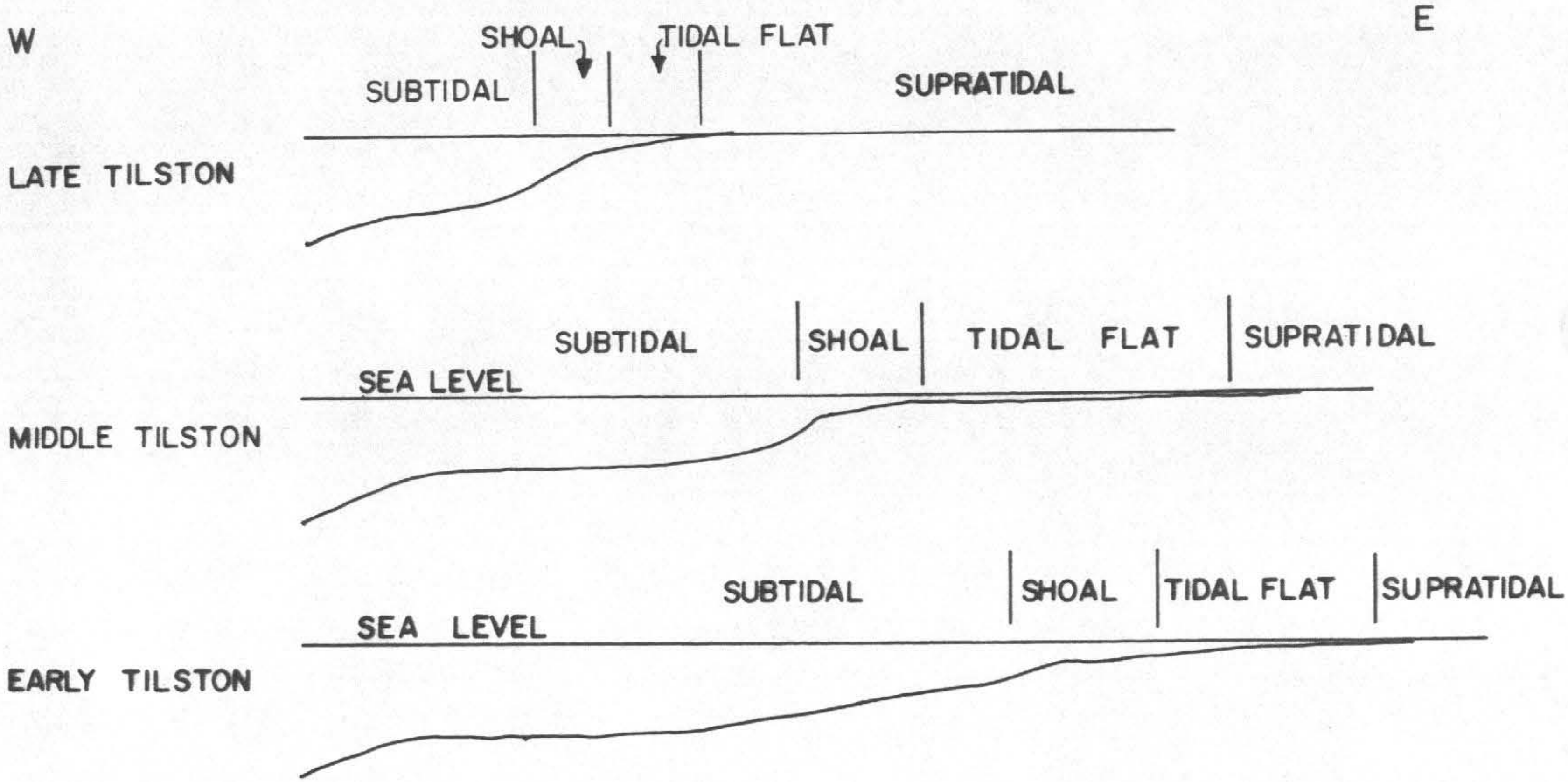
In the central portion of the study area, the water became shallow enough to provide the thicker oolite shoals and grainstones. The shoal facies is best developed here.

Further south, the water was too shallow, or the physical or chemical conditions were not conducive to thick subtidal or shoal facies development. This is also indicated by the thicker tidal flat facies and the occurrence of the red bed clastic facies and lagoonal facies located in this portion of the study area.

These facies distributions and lithologies are a result of regression during deposition of the Tilston interval (Figure 15). This has also been reported by previous authors (Fuller, 1956; McCabe, 1959; Carlson and Anderson, 1966).

The basal sediments were deposited on a broad, shallow open marine shelf. Shaw (1964, p. 5), Irwin (1965) and Wilson (1975) have interpreted the ancient shelves and platforms to have been broad,

Fig. 15. Diagrammatic illustration of the gradual regression during the Tilston interval.


W
E
SHOAL
TIDAL FLAT
SUBTIDAL
SUPRATIDAL
LATE TILSTON
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SEA LEVEL
MIDDLE TILSTON
SUBTIDAL
SHOAL
TIDAL FLAT
SUPRATIDAL
SEA LEVEL
EARLY TILSTON

shallow, low slopes, a few tens of meters deep and hundreds of miles wide, with low wave and current energy. This conclusion seems reasonable when one realizes how a slight change in the physical, chemical, or biological environment can effect large areas.

Wilson (1975, p. 42) has described a general regressive sequence model for epeiric seas to be a succession from lime muds to grainstones, overlain by mud which is capped by evaporites. The predominant lithology, packstone and wackestone, indicates deposition in a low energy, open marine environment. However, the oolites and grainstones indicate the existence of areas of shallower depth, with higher energy. The transition from a lower energy to a higher energy environment implies an increase in wave or current energy caused by a decrease in water depth due to a drop in sea level or progradation or both. Shaw (1964) postulates that winds may have created local high energy environments.

The predominant lithology above the shoal facies is a mudstone which, in places, contains secondary anhydrite infilling. This facies indicates a continual decrease in water depth or progradation, coupled with restricted circulation which would allow precipitation of the evaporites. It is possible that the shoals provided the barrier which would allow an increase in salinity. However, it is also possible that the low slopes of the epeiric seas may have caused the high salinity (Shaw, 1964). These factors, taken in conjunction with the transition from subtidal to shoal deposits, give credence to the regressive nature of the Tilston seas on the eastern margin of the Williston basin.

The deposition of supratidal anhydrites marks the final stage of Tilston regression. The westernmost extent of the anhydrites is interpreted to indicate the position of the shelf break. Beyond this point, the deeper water precluded the precipitation of anhydrite because normal marine circulation did not permit the increased salinity necessary for the precipitation of anhydrites.

A probable sequence of events is as follows:

1. Regression from the northeast (Porter, 1955; McCabe, 1959; Carlson and Anderson, 1966) began during Bottineau interval sedimentation (Heck, 1979).

2. Tilston interval sedimentation began in a shallow, low energy, open marine environment, with initial sediments having a higher clastic content.

3. With continual regression, sea level had dropped, permitting areas to be developed into oolitic shoals and permitting deposition of grainstones, and, possibly, still permitting normal marine deposition landward in lagoonal areas.

4. With further regression, possibly aided by progradation of sediments, a tidal flat environment was created.

5. With continued regression or progradation or both, restricted marine circulation resulted in the increased salinity indicated by the presence of the evaporites found within the upper portions of the tidal flat facies.

6. Tilston deposition ended during a final regressive phase, permitting the deposition of supratidal sabhka sediments over much of the eastern flank of the Williston basin of North Dakota and Canada.

7. A transgression permitted the deposition of the sediments of the overlying Frobisher-Alida interval.

PETROLEUM POTENTIAL

General Statement

As of January 1, 1979, the Tilston interval has produced 710,090 barrels of oil from the North Souris Field in Bottineau County, North Dakota (North Dakota Geological Survey, 1979). In Manitoba, 416,742 barrels have been produced from the Tilston as of June 1, 1978 (McCabe, written communication) and as of January 1, 1978, 19,180,891 barrels have been produced in Saskatchewan from the interval (Gillard, written communication). Also in Saskatchewan as of January 1, 1978, the Alida-Tilston undifferentiated has produced 3,099,194 barrels and 16,379,721 barrels from the Tilston-Souris Valley undifferentiated (Gillard, written communication). Although there have been a few shows from the Tilston scattered throughout the study area, the shows have generally been poor (Scott, 1963) (Figure 1).

Fuller (1956) has described four characteristics of Tilston petroleum occurrence in Saskatchewan: (1) oil is trapped in a southwest-northeast direction, structurally high, but stratigraphically low within the section; (2) pools are found in oolitic facies below anhydrite; (3) pools are trapped by updip porosity barriers due to secondary alternations, and (4) gravity of oil declines in a northeast-southwest direction (to the southwest). Christopher, Kent and Simpson (1971) state that updip porosity change and updip anhydrite infilling are characteristics within the Mississippian sediments which are conducive to petroleum entrapment. Anderson (1958) has also discussed characteristics of Mississippian strata which indicate its potential for petroleum occurrences. They are: (1) updip facies change from porous limestone to anhydrite, or porous limestone to dense limestone, (2) porous horizons associated with structure, (3) wedge-out of Mississippian sediments at the unconformity. In addition McCabe (1959) states that in the eastern flank of the Williston basin a topographic high with greater than twenty five feet per mile of updip closure would constitute a potential trap.

The Tilston interval has many of the characteristics described above which are associated with petroleum occurrence. The anhydrites of the T-2 unit may act as an impermeable barrier to vertical migration, also creating a channeling effect on petroleum migration. If any hydrocarbons are introduced into the Tilston in the west they must migrate under the anhydrites of the T-2 unit. There are facies changes from porous to dense limestones as well as porosity changes caused by the deposition of secondary anhydrite. There are oolitic shoals and grainstones within the Tilston interval and these types of rocks have produced reservoir strata elsewhere (Choquette and Traut, 1963; Cussey and Friedman, 1977). The subcrop area of the Tilston interval has been exposed to secondary alteration, causing both fresh water diagenetic changes as well as deposition of a secondary anhydrite seal over the sediments at the unconformity. Cussey and Friedman (1977) and Gerhard and others (1978) have noted that phreatic fresh water diagenesis yields good preserved porosity.

To assess the petroleum potential of the Tilston interval in North Dakota, the author looked for four possible types of hydrocarbon entrapment. They are: (1) paleogeomorphic trap, (2) wedge-out at the unconformity, (3) structural closure with an anhydrite cap, (4) updip facies change. There is also the possibility that combinations of the above-mentioned types of traps exist within the interval. In determining the petroleum potential of the Tilston, the author constructed cross-sections of mechanical logs from the study area, and looked for areas where porosity zones or areas might be conducive to hydrocarbon entrapment. McCabe (1959) states that the low argillaceous content of the carbonates makes the resistivity curve an important tool for the exploration of petroleum in the Mississippian rocks in that it may be used as an indicator of porosity.

Migration

Meissner (1978), Dow (1974) and Williams (1974) describe the Bakken Formation as the source rock for Madison oil. In their studies, these authors have illustrated the areas in which the Bakken has been subjected to sufficient heat and pressure to expel the hydrocarbons (Figure 16). Dow (1974) describes the migration path of the Bakken oil within the Williston Basin. Meissner and Dow both postulate that the oil migrated vertically through fractures from the Bakken to the Poplar evaporites. When the hydrocarbons reached this impermeable barrier, they migrated laterally beneath the evaporite seal. The petroleum was trapped in areas of structural close or at the unconformity.

The question which arises is whether hydrocarbons were ever introduced into the presently non-producing areas of the Tilston. According to Dow (1974), only the northern portion of the study area received hydrocarbons (Figure 17). If Dow is correct, no hydrocarbon reservoirs may be expected outside of this area. However, although there is no established production outside Dow's area, there have been scattered shows throughout the study area. Furthermore, some oil has been recovered from southeastern Morton County, North Dakota, which is east and south of Dow's projected limit of hydrocarbon migration (Figure 1).

If the scattered shows in the study area can be taken as an indication that there has been more extensive hydrocarbon migration into other portions of the study area, then there remains the possibility of the discovery of petroleum reservoirs, albeit the likelihood of discovering a large field within the study area is small. In the following portions of this report, the author will optimistically assume, for purposes of discussion, that hydrocarbons may be found within the study area.

Paleogeomorphic Trap

The importance of the paleogeomorphic type of entrapment is evident when one considers the fact that the existing Tilston production in North Dakota, Manitoba and Saskatchewan is from this type of trap. Miller (1972) offers a good review of the methods of exploration for the paleogeomorphic type of trap. The most convenient tool for exploration for this type of trap is the isopachous map.

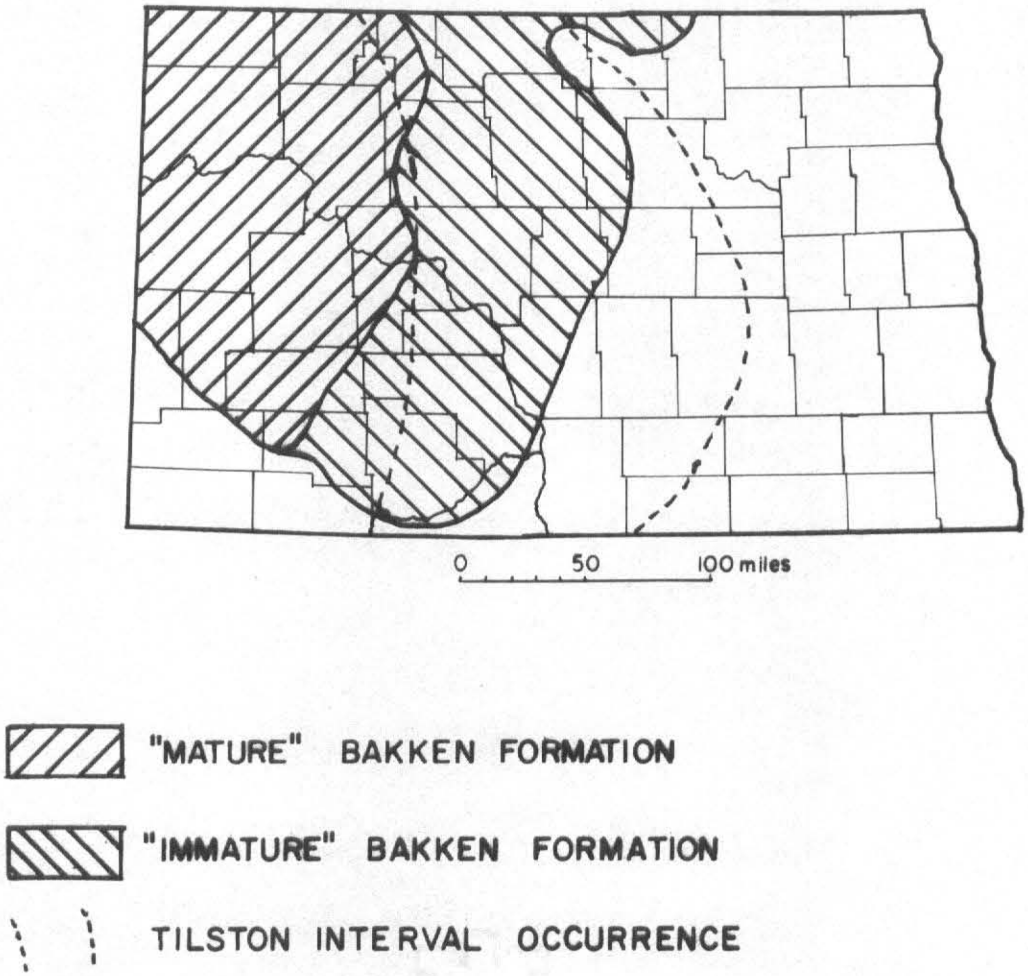

Fig. 16. The areal extent of the Bakken Formation in North Dakota and interpreted source-rock "maturity" (after Meissner, 1978).

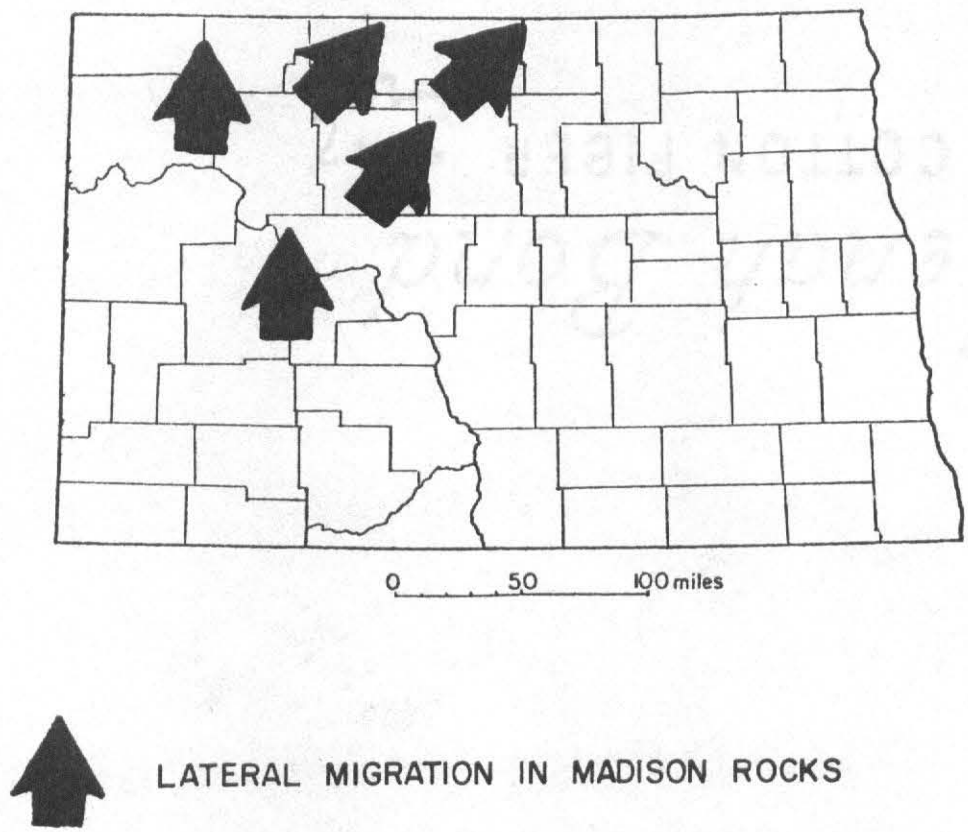

Fig. 17. Lateral hydrocarbon migration paths in Madison rocks (after Dow, 1974).

The paleogeomorphic type of trap is formed by erosion of the Tilston sediments by fluvial or terrestrial processes. This erosion creates a high, or cuesta, adjacent to erosional channels. Subsequent deposition of overlying impervious Mesozoic sediments creates the capping mechanism for the trap (Figure 18). Given the presence of a carbonate with sufficient porosity, a hydrocarbon reservoir is then formed, capped by the Mesozoic strata. Miller (1972) notes that weathering of the exposed zone has also enhanced the porosity of the potential reservoir rocks. This enhancement of porosity by subaerial diagenesis is also supported by research by Gerhard and others (1978) and Cussey and Friedman (1977).

To assess the possibility of the existence of a paleogeomorphic trap within the study area, the author overlaid an isopachous map of the overlying Mesozoic sediments on an isopachous map of the Tilston interval (Figures 19, 20). The areas of interest are where thick Tilston rocks are overlain by thin Mesozoic rocks.

In the northern one-third of the subcrop, the Tilston is overlain by Triassic rocks, and in the southern two-thirds the Tilston is overlain by rocks of Jurassic age. The Triassic Spearfish Formation was used for the Triassic isopachous map. The values expressed by the Jurassic contour lines are based on a marker that could be correlated throughout that portion of the subcrop.

Isopachous mapping of the Tilston interval subcrop and the Triassic Spearfish Formation reveals two potential areas for hydrocarbon entrapment by a paleogeomorphic type of trap (Figure 19). The first area is in northern Bottineau County, North Dakota, which

PALEOGEOMORPHIC TRAP AT THE TILSTON SUBCROP

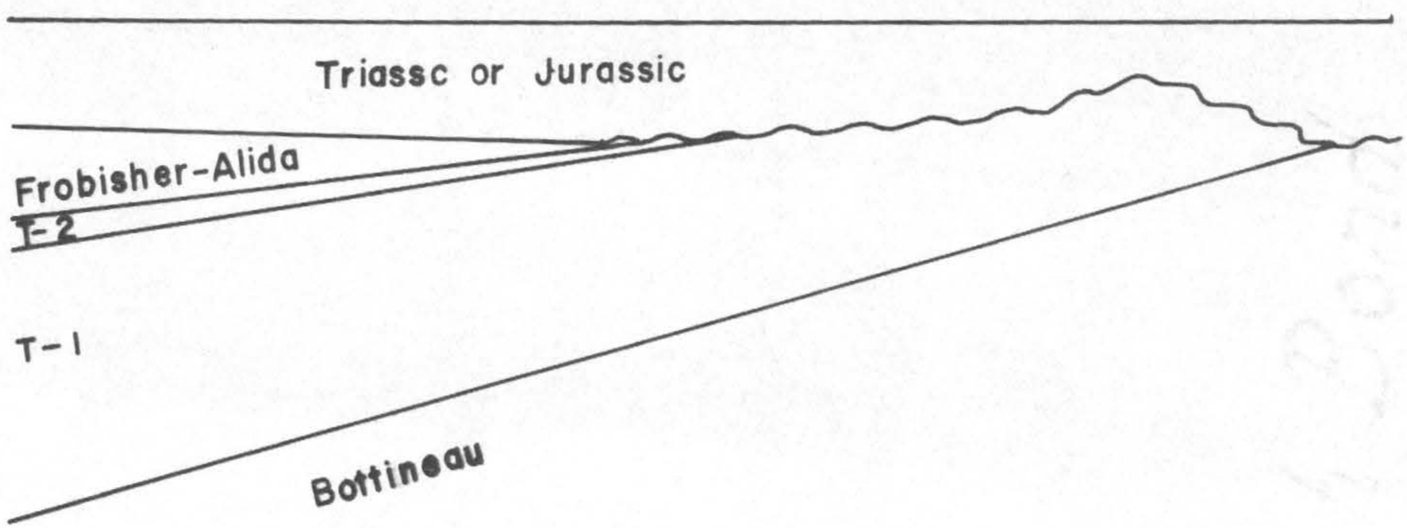

Fig. 18. Diagrammatic cross-section where hydrocarbons are trapped in a cuesta (topographic high) created by differential erosion at the Tilston interval subcrop.

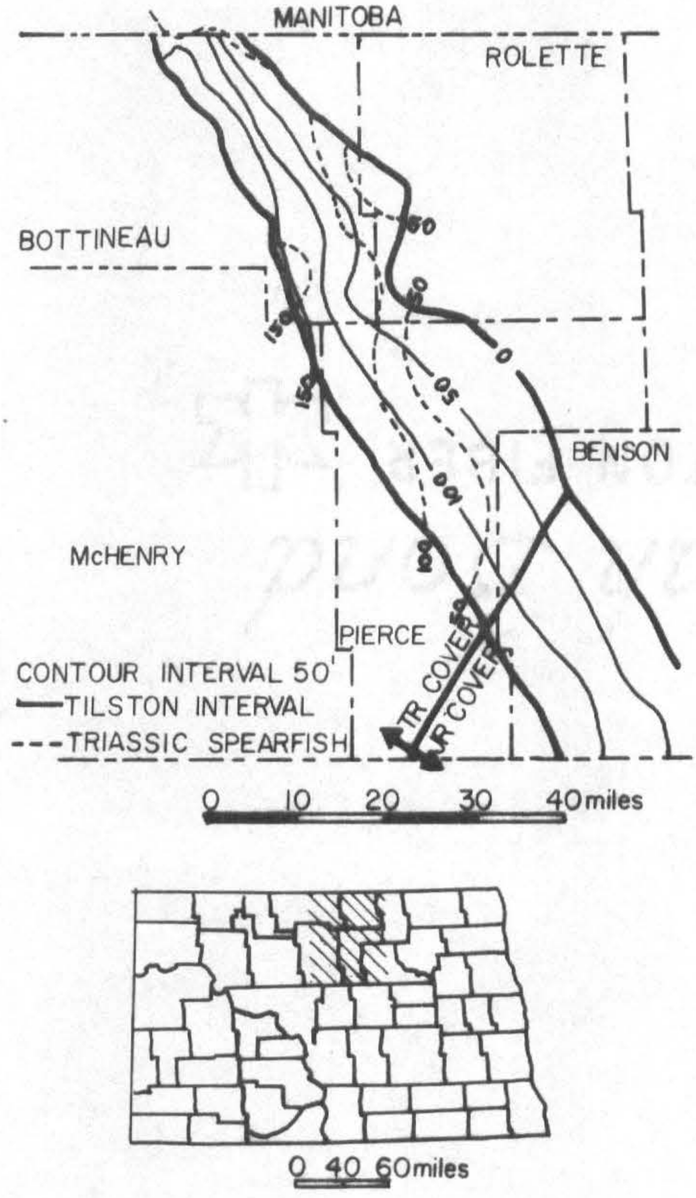

Fig. 19. Isopachous map of the Tilston interval and the Traissic Spearfish Formation in the northern one-third of the Tilston interval subcrop.

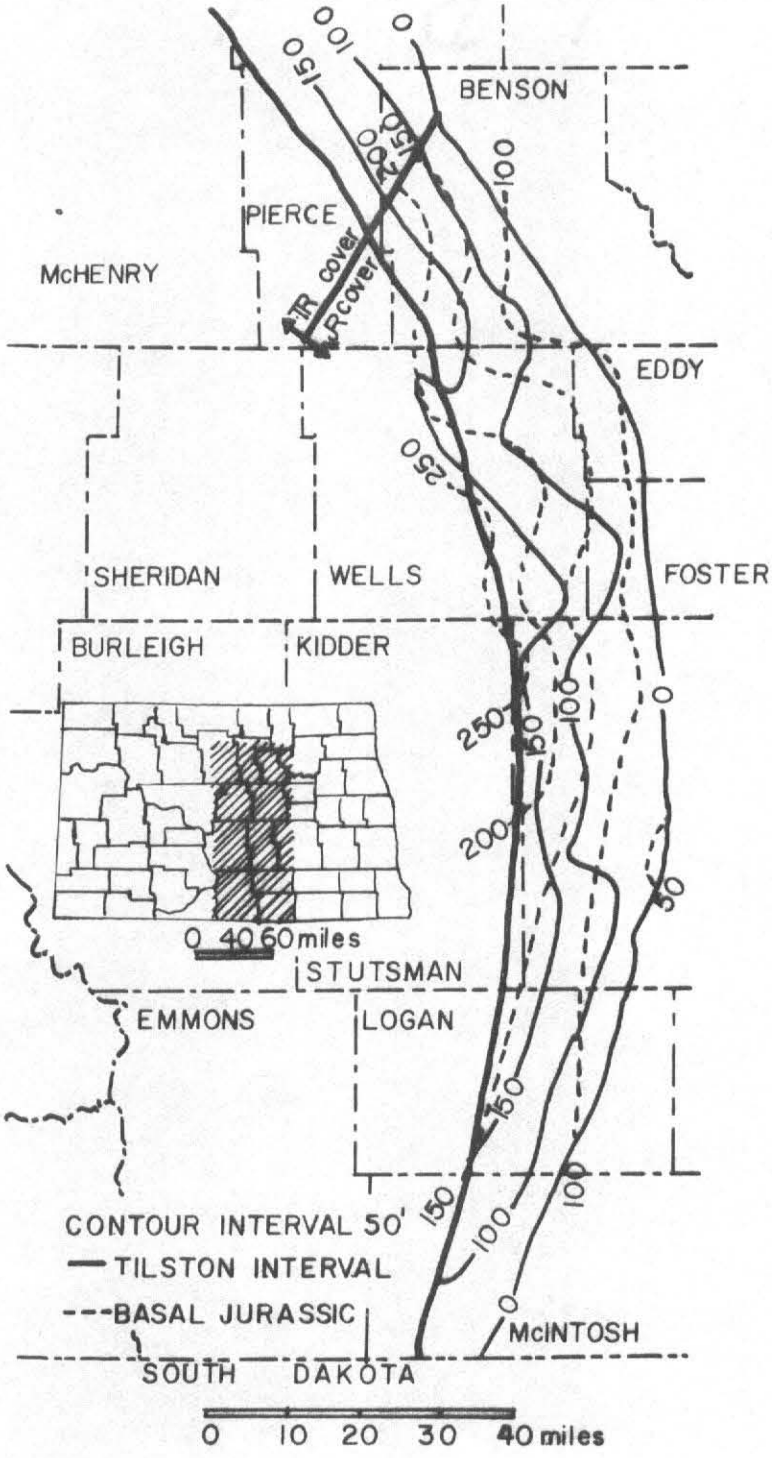

Fig. 20. Isopachous map of the Tilston interval and the basal Jurassic rocks in the southern two-thirds of the Tilston interval subcrop.

is the area of the North Souris Field. As can be observed from the map, the contour lines indicate thick Tilston rocks and thin Spearfish rocks. The second area is in southeastern Bottineau County, where a bending of the contour lines indicates a thick Tilston and thin Spearfish.

In the southern portion there are again two areas of possible interest (Figure 20). The first area is in southwestern Benson County, North Dakota, and the second area is in southern Foster County, North Dakota, and southern Wells County, North Dakota. There is a possibility of a third area in southern Stutsman County, North Dakota; however, the control for the Jurassic and Tilston contour maps is poor, particularly in the southern portions of the subcrop.

Wedgeout-Type Trap at the Unconformity

The wedgeout trap is formed by pre-Mesozoic erosion, truncating the Tilston and other Mississippian strata, on the eastern portion of the Williston basin (Figure 21). The subsequent deposition of impervious Mesozoic sediments forms the capping mechanism for this type of a trap. Secondary anhydrite deposition may also aid in the formation of the cap in this type of trap. The shale content near the Tilston and at the base of the interval may preclude petroleum migration to the east, out of the Tilston interval, and into the underlying Bottineau interval.

The cross-sections (Figures 22, 23, 24, 25, 26) show that the anhydrites of the T-2 unit form an effective barrier for vertical migration. If migration continued to the subcrop, as is the case in the producing areas, there is potential for hydrocarbon accumulation in the Tilston interval at the subcrop, trapped by a wedgeout type of trap. The mechanical logs indicate that there are some porosity zones in the

WEDGE-OUT AT THE TILSTON SUBCROP WITH IMPERVIOUS MESOZOIC CAP

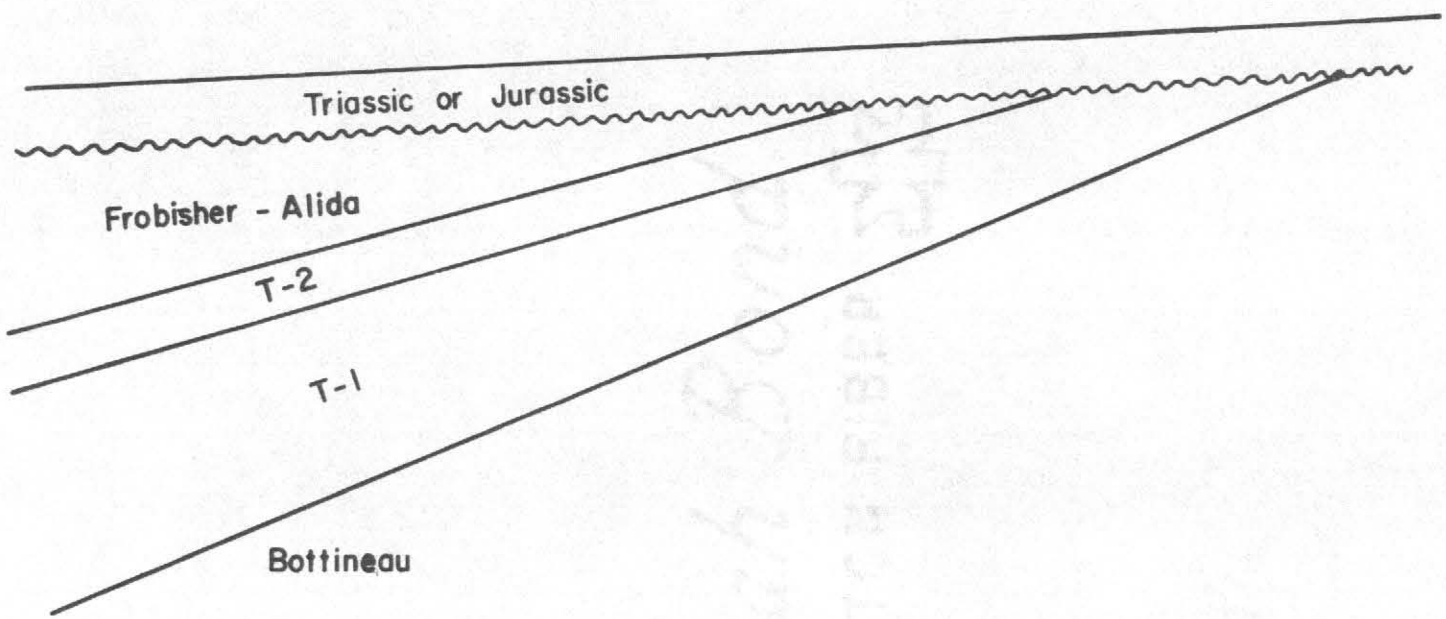

Fig. 21. Diagrammatic cross-section of possible hydrocarbon entrapment in a wedge-out trap formed by pre-Mesozoic uplift and erosion followed by deposition of Mesozoic sediments creating an angular unconformity at the Tilston interval subcrop.

Fig. 22. Index map for the mechanical log cross-sections through central North Dakota.


SASKATCHEWAN
MANITOBA
D
D'
A
A'
BOTTINEAU
ROLETTE
TOWNER
RENVILLE
WARD
McHENRY
PIERCE
BENSON
McLEAN
SHERIDAN
WELLS
EDDY
B
B'
FOSTER
MERCER
OLIVER
BURLEIGH
KIDDER
STUTSMAN
MORTON
C
C'
GRANT
SIOUX
EMMONS
LOGAN
McINTOSH
SOUTH
DAKOTA
0
50
100MILES

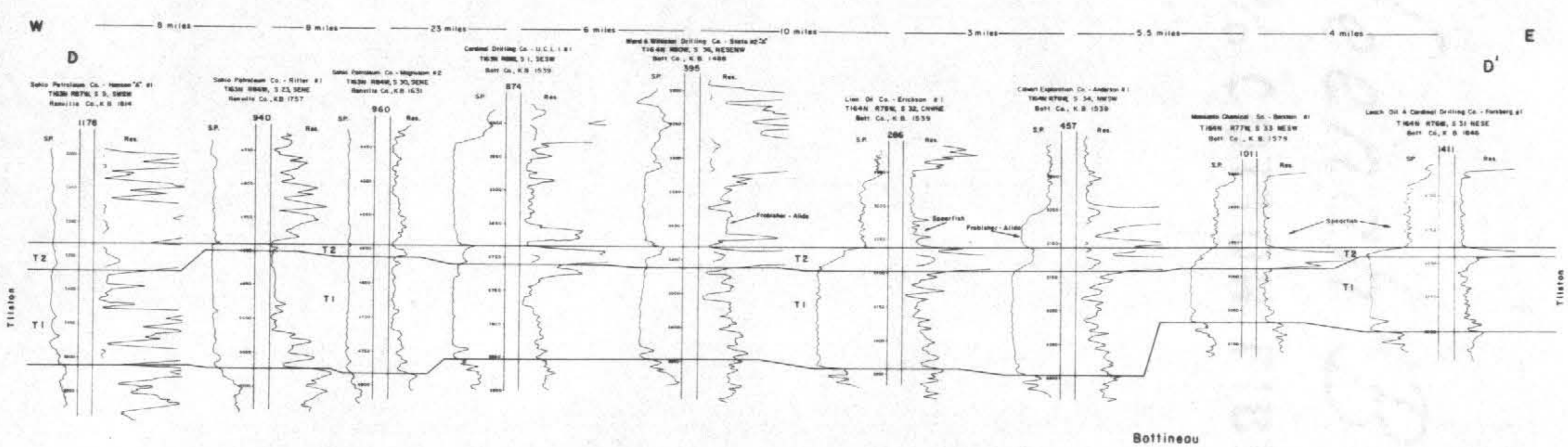

Fig. 23. Mechanical log cross-section D-D' through the extreme northern portion of the study area.

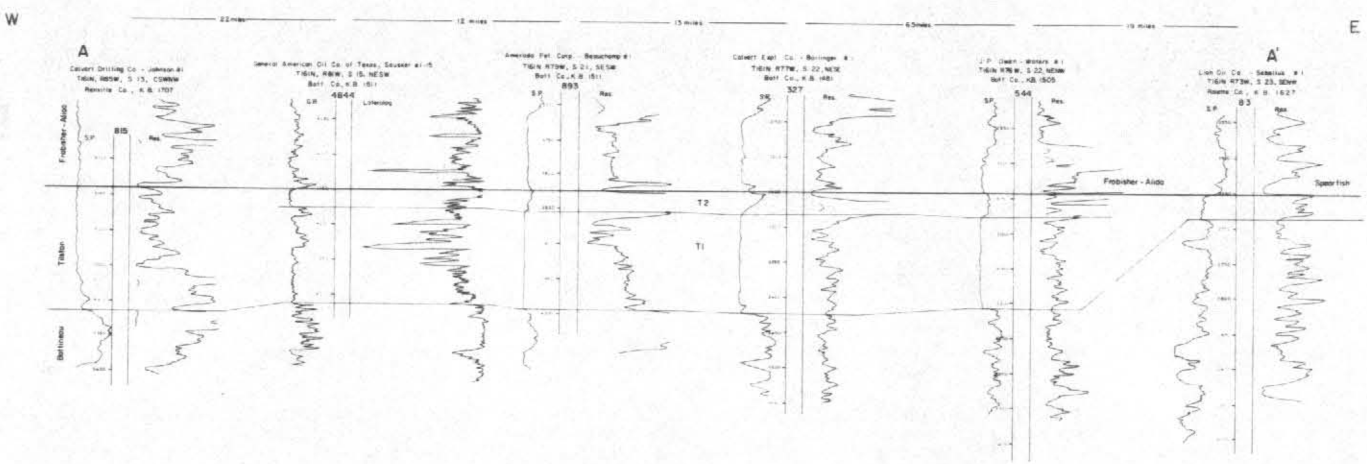

Fig. 24. Mechanical log cross-section A-A' through the northern portion of the study area.

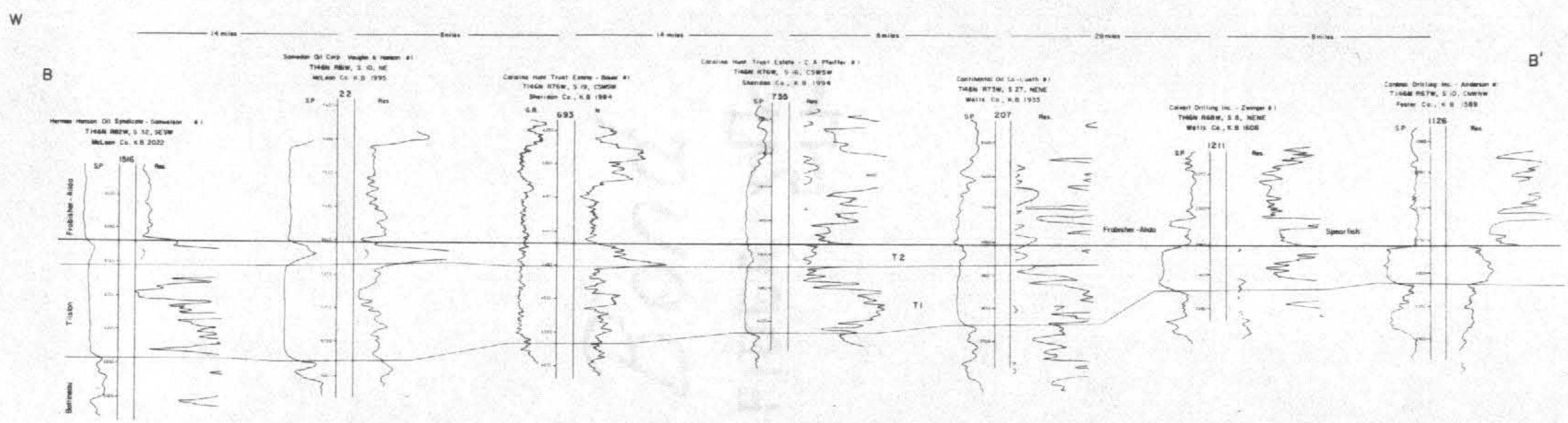

Fig. 25. Mechanical log cross-section B-B' through the central portion of the study area.

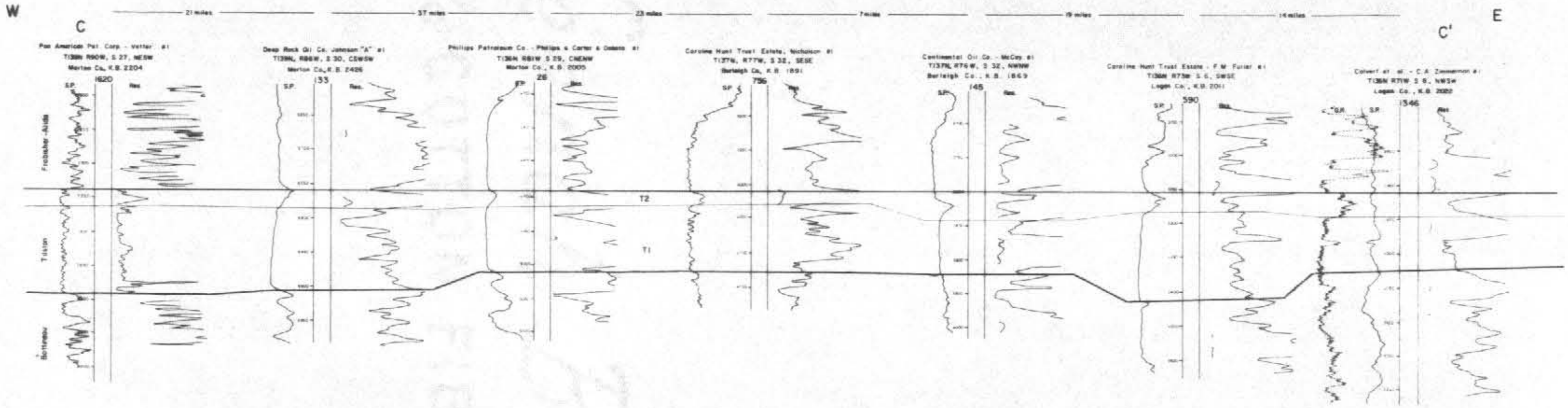

Fig. 26. Mechanical log cross-section C–C' through the southern portion of the study area.

carbonates at the subcrop, and this porosity may be sufficient to form a potential reservoir. The fresh water diagenesis mentioned earlier may also aid in the formation of the reservoir porosity.

An example of the wedgeout type of trap can be observed on the eastern portion of cross-section A-A' (Figure 24). At NDGS Well No. 544 and No. 83, the effect of pre-Mesozoic erosion is apparent. As indicated by the resistivity curve, there may be sufficient porosity to act as a reservoir. In Well No. 83, the resistivity curve indicates a decrease in porosity in the upper portion of the Tilston interval, which may act as the seal for a reservoir.

Structural Closure with Anhydrite Cap

Isostructural mapping of the study area illustrates the bowl-shape nature of the eastern flank of the Williston basin (Figure 5). There is not enough control to determine the amount or extent of small structural closure within the Tilston interval. This does not, however, preclude the possibility of hydrocarbon entrapment by this mechanism.

The mechanical log cross-sections (Figures 23, 24, 25, 26) indicate that there may be sufficient porosity in the carbonates to act as a reservoir. The cap is provided by the anhydrites of the T-2 unit. As noted earlier, if there were any hydrocarbons introduced into the eastern flank of the Williston basin within the Tilston interval, the anhydrite would have a channeling effect on hydrocarbon migration. Assuming the possibility of structural closure, there exists a potential for entrapment within the Tilston interval by this mechanism.

Cross-section D-D' (Figure 23), across the northern portion of the study area, illustrates the possibility of sufficient porosity for a reservoir, particular in NDGS Well No. 940 and NDGS Well No. 960, below the T-2 unit anhydrites. If there is sufficient porosity, the existence of structural closure in this area may form a hydrocarbon trap.

On cross-section B-B' (Figure 25), there are some areas of interest. In NDGS Well No. 1516, the resistivity curve indicates a porosity zone at 6150 feet. In NDGS Well Nos. 693, 735, and 207, there is a porosity zone directly below the T-2 unit. If these curves do indicate sufficient porosity, then any structural closure in these areas may provide a hydrocarbon trap. McCabe (1959) states that only 25 feet per mile of counter regional dip is required to form a reservoir.

In the southern portion of the study area (Cross-section C-C', Figure 26), there may also be sufficient porosity to provide a reservoir. NDGS Wells Nos. 133 and 26 indicate porosity zones directly below the anhydrites. It may be noted at this point that the first Madison recovery in North Dakota was from Well No. 26. It is conceivable that the petroleum recovered from that test may have been trapped by this type of mechanism.

Updip Facies Change

The updip facies change is created by a change in porosity from a porous carbonate downdip to a tight carbonate updip (Figure 27). This may be the result of a change caused by facies migration or by secondary porosity infilling by anhydrite or dolomite.

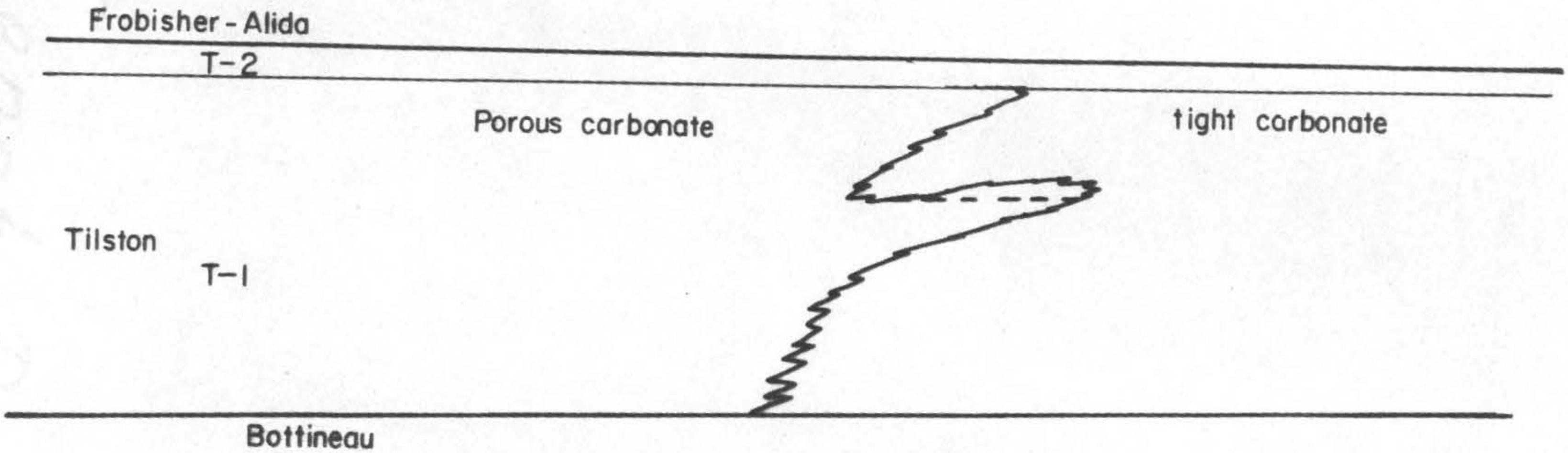

Fig. 27. Diagrammatic cross-section of a stratigraphic trap where a facies change may result in hydrocarbon entrapment due to an updip reduction or loss of porosity.

The mechanical log cross-sections (Figures 24, 25, 26) reveal that a few areas within the study area have the potential for trapping hydrocarbons in this manner. As can be observed in the cross-sections, there are areas in which there is a porosity change from west to east. The porosity zones not only become less porous, but also thin to the east. It is through these porosity "wedgeouts," or "fingers," that the potential for hydrocarbon entrapment by this type of mechanism exists.

In NDGS Well No. 1516 (Cross-section B-B', Figure 25), the porosity zone at 6150 feet becomes less porous to the east. In general, there is an increase in resistivity (decrease in porosity) throughout the entire interval covered on the cross-section. In the area of NDGS Well No. 1211, there appears to be insufficient porosity to allow hydrocarbon migration further to the east. Assuming the existence of lateral closure, there exists a potential for hydrocarbon entrapment by this mechanism.

On cross-section C-C' (Figure 26), the resistivity curve from the well on the extreme western end of the section indicates a large interval which exhibits some porosity. Toward the east, the resistivity again increases, indicating a decreasing porosity. As mentioned previously, Well No. 26 was the first Madison recovery in the state. As can be observed by cross-section C-C', there is an increase in resistivity from the porosity zone in NDGS Well No. 26 to Well No. 756. It is possible that an updip porosity change could be responsible for the hydrocarbons recovered from Well No. 26.

Facies and Porosity Development

The subtidal facies, as determined by well samples and thin sections, reveals very little porosity. There are areas, on the mechanical logs from this facies, however, that indicate some porosity development. This is particularly evident in the western portion of the study area, as can be observed on cross-section C-C' (Figure 26).

In general, the grainstones of the shoal facies correspond to more porous zones on mechanical logs. Thin sections of well cuttings indicate the opposite. The grainstones appear to be tightly cemented by a clear dolomite cement. This discrepancy between the mechanical logs and the thin sections may be the result of the size of the well cuttings studied. Alternately, the mechanical logs may be responding to fractures or some other type of porosity which is not represented in well cuttings. There are areas, as evidenced in well cuttings, where oolites, or other spherical grains, have been dissolved, resulting in very high moldic porosity.

The tidal flat facies usually exhibits some moldic or solution porosity. This porosity is developed throughout the facies. However, only in the lower portions has the porosity been preserved. In the upper portions, secondary cementation, usually composed of anhydrite, has substantially reduced the porosity.

The supratidal facies and the lagoonal facies, as can be observed on mechanical logs or in core or samples, has almost no porosity. It is unlikely that within the supratidal facies any other type of porosity exists. The lagoonal facies, however, may, in areas adjacent to the clastic facies, have some porosity development as the result of fresh water diagenesis.

The clastic facies, as evidenced by the mechanical logs, is generally a porous zone. However, because of the silt and clay content, the permeability may be inadequate for petroleum migration or accumulation.

There is also porosity developed within the Tilston interval that has no relation to the facies. As noted previously, the subcrop portion of the study area has been subaerially exposed. This exposure has resulted in enhanced porosity development, probably by fresh water diagenesis.

Also, the Tilston interval, as well as the entire Madison Formation, has areas or zones where fractures have increased the porosity of the rocks. This fracturing may be important when considering the large portion of the study area in which very few wells have been drilled.

Although there is not sufficient core to determine the extent of dolomitization of the Tilston rocks, this does not mean that porosity development by this mechanism is not important. Thin sections from the Tilston reveal some dolomitization throughout the interval. Usually, however, the dolomitization has effected only the matrix of the rock. It is possible that some areas of the Tilston have undergone extensive dolomitization and that this may have resulted in enhancement of the porosity, which may enable the migration and accumulation of petroleum in certain areas.

CONCLUSIONS

The sediments of the Tilston interval were deposited on a broad, shallow, open marine shelf, and have a two-fold distribution pattern. The rocks thin and environmentally shallow from west to east, and also from north to south. Vertically (from bottom to top), and laterally (from west to east) the facies are: subtidal, shoal, tidal flat, and supratidal anhydrite facies. There are two geographically restricted facies, the lagoonal and clastic facies found only in the southeastern portion of the study area.

The basal facies, the subtidal facies, is composed predominantly of a crinoidal, brachiopod, rugose coral wackestone. Overlying the subtidal facies is the shoal facies, characterized by grainstone, both oolitic and skeletal. The tidal flat facies is located above the shoal facies and consists primarily of mudstone with rare grainstones, packstones and wackestones. The supratidal anhydrite facies is typically the uppermost facies of the Tilston interval. An exception to this is in the southeastern portion of the study area (Logan County) where the clastic facies is the uppermost unit deposited. This facies consists of iron-stained clay, silt and sand.

The facies of the Tilston interval represent a regressive sequence for the eastern flank of the Williston basin. The subtidal facies was deposited in a normal marine environment. The shoal facies was deposited in normal marine very shallow water environment. With further regression, or progradation, or both, a restricted tidal flat environment developed which allowed deposition of mudstone. The final regressive stage is marked by the deposition of the supratidal anhydrites over most of the eastern flank of the Williston basin. The westernmost extent of the Tilston interval is interpreted to be the area in which the Tilston interval is not differentiable from the overlying Frobisher-Alida interval due to the loss of the supratidal anhydrites. This occurs at approximately 102° west longitude. This area is also interpreted to be the location of the shelf break where, because of deeper water, the area had sufficient circulation to prohibit the salinity buildup required for the deposition of evaporitic sediments.

The Tilston interval currently produces petroleum in Manitoba, Saskatchewan and from the North Souris field in Bottineau County, North Dakota. In addition to known production the interval has other characteristics that indicate the possibility for additional production. They are: (1) the interval has scattered shows throughout the study area, (2) the interval contains porous zones or facies, (3) the interval is capped by an impermeable anhydrite, and (4) the interval is associated with an angular unconformity at the subcrop portion of the interval.

Four types of hydrocarbon traps indicate the potential for further production outside the established producing areas. Two types of traps, paleogeomorphic and wedge-out, occur on the subcrop portion of the Tilston interval. These are the result of pre-Mesozoic uplift and erosion followed by deposition of impermeable Mesozoic sediments. This series of events created an angular unconformity and formed the wedge-out type trap. In addition to the formation of an unconformity, erosion at the subcrop resulted in the development of cuestas (topographic highs) adjacent to erosional channels. The subsequent deposition of impervious sediments created the capping strata of the paleogeomorphic type of trap. The third type of trap is due to porous zones or facies capped by impervious anhydrites associated with structure. The fourth type of trap is the result of updip porosity occlusions. The Tilston contains porous zones or facies that pinch out updip. This porosity pinch out is caused by either facies migration or by secondary porosity cementation by either dolomite or anhydrite.

APPENDICES

APPENDIX A

LIST OF WELLS USED IN THIS STUDY

LIST OF WELLS USED IN THIS STUDY

Explanation

The wells used in this study are arranged alphabetically by county and then numerically based on the standard Land Office Grid System. The tops of the units are given as depth in feet from the kelly bushing. The thickness is also given in feet.

BENSON COUNTY

T151N, R69W, S21, NESE, Shell Oil Co. - Christianson Hvinden No. 1
N.D.G.S. No. 561

K.B.	1510		
T-2	2327		
T-1	2340		
Bottineau	2393	Thickness	66

T151N, R70W, S10, CNENW, Shell Oil Co. - Rudolph Gigstad No. 1
N.D.G.S. No. 663

K.B.	1560		
T-1	2502		
Bottineau	2604	Thickness	102

T151N, R71W, S26, SESE, D. D. Bills - Ruben Olson No. 1
N.D.G.S. No. 4108

K.B.	1574		
T-2	2700		
T-1	2720		
Bottineau	2818	Thickness	118

T152N, R69W, S8, NWMW, I. J. Wilhite - Engstrom No. 1
N.D.G.S. No. 5082

K.B.	1613		
T-1	2465		
Bottineau	2492	Thickness	27

T152N, R69W, S21, CSENE, Shell Oil Co. - Eilert Spidahl No. 1
N.D.G.S. No. 654

K.B.	1589		
T-1	2385		
Bottineau	2420	Thickness	35

T163N, R81W, S1, CSESW, Cardinal Drilling Co. - U.C.L.L. No. 1
N.D.G.S. No. 874

K.B.	1508		
T-2	3683		
T-1	3710		
Bottineau	3853	Thickness	170

T164N, R76W, S31, NESE, Leach Oil Co. & Cardinal Drilling Co. - Forsberg No. 1
N.D.G.S. No. 1411

K.B.	1846		
T-2	3177		
T-1	3187		
Bottineau	3300	Thickness	123

T164N, R77W, S33, NWNE, Lion Oil Co. - Skarphol No. 2
N.D.G.S. No. 961

K.B.	1605		
T-2	2964		
T-1	2980		
Bottineau	3080	Thickness	116

T164N, R77W, S33, NESW, Monsanto Chemical Co. - Berstein No. 1
N.D.G.S. No. 1011

K.B.	1579		
T-2	2959		
T-1	2986		
Bottineau	3068	Thickness	109

T164N, R78W, S32, CNWNE, Lion Oil Co. - Hilmer Erickson No. 1
N.D.G.S. No. 286

K.B.	1539		
T-2	3060		
T-1	3097		
Bottineau	3240	Thickness	180

T164N, R78W, S34, NWSW, Calvert Exploration Co. - Anderson No. 1
N.D.G.S. No. 457

K.B.	1539		
T-2	3105		
T-1	3140		
Bottineau	3295	Thickness	190

T153N, R69W, S22, NWNE, Shell Oil Co. - Lars A. Togstad No. 1
N.D.G.S. No. 678

K.B.	1673		
T-1	2474		
Bottineau	2505	Thickness	31

T153N, R71W, S25, SENW, The Superior Oil Co. - Vetter No. 1
N.D.G.S. No. 5204

K.B.	1627
T-2	2690
T-1	2712
T.D.	2760

T154N, R70W, S31, CNWSE, Calvert Drilling Co. - John Stadum No. 1
N.D.G.S. No. 632

K.B.	1637		
T-1	2594		
Bottineau	2666	Thickness	72

BOTTINEAU COUNTY

T159N, R74W, S18, NWNW, Superior Oil Co. - Feuerhelm No. 1
N.D.G.S. No. 5503

K.B.	1476
T-2	2872
T-1	2897
T.D.	2932

T159N, R81W, S20, CSESE, Union Oil Co. - Steen No. 1
N.D.G.S. No. 4790

K.B.	1517		
T-2	4509		
T-1	4522		
Bottineau	4700	Thickness	191

T159N, R82W, S1, NWNW, Cardinal Drilling Co. - B. M. Keeler No. 1
N.D.G.S. 1069

K.B.	1536		
T-2	4440		
T-1	4455		
Bottineau	4650	Thickness	210

T160N, R75W, S6, SWSW, Champlin Petroleum Co. - Campbell No. 1
N.D.G.S. No. 4863

K.B.	1477		
T-2	2940		
T-1	2964		
Bottineau	3082	Thickness	142

T160N, R75W, S9, SWSW, I. J. Wilhite & Glen Burton - Fraser No. 1
N.D.G.S. No. 4645

K.B.	1509		
T-2	2915		
T-1	2950		
Bottineau	3062	Thickness	147

T160N, R75W, S23, SWNW, H. L. Hunt - Albright No. 1
N.D.G.S. No. 1577

K.B.	1487		
T-2	2865		
T-1	2890		
Bottineau	2990	Thickness	125

T160N, R75N, S28, CSWNE, Monsanto Chemical Co. - Hagen No. 1
N.D.G.S. No. 1053

K.B.	1466
T-2	2898
T-1	2917
T.D.	3023

T160N, R76W, S24, NWNW, I. J. Wilhite & Glen Burton - Roy Henes No. 1
N.D.G.S. No. 4644

K.B.	1469		
T-2	3010		
T-1	3047		
Bottineau	3170	Thickness	160

T160N, R77W, S1, CSESE, Davis Oil Co. - Vikan No. 1
N.D.G.S. No. 1481

K.B.	1467		
T-2	3133		
T-1	3177		
Bottineau	3295	Thickness	162

T160, R77W, S29, CNENW, Northwest Drilling Co. - Henry Schmidt No. 1
N.D.G.S. No. 362

K.B.	1454		
T-2	3316		
T-1	3352		
Bottineau	3495	Thickness	179

T160N, R78W, S10, SESE, Superior Oil Co. - Brandt #1
N.D.G.S. No. 3119

K.B.	1462
T-2	3420
T.D.	3438

T160N, R80W, S5, SWNE, Amerada Petroleum Corporation - Loddington No. 1
N.D.G.S. No. 962

K.B.	1503		
T-2	4021		
T-1	4040		
Bottineau	4196	Thickness	176

T160N, R80W, S19, SENW, Phillips Petroleum Co. - Brandt No. 1
N.D.G.S. No. 2596

K.B.	1511		
T-2	4212		
T-1	4250		
Bottineau	4396	Thickness	184

T160N, R80W, S23, CNESE, Winona Oil Co. - Anderson No. 1
N.D.G.S. No. 1183

K.B.	1507		
T-2	3988		
T-1	4010		
Bottineau	4185	Thickness	197

T160N, R81W, S5, NESW, Continental Oil Co. - Thompson No. 1
N.D.G.S. No. 4192

K.B.	1516		
T-2	4245		
T-1	4265		
Bottineau	4440	Thickness	195

T160N, R81W, S11, SENW, Chevron Oil Co. - Jack R. Rogers No. 1
N.D.G.S. No. 4362

K.B.	1508		
T-2	4166		
T-1	4187		
Bottineau	4344	Thickness	178

T160N, R81W, S31, SWSWSE, California Co. - Blanche Thompson No. 1
N.D.G.S. No. 38

K.B.	1526		
T-2	4370		
T-1	4393		
Bottineau	4670	Thickness	300

T160N, R83W, S8, SESE, Cardinal Petroleum Co. & Gay Co. - W. Selk and U.S.A. No. 1
N.D.G.S. No. 3067

K.B.	1609
T-2	4753
T-1	4780
T.D.	4854

T161N, R74W, S2, CSWNE, Cardinal Drilling Co. - Joseph Andrieux No. 1
N.D.G.S. No. 1102

K.B.	1664		
T-1	2795		
Bottineau	2821	Thickness	26

T161N, R74W, S21, SWSW, Placid Oil Co. - P. B. Peterson No. 1
N.D.G.S. No. 1102

K.B.	1589		
T-1	2878		
Bottineau	2928	Thickness	50

T161N, R75W, S8, SWSW, Lion Oil Co. - Duraas No. 1
N.D.G.S. No. 1579

K.B.	1560		
T-2	2938		
T-1	2981		
Bottineau	3102	Thickness	164

T161N, R75W, S12, CSWSW, Cardinal Drilling Co. - Bennison et al. No. 1
N.D.G.S. No. 348

K.B.	1603		
T-2	2923		
T-1	2930		
Bottineau	2995	Thickness	72

T161N, R75W, S29, NWNW, Placid Oil Co. - Beyer No. 1
N.D.G.S. 1523

K.B.	1534		
T-2	2946		
T-1	2987		
Bottineau	3108	Thickness	162

T161N, R75W, S33, CNENE, Russel D. Garner - John Kippen No. 1
N.D.G.S. No. 1054

K.B.	1545		
T-2	2928		
T-1	2958		
Bottineau	3080	Thickness	152

T161N, R76W, S1, SWNW, Placid Oil Co. - Stewart 1-6
N.D.G.S. No. 5507

K.B.	1581		
T-2	2976		
T-1	3030		
Bottineau	3145	Thickness	171

T161N, R76W, S8, NWNW, I. J. Wilhite & Glen Burton - Wilhelm No. 1
N.D.G.S. No. 4646

K.B.	1508		
T-2	3076		
T-1	3108		
Bottineau	3250	Thickness	174

T161N, R76W, S22, NENW, J. P. Owen - Waters No. 1
N.D.G.S. No. 544

K.B.	1505		
T-2	3040		
T-1	3074		
Bottineau	3210	Thickness	170

T161N, R77W, S22, CNESE, Calvert Exploration Co. - Herman Bollinger No. 1
N.D.G.S. No. 327

K.B.	1481		
T-2	3252		
T-1	3284		
Bottineau	3426	Thickness	174

T161N, R77W, S24, NENE, Hunt Oil Co. - Norman Glin No. 1
N.D.G.S. No. 1527

K.B.	1487		
T-2	3156		
T-1	3183		
Bottineau	3318	Thickness	162

T161N, R78W, S5, NWNE, Cardinal et al. - Hubert Thompson No. 1
N.D.G.S. No. 930

K.B.	1493		
T-2	3455		
T-1	3482		
Bottineau	3628	Thickness	173

T161N, R78W, S26, SENE, Cardinal Drilling Co. - Gilmore No. 1
N.D.G.S. No. 1667

K.B.	1479		
T-2	3403		
T-1	3433		
Bottineau	3578	Thickness	175

T161N, R79W, S21, SESW, Amerada Petroleum Corporation - Beauchamp No. 1
N.D.G.S. No. 893

K.B.	1473		
T-2	3824		
T-1	3852		
Bottineau	3995	Thickness	171

T161N, R80W, S17, SWNW, Winona Oil Co. - Mina Gagnon No. 1
N.D.G.S. No. 1155

K.B.	1510		
T-2	4025		
T-1	4043		
Bottineau	4198	Thickness	173

T161N, R81W, S2, CNENE, Union Oil Co. - Huber No. 1-A-2
N.D.G.S. No. 4924

K.B.	1514		
T-2	4070		
T-1	4080		
Bottineau	4248	Thickness	178

T161N, R81W, S15, NESW, General American Oil Co. of Texas - Sausker No. 1-15
N.D.G.S. No. 4844

K.B.	1511		
T-2	4145		
T-1	4164		
Bottineau	4316	Thickness	171

T161N, R81W, S19, CSENW, Dakota Drilling Co. - Ole Anderson No. 1
N.D.G.S. No. 524

K.B.	1522		
T-2	4224		
T-1	4250		
Bottineau	4410	Thickness	186

T161N, R82W, S33, NWSW, Marathon Oil Co. - George Adams No. 1
N.D.G.S. No. 4918

K.B.	1561		
T-2	4523		
T-1	4540		
Bottineau	4707	Thickness	184

T162N, R74W, S28, CNWNW, Calvert Exploration Co. - Carbonneau No. 1
N.D.G.S. No. 328

K.B.	1895		
T-1	3070		
Bottineau	3100	Thickness	30

T162N, R75W, S28, NENW, Placid Oil Co. - F. Kofoid No. 1
N.D.G.S. No. 1585

K.B.	1705		
T-2	3028		
T-1	3040		
Bottineau	3108	Thickness	80

T162N, R75W, S12, NWNW, Clinton Oil Co. - Thorson No. 1
N.D.G.S. No. 5764

K.B.	2240		
T-1	3482		
Bottineau	3525	Thickness	43

T162N, R76W, S9, NWNE, Placid Oil Co. - Jena Hansen No. 1
N.D.G.S. No. 1524

K.B.	1674		
T-2	3066		
T-1	3100		
Bottineau	3225	Thickness	159

T162N, R76W, S14, NWNW, Lion Oil Co. - Wallace No. 1
N.D.G.S. No. 895

K.B.	1683		
T-2	3050		
T-1	3060		
Bottineau	3176	Thickness	126

T162N, R76W, S35, CSWSW, Placid Oil Co. - Marvin Wolfe & Bank of N. D. No. 1
N.D.G.S. No. 1583

K.B.	1627		
T-2	3023		
T-1	3062		
Bottineau	3197	Thickness	174

T162N, R77W, S9, CSENW, Hunt Oil Co. - Dunbar No. 1
N.D.G.S. No. 1584

K.B.	1518		
T-2	3060		
T-1	3083		
Bottineau	3235	Thickness	175

T162N, R77W, S14, SENE, Champlin Petroleum Co. - Champlin & Bridger & Dunbar No. 1
N.D.G.S. No. 5184

K.B.	1552		
T-2	3098		
T-1	3118		
Bottineau	3272	Thickness	174

T162N, R78W, S12, SWSE, Phillips Petroleum Co. - Brandvold No. 1
N.D.G.S. No. 2638

K.B.	1495		
T-2	3108		
T-1	3135		
Bottineau	3285	Thickness	177

T162N, R78W, S20, SESE, Amerada Petroleum Co. & Arex Corporation - Lila Stark No. 1
N.D.G.S. No. 3827

K.B.	1502		
T-2	3400		
T-1	3430		
Bottineau	3574	Thickness	174

T162N, R78W, S25, SWNW, Calvert et al. - M. McMillan No. 1
N.D.G.S. No. 2058

K.B.	1491
T-2	3290
T-1	3314
T.D.	3418

T162N, R78W, S31, SESW, Amerada Petroleum Corporation - Lillestrand No. 1
N.D.G.S. No. 4655

K.B.	1486		
T-2	3355		
T-1	3386		
Bottineau	3532	Thickness	177

T162N, R79W, S3, CNESE, National Associated Petroleum Co. - Sarah G. Newhouse No. 1
N.D.G.S. No. 288

K.B.	1498
T-2	3517
T-1	3555
T.D.	3600

T162N, R79W, S14, CSENE, Calvert Drilling Inc. - Siercks No. 1
N.D.G.S. No. 839

K.B.	1500		
T-2	3408		
T-1	3447		
Bottineau	3590	Thickness	182

T162N, R80W, S6, CSWNE, Signal Drilling and Exploration Inc. & Gulf Oil Co. - Ole Haugen No. 1
N.D.G.S. No. 1670

K.B.	1511.6
T-2	3868
T-1	3900
T.D.	3947

T162N, R80W, S12, SWNW, Cardinal et al. - Jena Jenson No. 1
N.D.G.S. No. 1899

K.B.	1493		
T-2	3680		
T-1	3703		
Bottineau	3860	Thickness	180

T162N, R81W, S23, NWNW, Davis Oil Co. - Hawke No. 1
N.D.G.S. No. 1629

K.B.	1505
T-2	3943
T-1	3960
T.D.	4020

T162N, R81W, S31, NENE, Carter Oil Co. & Phillips Petroleum Co. - Oscar Fossum No. 1
N.D.G.S. No. 1431

K.B.	1523		
T-2	4114		
T-1	4130		
Bottineau	4300	Thickness	186

T162N, R82W, S34, NESE, Daves Oil Co. - Sterart No. 1
N.D.G.S. No. 1637

K.B.	1533
T-2	4173
T-1	4185
T.D.	4245

T162N, R83W, S , NWNW, Lowell J. Williamson Inc. - Thorpe No. 1
N.D.G.S. No. 1439

K.B.	1568		
T-2	4380		
T-1	?		
Bottineau	4560	Thickness	180

T163N, R75W, S27, CNESW, Calvert Exploration Co. - Christensen No. 1
N.D.G.S. No. 503

K.B.	2136		
T-1	3400		
Bottineau	3415	Thickness	15

T163N, R76W, S18, CSESE, Calvert Williamson - Hagboe No. 1
N.D.G.S. No. 1302

K.B.	1723		
T-2	3094		
T-1	3124		
Bottineau	3248	Thickness	154

T163N, R76W, S21, SENW, Placid Oil Co. - E. H. Paulson No. 1
N.D.G.S. No. 1524

K.B.	1835		
T-2	3178		
T-1	3190		
Bottineau	3300	Thickness	122

T163N, R77W, S2, SESW, Lion Oil Co. - Magnussen No. 1
N.D.G.S. No. 170

K.B.	1669		
T-2	3062		
T-1	3090		
Bottineau	3230	Thickness	168

T163N, R77W, S3, NWSW, Champlin Petroleum Co. - Pederson No. 1
N.D.G.S. No. 4625

K.B.	1632
T-2	3020
T-1	3026
T.D.	3030

T163N, R77W, S3, NENW, Cardinal Drilling Co. & Lonbert Oil Co. - R. Olson No. 1
N.D.G.S. No. 1953

K.B.	1638
T-2	3023
T-1	3045
T.D.	3085

T163N, R77W, S4, NESE, Hunt Oil Co. - Karolyn Nesteboe No. 1
N.D.G.S. No. 1627

K.B.	1612		
T-2	3005		
T-1	3025		
Bottineau	3123	Thickness	118

T163N, R77W, S27, SENW, Lion Oil Co. - Einar No. 1
N.D.G.S. No. 939

K.B.	1563		
T-2	3048		
T-1	3094		
Bottineau	3228	Thickness	180

T163N, R78W, S9, NESW, Cardinal et al. - Ekrehagen Estate No. 1-A
N.D.G.S. No. 4347

K.B.	1532		
T-2	3120		
T-1	3160		
Bottineau	3295	Thickness	175

T163N, R78W, S26, NWSE, Hunt Oil Co. - Nels Nelson No. 1
N.D.G.S. No. 1702

K.B.	1508		
T-2	3184		
T-1	3214		
Bottineau	3360	Thickness	176

T163N, R78W, S30, SWSW, Calvert et al. - L. T. Hanson No. 1
N.D.G.S. No. 1968

K.B.	1513		
T-2	3268		
T-1	3295		
Bottineau	3440	Thickness	172

T163N, R78W, S30, SWSE, Great American Exploration Co. - Nordmark No. 1
N.D.G.S. No. 1788

K.B.	1510		
T-2	3186		
T-1	3218		
Bottineau	3360	Thickness	174

T163N, R79W, S11, CNWSE, Cardinal Drilling Co. - Oscar Brenden No. 1
N.D.G.S. No. 240

K.B.	1509
T-2	3352
T-1	3387
T.D.	3520

T163N, R79W, S29, NENE, Northwest Oil Drilling Co. - Dahl & State No. 1
N.D.G.S. No. 921

K.B.	1472		
T-2	3488		
T-1	3518		
Bottineau	3668	Thickness	180

T163N, R80W, S5, SESW, Cardinal Drilling Co. - U.C.L.I. & Zahn No. 1
N.D.G.S. No. 1207

K.B.	1502
T-2	3657
T.D.	3688

T163N, R80W, S11, CNWNE, Zach Brooks Drilling Co. - H. Haugen No. 1
N.D.G.S. No. 426

K.B.	1501		
T-2	3504		
T-1	3550		
Bottineau	3684	Thickness	180

T164N, R80W, S36, NESENW, Ward & Williston Drilling Co. - State No. 2-A
N.D.G.S. No. 395

K.B.	1488		
T-2	3424		
T-1	3460		
Bottineau	3596	Thickness	172

BURKE COUNTY

T162N, R90W, S25, SWSE, Anschutz Corporation Inc. - Ormiston No. 1
N.D.G.S. No. 4599

K.B.	1957		
T-2	6273		
T-1	?		
Bottineau	6460	Thickness	187

T163N, R88W, S31, CSESE, Northern Pump Co. - Bauer No. 1
N.D.G.S. No. 1490

K.B.	1895
T-2	5838
T-1	?
T.D.	5940

T163N, R92W, S12, CNENE, Mar-Win Development Co. - R. M. Hanson No. 3-D
N.D.G.S. No. 3154

K.B.	1952		
T-2	6360		
T-1	?		
Bottineau	6547	Thickness	187

BURLEIGH COUNTY

T137N, R76W, S32, NWNWNW, Continental Oil Co. - McCay No. 1
N.D.G.S. No. 145

K.B.	1869		
T-2	3800		
T-1	3840		
Bottineau	3920	Thickness	120

T137N, R77W, S32, SESE, Caroling Hunt Trust Estate - Robert Nicholson No. 1
N.D.G.S. No. 756

K.B.	1891		
T-2	4012		
T-1	4048		
Bottineau	4130	Thickness	118

T139N, R76W, S20, SESE, Chevron Oil Co. - Lang No. 1
N.D.G.S. No. 4208

K.B.	1938		
T-2	3964		
T-1	4003		
T.D.	4141		

T139N, R76W, S36, NENE, Caroline Hunt Trust Estate - Schlaback No. 1
N.D.G.S. No. 723

K.B.	1878		
T-2	3753		
T-1	3792		
Bottineau	3877	Thickness	124

T140N, R76W, S36, NWNE, Chevron Oil Co. - N. D. State No. 1
N.D.G.S. No. 4201

K.B.	1875		
T-2	3808		
T-1	3848		
T.D.	3898		

T140N, R77W, S3, CNWNW, Continental Oil Co. - Duemeland No. 1
N.D.G.S. No. 174

K.B.	1981		
T-2	4257		
T-1	4300		
Bottineau	4397	Thickness	140

T140N, R77W, S6, SWSWSW, Continental Oil Co. - Strat Test G-18
N.D.G.S. No. 19

K.B.	1909		
T-2	4292		
T-1	4340		
Bottineau	4437	Thickness	145

T140N, R77W, S11, CNWSE, Calvert Drilling Inc. & Leach Oil Corporation - Patterson Land Co. No. 1
N.D.G.S. No. 1409

K.B.	2019		
T-2	4220		
T-1	4256		
Bottineau	4355	Thickness	135

T140N, R79W, S23, CNWNW, Caroline Hunt Trust Estate - Paul Ryberg No. 1
N.D.G.S. No. 772

K.B.	2007		
T-2	4694		
T-1	4730		
Bottineau	4830	Thickness	136

T140N, R80W, S18, CSWSW, Hunt Oil Co. - Emma Kleven No. 1
N.D.G.S. No. 151

K.B.	1922		
T-2	5043		
T-1	5070		
Bottineau	5185	Thickness	142

T140N, R80W, S19, SWSW, E. C. Johnston Jr. - Edward No. 1
N.D.G.S. No. 4685

K.B.	1865		
T-2	4980		
T-1	5013		
Bottineau	5118	Thickness	138

T141N, R75W, S15, SESW, Continental & Pure Oil Co. - Patterson Land Co. No. 1
N.D.G.S. No. 1375

K.B.	2073		
T-2	3987		
T-1	4024		
Bottineau	4120	Thickness	133

T141N, R80W, S33, SWNE, Tom Vessels & Perry Bass - Helen Bourgois No. 1
N.D.G.S. No. 4389

K.B.	2126		
T-2	5268		
T-1	5298		
Bottineau	5407	Thickness	139

T142N, R76W, S31, CSWSW, Caroline Hunt Trust Estate - Soder Investment Co. No. 1
N.D.G.S. No. 765

K.B.	2027		
T-2	4315		
T-1	4353		
Bottineau	4450	Thickness	135

T143N, R75W, S30, CSESW, Continental & Pure Oil Co. - J. F. Miller No. 1
N.D.G.S. No. 1371

K.B.	2051		
T-2	4133		
T-1	4171		
Bottineau	4270	Thickness	137

T144N, R75W, S36, CNENE, Caroline Hunt Trust Estate - Board of University School Lands No. 1
N.D.G.S. No. 701

K.B.	2023		
T-2	3927		
T-1	3960		
Bottineau	4055	Thickness	128

T144N, R77W, S14, CSESE, Caroline Hunt Trust Estate - Anton Novy No. 1
N.D.G.S. No. 763

K.B.	1947		
T-2	4342		
T-1	4370		
Bottineau	4486	Thickness	144

EDDY COUNTY

T148N, R67W, S35, SWNW, Calvert Drilling Inc. - Dorothy Elliot No. 1
N.D.G.S. No. 1197

K.B.	1557		
T-1	2110		
Bottineau	2137	Thickness	27

T149N, R67W, S35, NESE, Calvert Drilling Inc. - Thomas Irmen No. 1
N.D.G.S. No. 1198

K.B.	1559		
T-1	2160		
Bottineau	2183	Thickness	23

T150N, R67W, S16, CNWNW, Calvert Exploration Co. - State No. 1
N.D.G.S. No. 437

K.B.	1478		
T-1	2028		
Bottineau	2053	Thickness	25

EMMONS COUNTY

T132N, R78W, S8, CNESE, Peak Drilling Co. - Ohlhauser No. 1
N.D.G.S. No. 43

K.B.	1820		
T-2	3663		
T-1	3700		
Bottineau	3790	Thickness	127

T133N, R75W, S35, CNWSW, Northern Ordnance Corporation - Franklin Investment No. 1
N.D.G.S. No. 16

K.B.	2027		
T-1	3375		
Bottineau	3445	Thickness	70

T133N, R76W, S35, NENESE, Roeser & Pendleton Inc. - J. J. Weber No. 1
N.D.G.S. No. 23

K.B.	2012		
T-2	3500		
T-1	3512		
Bottineau	3570	Thickness	70

T134N, R75W, S30, CSENW, Mobile Production Co. - Kruse F-22-30P
N.D.G.S. No. 742

K.B.	2044		
T-2	3536		
T-1	3550		
Bottineau	3700	Thickness	164

T136N, R76W, S17, SESE, Chevron Oil Co. - Engleman No. 2-1
N.D.G.S. No. 4212

K.B.	1890
T-2	3678
T-1	3716
T.D.	3768

FOSTER COUNTY

T145N, R67W, S20, CS½,SW, S. D. Johnson - Joseph Taylor No. 1
N.D.G.S. No. 652

K.B.	1660		
T-1	2291		
Bottineau	2371	Thickness	80

T146N, R67W, S10, CNWNW, Cardinal Drilling Inc. - James M. Anderson No. 1
N.D.G.S. No. 1126

K.B.	1589		
T-1	2160		
Bottineau	2220	Thickness	60

T147N, R67W, S28, NENE, Calvert Drilling Inc. - George S. Garland No. 1
N.D.G.S. No. 1205

K.B.	1588		
T-1	2166		
Bottineau	2212	Thickness	46

GRANT COUNTY

T133N, R83W, S26, CSWSW, Youngblood & Youngblood - Kelstrom No. 1
N.D.G.S. No. 232

K.B.	1997		
T-2	4880		
T-1	?		
Bottineau	5000	Thickness	120

T133N, R90W, S1, SWNE, Cardinal Petroleum et al. - Beirwagen No. 1
N.D.G.S. No. 3636

K.B.	2350		
T-2	6670		
T-1	?		
Bottineau	6794	Thickness	124

KIDDER COUNTY

T141N, R73W, S36, SENE, Magnolia Petroleum Corporation - N. D. State No. A-1
N.D.G.S. No. 24

K.B.	1968		
T-2	3368		
T-1	3412		
Bottineau	3490	Thickness	122

T142N, R74W, S32, CNWNE, Caroline Hunt Trust Estate - E. B. Sauter Estate No. 1
N.D.G.S. No. 748

K.B.	1848		
T-2	3660		
T-1	3692		
Bottineau	3782	Thickness	122

T143N, R71W, S16, CNESE, Carter Oil Co. - State No. 1
N.D.G.S. No. 230

K.B.	1889		
T-2	3042		
T-1	?		
Bottineau	3166	Thickness	124

LOGAN COUNTY

T133N, R71W, S21, NWSW, Calvert et al. - A. Lang No. 1
N.D.G.S. No. 1377

K.B.	2054		
T-2	2797		
T-1	2816		
Bottineau	2912	Thickness	115

T133N, R72W, S20, CNENW, Herman Hanson Oil Syndicate - Welder No. 1
N.D.G.S. No. 1835

K.B.	2004		
T-2	2930		
T-1	?		
Bottineau	3046	Thickness	116

T134N, R69W, S26, CNENE, Calvert et al. - Albert Roesler No. 1
N.D.G.S. No. 1376

K.B.	1954		
T-1	2460		
Bottineau	2502	Thickness	42

T134N, R71W, S6, CNESW, Calvert et al. - Knute Jensen No. 1
N.D.G.S. No. 1349

K.B.	2111		
T-2	2955		
T-1	2980		
Bottineau	3074	Thickness	119

T134N, R71W, S22, SESE, Calvert et al. - Leroy Burnstad No. 1
N.D.G.S. No. 1390

K.B.	2013		
T-2	2764		
T-1	2786		
Bottineau	2872	Thickness	108

T134N, R71W, S33, NWSW, Calvert et al. - Edmore Will No. 1
N.D.G.S. No. 1378

K.B.	2031		
T-2	2790		
T-1	2807		
Bottineau	2900	Thickness	110

T136N, R71W, S8, CNWSW, Calvert et al. - C. A. Zimmerman
N.D.G.S. No. 1346

K.B.	2022		
T-2	2910		
T-1	2940		
Bottineau	3046	Thickness	136

T136N, R71W, S25, CNWNW, Calvert et al. - Ray Craig No. 1
N.D.G.S. No. 1347

K.B.	1917		
T-2	2710		
T-1	2740		
Bottineau	2833	Thickness	123

T136N, R71W, S28, CNWSE, Calvert et al. - Alfred Bakken No. 1
N.D.G.S. No. 1348

K.B.	2005		
T-2	2930		
T-1	2863		
Bottineau	2964	Thickness	134

T136N, R73W, S6, CSWSE, Caroline Hunt Trust Estate - F. M. Fuller No. 1
N.D.G.S. No. 590

K.B.	2011		
T-2	3254		
T-1	3287		
Bottineau	3416	Thickness	162

MCHENRY COUNTY

T153N, R75W, S27, CSENW, Owen Drilling - Bromley No. 1
N.D.G.S. No. 583

K.B.	1548		
T-2	3470		
T-1	3500		
Bottineau	3612	Thickness	142

T153N, R76W, S4, SESW, Triton Oil Co. - Gange No. 1
N.D.G.S. No. 1697

K.B.	1551		
T-2	3702		
T-1	3732		
Bottineau	3848	Thickness	146

T153N, R77W, S17, NWSE, Hunt Oil Co. - Peter Lenertz No. 1
N.D.G.S. No. 61

K.B.	1570		
T-2	4022		
T-1	4060		
Bottineau	4172	Thickness	150

T154N, R76W, S23, CNWSW, Calvert Exploration & Don Traders Inc. - J. Bachmeier (Zeigler) No. 1
N.D.G.S. No. 360

K.B.	1554		
T-2	3609		
T-1	3630		
Bottineau	3747	Thickness	138

T154N, R77W, S30, NENE, Hunt Oil Co. - Frank Boehm No. 1
N.D.G.S. No. 1720

K.B.	1557		
T-2	3965		
T-1	3997		
Bottineau	4122	Thickness	157

T155N, R77W, S19, NESE, General Crude Oil Co. - Lloyd Moen No. 1
N.D.G.S. No. 1631

K.B.	1559		
T-2	3879		
T-1	3900		
Bottineau	4032	Thickness	153

T155N, R78W, S8, SWNE, Triton Oil Co. - Freeman No. 1
N.D.G.S. No. 1668

K.B.	1521		
T-2	4080		
T-1	4110		
Bottineau	4248	Thickness	168

T156N, R75W, S11, CSENE, Calvert Exploration Co. - Fylken No. 1
N.D.G.S. No. 387

K.B.	1502
T-2	3076
T-1	3114
Bottineau	3224	Thickness 148

T156N, R76W, S34, SENE, Calvert Exploration Co. & Don Traders Inc. - A. Payne No. 1
N.D.G.S. No. 358

K.B.	1502
T-2	3420
T-1	3445
Bottineau	3562	Thickness 142

T156N, R77W, S19, CSWSW, Tenneco Oil Co. - Elizabeth Kuhnhenn No. 2-A
N.D.G.S. No. 3270

K.B.	1526
T-2	3772
T.D.	3803

T156N, R77W, S26, CNWNW, Lion Oil Co. (Div. of Monsanto Chem. Co.) - Ed No. 1
N.D.G.S. No. 1354

K.B.	1489
T-2	3575
T-1	3606
Bottineau	3726	Thickness 151

T156N, R80W, S8, NWSE, Kewanee Oil Co. - Torg No. 1
N.D.G.S. No. 4112

K.B.	1526.2
T-2	4526
T-1	4553
T.D.	4650

T157N, R75W, S1, Lot 2, NWNE, Amerada Petroleum Corporation - N. D. "L." No. 1
N.D.G.S. No. 2567

K.B.	1490
T-2	3006
T-1	3040
Bottineau	3154	Thickness 148

T157N, R75W, S10, CSWNE, Amerada Petroleum Co. - A. Dugan No. 1
N.D.G.S. No. 2610

K.B.	1490		
T-2	3092		
T-1	3128		
Bottineau	3243	Thickness	151

T157N, R75W, S28, CNENW, David Oil Co. - Tagstad No. 1
N.D.G.S. No. 1471

K.B.	1477		
T-2	3183		
T-1	3220		
Bottineau	3343	Thickness	160

T157N, R76W, S3, NWSW, Amerada Petroleum Corporation - Carl Miller r. 1 No. 1
N.D.G.S. No. 2312

K.B.	1480
T-2	3346
T-1	3390
T.D.	3422

T157N, R76W, S34, NESW, McMoRan Exploration Co. - State No. 1
N.D.G.S. No. 5279

K.B.	1476		
T-2	3411		
T-1	3450		
Bottineau	3580	Thickness	169

T157N, R77W, S34, NWSW, General Crude Oil Co. - Loren Hanson No. 1
N.D.G.S. No. 1674

K.B.	1506		
T-2	3670		
T-1	3713		
Bottineau	3835	Thickness	165

T157N, R78W, S3, NNESW, Hunt Oil Co. - Shoemaker No. 1
N.D.G.S. No. 39

K.B.	1480		
T-2	3837		
T-1	3870		
Bottineau	4010	Thickness	173

T157N, R78W, S23, SESW, Amerada Petroleum Corporation - C. Brummond No. 1
N.D.G.S. No. 1986

K.B.	1513
T-2	3874
T-1	3898
T.D.	3916

T157N, R78W, S29, CSENE, Dow et al. - R. E. Carty
N.D.G.S. No. 3229

K.B.	1492
T-2	3840
T-1	3860
T.D.	3989

T157N, R79W, S10, CNWSW, British American - Nicolaisen No. 1
N.D.G.S. No. 2402

K.B.	1492
T-2	4083
T-1	4115
T.D.	4133

T157N, R80W, S21, NENW, Farmers Union Central Exchange - Wiltse No. 1
N.D.G.S. No. 883

K.B.	1533		
T-2	4525		
T-1	4554		
Bottineau	4717	Thickness	192

T157N, R80W, S24, SWNE, Triton Oil Co. - Fredrickson No. 1
N.D.G.S. No. 1632

K.B.	1509		
T-2	4362		
T-1	4380		
Bottineau	4530	Thickness	168

T158N, R75W, S5, CSWSE, Davis Oil Co. - Prellwitz No. 1
N.D.G.S. No. 1462

K.B.	1490		
T-2	3094		
T-1	3130		
Bottineau	3247	Thickness	153

T158N, R75W, S16, SWSW, McMoRan Exploration Co. - State No. 2
N.D.G.S. No. 5281

K.B.	1470		
T-2	3098		
T-1	3132		
Bottineau	3250	Thickness	152

T158N, R77W, S34, NENE, McMoRan Exploration Co. - Fairbrother No. 1
N.D.G.S. No. 5283

K.B.	1477		
T-2	3542		
T-1	3595		
Bottineau	3704	Thickness	162

T158N, R78W, S12, CSENE, Davis Oil Co. - Torr No. 1
N.D.G.S. No. 1463

K.B.	1471		
T-2	3640		
T-1	3660		
Bottineau	3796	Thickness	156

T158N, R78W, S30, NWNW, Hunt Oil Co. - W. M. Harrington No. 1
N.D.G.S. No. 1635

K.B.	1468		
T-2	3938		
T-1	3990		
Bottineau	4123	Thickness	185

T159N, R76W, S2, NWNW, Placid Oil Co. - Charles Erdman No. 1
N.D.G.S. No. 1626

K.B.	1460		
T-2	3080		
T-1	3115		
Bottineau	3242	Thickness	162

T159N, R76W, S15, CNENE, Davis Oil Co. - W. S. Klebe No. 1
N.D.G.S. No. 146-

K.B.	1474		
T-2	3140		
T-1	3178		
Bottineau	3298	Thickness	158

T159N, R77W, S12, NENW, Hunt Oil Co. - W. S. Klebe No. 1
N.D.G.S. No. 1652

K.B.	1481		
T-2	3300		
T-1	3348		
Bottineau	3464	Thickness	164

T159N, R79W, S3, NWNW, Cardinal Drilling Co. - Arthur Krenz No. 1
N.D.G.S. No. 1538

K.B.	1461		
T-2	3770		
T-1	3800		
Bottineau	3950	Thickness	180

T159N, R79W, S17, SESE, Hunt Oil Co. - B. Rosenau No. 1
N.D.G.S. No. 1651

K.B.	1473		
T-2	3866		
T-1	3887		
Bottineau	4050	Thickness	184

T159N, R79W, S34, CNWNW, Amerada Petroleum Corporation - Ted Pfau No. 1
N.D.G.S. No. 2675

K.B.	1478		
T-2	3854		
T-1	3895		
Bottineau	4040	Thickness	186

T159N, R80W, S28, CNWNE, Winona Oil Co. - Walstad No. 1
N.D.G.S. No. 1187

K.B.	1492		
T-2	4268		
T-1	4280		
Bottineau	4460	Thickness	192

MCINTOSH COUNTY

T131N, R73W, S15, NENE, General Atlas Carbon Co. - A. Ketterling No. 1
N.D.G.S. No. 89

K.B.	2176		
T-2	3106		
T-1	3125		
Bottineau	3170	Thickness	64

MCLEAN COUNTY

T146N, R81W, S10, NE, Samedan Oil Corporation - Vaughn & Hanson No. 1
N.D.G.S. No. 22

K.B.	1995		
T-2	5610		
T-1	5640		
Bottineau	5770	Thickness	160

T146N, R82W, S32, SESW, Herman Hanson Oil Syndicate - Samuelson No. 1
N.D.G.S. No. 1516

K.B.	2022		
T-2	6068		
T-1	6100		
Bottineau	6240	Thickness	172

T150N, R79W, S14, CSENW, I. J. Wilhite - Arnold No. 1
N.D.G.S. No. 3076

K.B.	2089
T-2	5080
T-1	5115
T.D.	5153

T150N, R80W, S14, NWNW, Cardinal Petroleum Co. et al. - Carl Ecklund No. 1
N.D.G.S. No. 3089

K.B.	2006
T-2	5288
T.D.	5300

T150N, R80W, S28, CSWSW, Stanolind Oil and Gas Co. - McLean County No. 1
N.D.G.S. No. 49

K.B.	2100		
T-2	5480		
T-1	5512		
Bottineau	5667	Thickness	187

MERCER COUNTY

T142N, R89W, S28, CNWNE, F. F. Kellu - E. Leutz No. 1
N.D.G.S. No. 21

K.B.	2285		
T-2	7993		
T-1	?		
Bottineau	8211	Thickness	218

MORTON COUNTY

T135N, R82W, S11, NWNW, Deep Rock Corporation - Gangl A-1
N.D.G.S. No. 464

K.B.	2134		
T-2	5120		
T-1	5150		
Bottineau	5243	Thickness	123

T135N, R83W, S34, SENE, Amerada Petroleum Corporation - James Meyer No. 1
N.D.G.S. No. 3859

K.B.	2125		
T-2	5260		
T-1	5286		
Bottineau	5380	Thickness	120

T136N, R81W, S20, CNWNE, National Bulk Carriers - Miller No. 1
N.D.G.S. No. 491

K.B.	1925		
T-2	4841		
T-1	4867		
Bottineau	4962	Thickness	121

T136N, R81W, S29, CNENW, Phillips Petroleum Co. - Phillips & Carter Dakota No. 1
N.D.G.S. No. 26

K.B.	2005		
T-2	4890		
T-1	4917		
Bottineau	5014	Thickness	124

T137N, R83W, S34, SENW, Austral Oil Co. Inc. - John J. Leingang Unit 6524 No. 1
N.D.G.S. No. 3978

K.B.	2281.1		
T-2	5704		
T-1	5733		
Bottineau	5833	Thickness	129

T138N, R83W, S5, CNWNE, Campbell and Partners - Picha No. 1
N.D.G.S. No. 5379

K.B.	1980		
T-2	5663		
T-1	5694		
Bottineau	5803	Thickness	140

T139N, R82W, S11, SWNE, Fletcher Oil and Gas Co. et al. - Boehm No. 1
N.D.G.S. No. 2185

K.B.	1861		
T-2	5290		
T-1	5320		
T.D.	5350		

T139N, R86W, S30, CSWSW, Deep Rock Oil Co. - Hilda Johnson "A" No. 1
N.D.G.S. No. 133

K.B.	2204		
T-2	6760		
T-1	6790		
Bottineau	6907	Thickness	147

T139N, R90W, S27, NESW, Pan American Petroleum Corporation - Raymond Vetter No. 1
N.D.G.S. No. 1620

K.B.	2426		
T-2	7740		
T-1	7762		
Bottineau	7892	Thickness	152

MOUNTRAIL COUNTY

T156N, R88W, S27, CSWSE, Texota Oil Co. - W. F. Bauer No. 1
N.D.G.S. No. 1223

K.B.	2180		
T-2	7385		
T-1	?		
Bottineau	7580	Thickness	195

OLIVER COUNTY

T141N, R81W, S3, SESW, Youngblood & Youngblood - Wachter No. 1
N.D.G.S. No. 95

K.B.	1924		
T-2	5360		
T-1	5400		
Bottineau	5508	Thickness	148

T141N, R81W, S18, CSESE, Carter Oil Co. - E. L. Semling No. 1
N.D.G.S. No. 15

K.B.	2037		
T-2	5575		
T-1	5617		
Bottineau	5727	Thickness	152

T141N, R85W, S34, NWNW, Fletcher Oil and Gas Co. et al. - Buelinger No. 1
N.D.G.S. No. 2183

K.B.	2173		
T-2	6687		
T-1	6720		
Bottineau	6842	Thickness	155

PIERCE COUNTY

T151N, R74W, S15, SENW, The Oil Capitol Corporation - Hager F. L. B. No. 1
N.D.G.S. No. 3877

K.B.	1577
T-2	3323
T-1	?
T.D.	3334

T152N, R72W, S33, SENE, Cardinal & Great American - Bessel No. 1
N.D.G.S. No. 2209

K.B.	1624		
T-2	2933		
T-1	2973		
Bottineau	3076	Thickness	143

T152N, R73W, S34, SWSW, Getty Oil Co. - Ludwig Vetter No. 1
N.D.G.S. No. 5576

K.B.	1579		
T-2	3110		
T-1	3150		
Bottineau	3257	Thickness	147

T152N, R73W, S36, SWNE, D. D. Bills - State of N. D. No. 1
N.D.G.S. No. 4099

K.B.	1593		
T-2	3028		
T-1	3068		
Bottineau	3173	Thickness	145

T152N, R72W, S23, SESE, A. J. Hodges Industries - Martin No. 1
N.D.G.S. No. 3920

K.B.	1605		
T-2	3223		
T-1	3260		
Bottineau	3363	Thickness	140

T154N, R72W, S17, CNESE, Calvert Exploration - Ranberg No. 1
N.D.G.S. No. 538

K.B.	1566		
T-2	2833		
T-1	2852		
Bottineau	2945	Thickness	112

T154N, R73W, S11, NWNW, Hyde and Associates - Schaan No. 1
N.D.G.S. No. 557

K.B.	1555		
T-2	2916		
T-1	2939		
Bottineau	3040	Thickness	124

T154N, R73W, S33, SWSW, Cardinal Petroleum Co. - Klein No. 1
N.D.G.S. No. 4567

K.B.	1503
T-2	2995
T.D.	3035

T154N, R74W, S22, CSWNW, Calvert Exploration Co. & Don Traders Inc. - Martin A. Voeller No. 1
N.D.G.S. No. 361

K.B.	1545		
T-2	3180		
T-1	3210		
Bottineau	3320	Thickness	140

T151N, R73W, S17, SENW, Amerada Petroleum Co. - Charles Bischoff No. 1
N.D.G.S. No. 2530

K.B.	1559		
T-2	2940		
T-1	2972		
Bottineau	3082	Thickness	142

T155N, R74W, S25, NWSW, Clinton Oil Co. - Vetsch No. 1
N.D.G.S. No. 5765

K.B.	1553		
T-2	3047		
T-1	3078		
Bottineau	3180	Thickness	133

T156N, R73W, S18, CSWNW, Hyde and Associates - Hyde Associates & Tjon No. 1
N.D.G.S. No. 560

K.B.	1528		
T-2	2896		
T-1	2910		
Bottineau	3014	Thickness	118

T156N, R74W, S5, SWNE, Tom Jorden - Hagboe No. 1
N.D.G.S. No. 2827

K.B.	1509
T-2	2970
T-1	3000
T.D.	3035

T157N, R73W, S3, NWSW, Earl F. Wakefield - Christianson No. 1
N.D.G.S. No. 780

K.B.	1486		
T-1	2714		
Bottineau	2804	Thickness	90

T157N, R74W, S22, NENW, Apache Oil Corporation - B. Olson No. 1
N.D.G.S. No. 2728

K.B.	1480		
T-2	2912		
T-1	2940		
Bottineau	3053	Thickness	141

T157N, R74W, S26, SENW, Cardinal Drilling Co. - M. T. Thompson No. 1
N.D.G.S. No. 1457

K.B.	1488		
T-2	2899		
T-1	2930		
Bottineau	3027	Thickness	128

T157N, R74W, S30, SENW, I. J. Wilhite & Simcox
N.D.G.S. No. 5081

K.B.	1489		
T-2	3023		
T-1	3065		
Bottineau	3182	Thickness	159

T158N, R72W, S8, SWNW, Mobile Producing Co. - Fleck No. 1
N.D.G.S. No. 712

K.B.	1642		
T-1	2707		
Bottineau	2732	Thickness	25

T158N, R74W, S19, CNWSE, Phillips Petroleum Co. & Carter Oil Co. - Oliva Saude No. 1
N.D.G.S. No. 274

K.B.	1487		
T-2	2934		
T-1	2964		
Bottineau	3073	Thickness	139

RENVILLE COUNTY

T158N, R81W, S7, NENW, Anschutz Drilling Co. - Einar Christianson No. 1
N.D.G.S. No. 1689

K.B.	1532		
T-2	4652		
T-1	4680		
Bottineau	4820	Thickness	168

T158N, R81W, S34, CSESW, Sohio Petroleum Co. - J. Nelson No. 1
N.D.G.S. No. 369

K.B.	1541		
T-2	4640		
T-1	4663		
Bottineau	4868	Thickness	228

T158N, R83W, S26, SWSW, Cardinal Petroleum Co. & Rex Baker - Sanders & Armstrong No. 14-26
N.D.G.S. No. 4006

K.B.	1634
T-2	5070
T-1	?
T.D.	5177

T158N, R84W, S10, SWNW, Tiger Oil Co. - Bloms No. 1
N.D.G.S. No. 4277

K.B.	1721
T-2	5239
T-1	5260
T.D.	5293

T158N, R84W, S35, NWNE, Cardinal Petroleum Co. & Rex Baker - Anna Nett No. 31-35
N.D.G.S. No. 4007

K.B.	1724
T-2	5445
T-1	5480
T.D.	5520

T158N, R86W, S16, SENW, Great Western Drilling Co. & Warren J. Hancock - Erickson No. 1
N.D.G.S. No. 5063

K.B.	1907
T-2	6023
T-1	6044
T.D.	6069

T161N, R84W, S23, CSENW, H. Mack Cox - Southam No. 1
N.D.G.S. No. 1136

K.B.	1651		
T-2	4873		
T-1	4900		
Bottineau	5064	Thickness	191

T161N, R84W, S32, SESW, Gulf Oil Corporation & Signal Drilling and Exploration Co. - Roy Hoke No. 1
N.D.G.S. No. 1727

K.B.	1705		
T-2	5130		
T-1	?		
Bottineau	5320	Thickness	190

T161N, R85W, S13, CSWNW, Calvert Drilling Co. - Oscar W. Johnson No. 1
N.D.G.S. No. 815

K.B.	1707		
T-2	5136		
T-1	?		
Bottineau	5317	Thickness	181

T162N, R84W, S9, CSENW, Lowell Williamson, Inc. - Noramark No. 1
N.D.G.S. No. 1450

K.B.	1634		
T-2	4655		
T-1	?		
Bottineau	4847	Thickness	192

T162N, R84W, S27, CNWSW, Winona Oil Co. - George Krause No. 1
N.D.G.S. No. 1201

K.B.	1640		
T-2	4755		
T-1	?		
Bottineau	4955	Thickness	200

T162N, R85W, S5, CNESE, Anschutz Oil Co. Inc. - Knutson No. 1
N.D.G.S. No. 2059

K.B.	1723
T-2	4962
T-1	4976
T.D.	5065

T162N, R86W, S29, CNESW, Calvert Drilling Inc. - Stangelane No. 1
N.D.G.S. No. 867

K.B.	1768
T-2	5510
T-1	?
T.D.	5555

T163N, R84W, S30, SENE, Sohio Petroleum Co. - Magnuson No. 1
N.D.G.S. No. 960

K.B.	1631		
T-2	4593		
T-1	4627		
Bottineau	4785	Thickness	192

T163N, R86W, S12, SENE, Sohio Petroleum Co. - Walsh No. 1
N.D.G.S. No. 1059

K.B.	1733		
T-2	4788		
T-1	?		
Bottineau	4975	Thickness	187

T163N, R86W, S23, SENE, Sohio Petroleum Co. - Harold Ritter No. 1
N.D.G.S. No. 940

K.B.	1757		
T-2	4886		
T-1	?		
Bottineau	5075	Thickness	189

T163N, R87W, S9, SWSW, Sohio Petroleum Co. - Hanson A No. 1
N.D.G.S. No. 1178

K.B.	1814		
T-2	5337		
T-1	5373		
Bottineau	5510	Thickness	173

T164N, R87W, S36, SWSW, Calvert Exploration Co. & Leonard Wood - State A No. 1
N.D.G.S. No. 599

K.B.	1807		
T-2	5100		
T-1	?		
Bottineau	5276	Thickness	176

ROLETTE COUNTY

T160N, R73W, S8, CSENE, Cardinal Drilling Co. - Alex Swanson No. 1
N.D.G.S. No. 582

K.B.	1565		
T-1	2686		
Bottineau	2702	Thickness	16

T161N, R73W, S21, NWSE, Tom Jordon - Smith No. 1
N.D.G.S. No. 2862

K.B.	1607		
T-1	2662		
Bottineau	2701	Thickness	39

T161N, R73W, S23, SENW, Lion Oil Co. - Sebelius No. 1
N.D.G.S. No. 83

K.B.	1627		
T-1	2651		
Bottineau	2688	Thickness	37

T161N, R73W, S27, CSWSW, Cardinal Drilling Co. - LaMont No. 1
N.D.G.S. No. 571

K.B.	1594		
T-1	2660		
Bottineau	2690	Thickness	30

SHERIDAN COUNTY

T145N, R75W, S18, CNENW, General Crude Oil Co. - McElvain No. 1
N.D.G.S. No. 1605

K.B.	2011		
T-2	4186		
T-1	4210		
Bottineau	4328	Thickness	142

T146N, R74W, S16, CSWSW, Caroline Hunt Trust Estate - C. A. Pfeiffer No. 1
N.D.G.S. No. 735

K.B.	1994		
T-2	3885		
T-1	3920		
Bottineau	4020	Thickness	135

T146N, R76W, S19, CSWSW, Caroline Hunt Trust Estate - Walter E. Bauer No. 1
N.D.G.S. No. 693

K.B.	1984		
T-2	4420		
T-1	4455		
Bottineau	4565	Thickness	145

T146N, R77W, S27, NENE, Continental & Pure Oil Co. - Albrecht No. 1
N.D.G.S. No. 1392

K.B.	1954		
T-2	4482		
T-1	4513		
Bottineau	4625	Thickness	143

T147N, R75W, S1, CNENE, Caroline Hunt Trust Estate - Julius R. Matz No. 1
N.D.G.S. No. 684

K.B.	1849		
T-2	3805		
T-1	3841		
Bottineau	3948	Thickness	143

T148N, R74W, S22, CNESE, Wilson et al. - Leo Fallon No. 1
N.D.G.S. No. 337

K.B.	1891		
T-2	3673		
T-1	3708		
Bottineau	3818	Thickness	145

T148N, R76W, S15, NENE, Caroline Hunt Trust Estate - John Waltz No. 1
N.D.G.S. No. 665

K.B.	1792		
T-2	4047		
T-1	4080		
Bottineau	4189	Thickness	142

T150N, R74W, S1, NENW, Wilhite & Simcox - Thingvold No. 1
N.D.G.S. No. 5083

K.B.	1740
T-2	3440
T-1	3480
T.D.	3532

T150N, R74W, S36, NWNE, General Crude Oil Co. - 150-74 State No. 1
N.D.G.S. No. 1581

K.B.	1624		
T-2	3336		
T-1	3380		
Bottineau	3493	Thickness	157

SIOUX COUNTY

T131N, R80W, S29, CNESW, The Ohio Oil Co. - Standing Rock Sioux Tribal No. 1
N.D.G.S. No. 631

K.B.	1731		
T-2	3850		
T-1	?		
Bottineau	3972	Thickness	122

STUTSMAN COUNTY

T139N, R67W, S12, CNWNW, Calvert Exploration Co. - Vincet Wahzek No. 1
N.D.G.S. No. 672

K.B.	1867		
T-1	2296		
Bottineau	2343	Thickness	47

T139N, R67W, S24, CSESW, Calvert Exploration Co. - Wood No. 1
N.D.G.S. No. 670

K.B.	1874		
T-1	2305		
Bottineau	2325	Thickness	20

T139N, R68W, S5, SESE, Gordon B. Butterfield - Rudolph Trautman No. 1
N.D.G.S. No. 644

K.B.	1945		
T-1	2597		
Bottineau	2633	Thickness	36

T139N, R68W, S35, CSESW, Calvert Exploration Co. - Christ Rau No. 1
N.D.G.S. No. 669

K.B.	1880		
T-1	2436		
Bottineau	2506	Thickness	70

T141N, R67W, S11, NWNW, Barnett Drilling Co. - Gaier Brothers No. 1
N.D.G.S. No. 40

K.B.	1864		
T-1	2424		
Bottineau	2450	Thickness	26

T141N, R69W, S14, CNWSE, Mobile Producing Co. - Gross No. 1
N.D.G.S. No. 750

K.B.	1893		
T-1	2735		
Bottineau	2825	Thickness	90

T143N, R69W, S4, NWNW, S. D. Johnson - John Johnson No. 1
N.D.G.S. No. 602

K.B.	1947		
T-1	2878		
Bottineau	2940	Thickness	62

WARD COUNTY

T152N, R82W, S33, CSWSE, W. H. Hunt - F. C. Newman No. 1
N.D.G.S. No. 588

K.B.	2087		
T-2	5950		
T-1	5960		
Bottineau	6122	Thickness	172

T152N, R86W, S28, NWNW, General Crude Oil Co. - Jerome Jenson No. 1
N.D.G.S. No. 5105

K.B.	2120		
T-2	7186		
T-1	7218		
Bottineau	7396	Thickness	210

T153N, R84W, S30, CSWSW, Calvert Drilling Co. - Gilbert Jacobson No. 1
N.D.G.S. No. 1061

K.B.	2112		
T-2	6647		
T-1	6660		
Bottineau	6820	Thickness	173

T153N, R85W, S2, CSWNE, Stanolind Oil and Gas Co. - W. Waswick No. 1
N.D.G.S. No. 105

K.B.	2155		
T-2	6695		
T-1	6750		
Bottineau	6875	Thickness	180

T153N, R85W, S13, NENW, Union Oil Co. of California - Hanson No. 1-C-13
N.D.G.S. No. 5158

K.B.	2117		
T-2	6675		
T-1	?		
Bottineau	6857	Thickness	182

T154N, R81W, S19, NENW, I. J. Wilhite - Vern Waldref No. 1
N.D.G.S. No. 3237

K.B.	1566
T-2	5212
T-1	5232
T.D.	5282

T155N, R81W, S23, SESW, Herbert Hunt Trust Estate - Wald No. 1
N.D.G.S. No. 47

K.B.	1596		
T-2	4900		
T-1	4915		
Bottineau	5070	Thickness	170

T155N, R82W, S13, CNENE, W. H. Hunt - Guy Almy No. 1
N.D.G.S. No. 656

K.B.	1632		
T-2	5196		
T-1	5203		
Bottineau	5376	Thickness	180

T156N, R81W, S5, NWNE, Union Oil Co. of California - Olson No. 1-B-5
N.D.G.S. No. 4923

K.B.	1573		
T-2	4812		
T-1	4820		
Bottineau	4990	Thickness	178

T156N, R81W, S12, CNWNE, Tenneco Oil Co. - W. J. Bortzfield No. 1
N.D.G.S. No. 2946

K.B.	1556		
T-2	4642		
T-1	4652		
Bottineau	4822	Thickness	180

T156N, R82W, S2, CNESE, Union Oil Co. of California - Harold Anderson No. 1-1-2
N.D.G.S. No. 4992

K.B.	1618		
T-2	4917		
T-1	4940		
Bottineau	5100	Thickness	183

T156N, R82W, S19, CNWSW, H. Mack Cox - Kotasek No. 1
N.D.G.S. No. 1138

K.B.	1636		
T-2	5246		
T-1	?		
Bottineau	5432	Thickness	186

T156N, R83W, S33, SWSE, Quintana Production Co. - Chris W. Linnertz No. 1
N.D.G.S. No. 126

K.B.	1772		
T-2	5506		
T-1	5540		
Bottineau	5720	Thickness	214

T156N, R84W, S22, NWNW, Anschutz Corp. et al. - Musch No. 1
N.D.G.S. No. 4990

K.B.	1788		
T-2	5692		
T-1	5702		
Bottineau	5932	Thickness	240

T156N, R85W, S4, CNWSW, The Arex Corporation - Clouse No. 1
N.D.G.S. No. 3812

K.B.	1828		
T-2	6035		
T-1	6080		
T.D.	6252		

T156N, R85W, S24, NENE, Wanete Oil Co. - M. O. Lee No. 1
N.D.G.S. No. 52

K.B.	1839		
T-2	5855		
T-1	?		
Bottineau	6100	Thickness	245

T156N, R86W, S6, CNWSW, Lowell J. Williamson Inc. - Pederson No. 1
N.D.G.S. No. 1438

K.B.	2104		
T-2	6732		
T-1	?		
Bottineau	6935	Thickness	203

T156N, R86W, S11, SWNE, Calvert et al. - Troxel No. 1
N.D.G.S. No. 3125

K.B.	1990		
T-2	6335		
T-1	6352		
Bottineau	6562	Thickness	227

T157N, R85W, S16, SE, Pierce Drilling Co. - Kline No. 1
N.D.G.S. No. 18

K.B.	1679		
T-2	6080		
T-1	?		
Bottineau	6296	Thickness	216

T157N, R85W, S21, CSWSW, Sam G. Harrison - Anderson No. 1
N.D.G.S. No. 392

K.B.	1875		
T-2	6098		
T-1	6114		
Bottineau	6326	Thickness	228

T158N, R87W, S8, SWSE, Hanlon Drilling & Lowell J. Williamson Inc. - Enget No. 1
N.D.G.S. No. 1340

K.B.	2027		
T-2	7602		
T-1	?		
Bottineau	6870	Thickness	168

T159N, R87W, S3, CNENW, The Texas Co. - B. T. James No. 1
N.D.G.S. No. 2134

K.B.	1921		
T-2	5962		
T-1	?		
Bottineau	6117	Thickness	155

T160N, R88W, S5, CSESE, Northern Pump Co. - C. J. Johnson No. 1
N.D.G.S. No. 1410

K.B.	1942		
T-2	6103		
T-1	6127		
Bottineau	6245	Thickness	142

WELLS COUNTY

T145N, R68W, S30, CNENE, S. D. Johnson - Hagel No. 1
N.D.G.S. No. 635

K.B.	1783		
T-2	2520		
T-1	2553		
Bottineau	2648	Thickness	128

T145N, R71W, S13, CNWNE, Wilson et al. - George Seibel No. 1
N.D.G.S. No. 384

K.B.	1891		
T-2	3034		
T-1	3064		
Bottineau	3163	Thickness	129

T145N, R72W, S26, CSESE, Cardinal Drilling Co. - Gerhart Bohmiller No. 1
N.D.G.S. No. 385

K.B.	1914.5		
T-2	3280		
T-1	3300		
Bottineau	3404	Thickness	124

T145N, R73W, S28, SWNE, Chevron Oil Co. - Grimm No. 1
N.D.G.S. No. 4252

K.B.	1998		
T-2	3664		
T-1	3702		
T.D.	3798		

T146N, R68W, S8, NENE, Calvert Drilling Inc. - Zwinger No. 1
N.D.G.S. No. 1211

K.B.	1608		
T-1	2357		
Bottineau	2425	Thickness	68

T146N, R73W, S27, NENE, Continental Oil Co. - Lueth No. 1
N.D.G.S. No. 207

K.B.	1933		
T-2	3553		
T-1	3573		
Bottineau	3676	Thickness	123

T147N, R71W, S31, CNENE, Caroline Hunt Trust Estate - Morris Thormodsgard No. 1
N.D.G.S. No. 689

K.B.	1702		
T-2	2975		
T-1	3010		
Bottineau	3100	Thickness	125

T147N, R73W, S16, SWSW, Continental & Pure Oil Co. - Board of University and School Lands No. 1
N.D.G.S. No. 1384

K.B.	1941		
T-2	3600		
T-1	3639		
Bottineau	3727	Thickness	127

T148N, R73W, S10, NESE, D. D. Bills - Hove No. 1
N.D.G.S. No. 4096

K.B.	1640		
T-2	3215		
T-1	3259		
Bottineau	3360	Thickness	145

T148N, R73W, S13, SENW, Wilson et al. - Fauls No. 1
N.D.G.S. No. 336

K.B.	1639		
T-2	3150		
T-1	3190		
Bottineau	3295	Thickness	145

T148N, R73W, S30, NENE, Apco Oil Corporation - Martin No. 1
N.D.G.S. No. 3728

K.B.	1827		
T-2	3523		
T-1	3547		
Bottineau	3644	Thickness	121

T148N, R73W, S34, SWNE, Apco Oil Corporation - Mathison No. 1
N.D.G.S. No. 3754

K.B.	1673		
T-2	3290		
T-1	3314		
Bottineau	3408	Thickness	118

T149N, R73W, S22, CNWNE, Cardinal Petroleum Co. - A. Patzer No. 1
N.D.G.S. No. 3296

K.B.	1622
T-2	3210
T-1	3252
T.D.	3298

T150N, R70W, S32, NWNE, Caroline Hunt Trust Estate - Obed Larson No. 1
N.D.G.S. No. 642

K.B.	1599		
T-2	2672		
T-1	2703		
Bottineau	2775	Thickness	103

T150N, R71W, S34, NENE, Gulf Oil Co. (U.S.) - G. A. Brauer No. 1
N.D.G.S. No. 5092

K.B.	1615		
T-2	2812		
T-1	2844		
Bottineau	2910	Thickness	98

APPENDIX B

CORE, WELL SAMPLE AND THIN SECTION DESCRIPTION

CORE, WELL SAMPLE AND THIN SECTION DESCRIPTION

Wells are listed alphabetically by county and then numerically based on the Standard Land Office Grid System. Thin sections (T.S.) are listed by depth, from stratigraphically highest to lowest.

BOTTINEAU COUNTY

T160N, R81W, S31, SWSWSE, N.D.G.S. no. 38

depth	T.S.	Description
4399-4400		light brown wackestone (intraclastic, clay laminations in part) with intergranular and solution porosity
	4399	crinoidal micritized grain wackestone with high solution porosity
4400-4401		light gray to medium gray mudstone (anhydritic) desiccation cracks
	4400	anhydritic mudstone
4401-4402		buff wackestone (intraclastic) with intergranular and solution porosity
	4401	intraclastic crinoidal skeletal hash micritized grain foraminifera packstone with some solution porosity
4402-4417		light gray grainstone (laminated near base) with intergranular and solution porosity
	4402	crinoidal micritized grain grainstone
	4404	same as above
	4417	same as above
4417-4420		core missing
4420-4447		light gray to dark gray wackestone with shaley laminae (bioturbated, anhydrite infilling some solution porosity)
	4423	slightly laminated crinoidal bryozoan wackestone
	4428.5	same as above
	4438.5	same as above
	4447	laminated crinoidal ostracodal brachiopod wackestone

depth	T.S.	Description
4447-4451		medium gray wackestone with high solution porosity (anhydritic, dolomitic)
	4450.5	crinoidal sparse wackestone
4451-5567		light brown to light gray mudstone to sparse wackestone with solution porosity
	4452	crinoidal brachiopod sparse wackestone with high solution porosity
	4457	mudstone with interbeds of well sorted crinoidal grainstone with high solution porosity
	4459	crinoidal brachiopod sparse wackestone with high solution porosity
	4463	mudstone with solution porosity with some porosity infilled with anhydrite
	4466	same as above
4466-4500		light brown mudstone to wackestone (fractured, anhydritic) with shaley laminations in part
	4468	mudstone with high solution porosity
	4476	whispy shale laminated crinoidal wackestone
	4477	same as above
	4487	same as above
	4488	crinoidal brachiopod wackestone with some solution porosity
	4492A	same as above
	4492B	shale laminated crinoidal brachiopod wackestone
	4493	same as above
	4496	same as above
	4497	same as above
4500-4522		light gray to medium gray mudstone wackestone (fractured, whole rugose coral and brachiopods) with intergranular porosity
	4500	skeletal hash wackestone
	4505	crinoidal brachiopod wackestone

depth	T.S.	Description
	4509	mudstone with solution porosity
	4512A	anhydritic dolomitic mudstone
	4512B	mudstone with solution porosity
	4515	same as above
	4519.5	argillaceous crinoidal brachiopod coral packstone
	4520	crinoidal brachiopod mudstone with high solution porosity
4522-4523		light brown packstone to grainstone (intraclastic)
	4523	crinoidal coral brachiopod packstone
4523-4546		medium gray wackestone to packstone (shaley laminations, whole rugose corals and brachiopods)
	4523	crinoidal brachiopod packstone
	4525A	same as above
	4525B	same as above
	4532	same as above
	4534	crinoidal brachiopod wackestone to packstone
	4539	crinoidal brachiopod packstone
	4539.5	crinoidal mudstone overlying crinoidal brachiopod wackestone
	4940	crinoidal brachiopod packstone
	4544	crinoidal brachiopod wackestone with high solution porosity
4546-4555		core missing
4555-4555.5		anhydrite
4555.5-4561		light gray packstone to grainstone (intraclastic) with some solution porosity
	4557.5	coarse grained crinoidal, brachiopod packstone to grainstone
	4559	coral crinoidal brachiopod wackestone to packstone

depth	T.S.	Description
	4561	coarse-grained crinoidal coral, intraclastic grainstone with intergranular porosity
4561-4577		light gray wackestone (large whole rugose corals and brachiopods, burrowed)
	4562	crinoidal wackestone
	4567	same as above
	4569A	same as above
	4569B	same as above
	4572	crinoidal skeletal hash sparse wackestone with high solution porosity
	4576	crinoidal skeletal hash sparse wackestone
	4577	crinoidal brachiopod coral packstone
4577-4582		light gray to light brown grainstone (coarse-grained) with intergranular porosity
	4577.5	crinoidal brachiopod micritized grain grainstone
	4578	coarse-grained crinoidal brachiopod coral wackestone
	4582	crinoidal coral brachiopod intraclastic grainstone with good intergranular porosity
4582-4606		buff wackestone
	4588	crinoidal brachiopod packstone
	4589	crinoidal brachiopod coral wackestone
	4591	crinoidal micritized grain wackestone
	4592 wit	crinoidal brachiopod micritized grain wackestone with some solution porosity
	4597	crinoidal, brachiopod micritized grain grainstone with fair intergranular porosity
	4602	crinoidal brachiopod coral wackestone
	4604	same as above
	4606	same as above

depth	T.S.	Description
4606-4608		light brown packstone to grainstone (intraclastic)
	4607	crinoidal coral intraclastic grainstone
	4607.5A	same as above
	4607.5B	coral crinoidal, brachiopod intraclastic packstone to grainstone
5608-4613		buff wackestone (few interbeds of mudstone)
	4611	mudstone
	4613	crinoidal skeletal hash wackestone
4613-4625		light gray grainstone (few interbeds of wackestone and packstone, burrowed) with solution porosity
	4614	crinoidal intraclastic brachiopod micritized grain grainstone
	4615	same as above
	4619	same as above
	4621A	same as above
	4621B	crinoidal intraclast brachiopod micritized grain packstone with some solution porosity
	4624A	crinoidal skeletal hash wackestone with some solution porosity
	4624B	same as above
	4625	crinoidal intraclast coral brachiopod packstone to grainstone

T161N, R76W, S22, NENW, N.D.G.S. No. 544

3050-3075		anhydritic; dolomitic mudstone
3075-3085		oolitic grainstone; wackestone to packstone
3085-3115		packstone; mudstone; anhydrite; oolitic grainstone
3115-3185		wackestone; oolitic grainstone; skeletal grainstone; wackestone

T161N, R77W, S22, NESE, N.D.G.S. No. 327

depth	T.S.	Description
3250-3265		anhydrite; anhydritic wackestone
3265-3280		wackestone
3280-3290		dolomitic mudstone
3290-3295		grainstone
3295-3300		micritized oolitic grainstone with some intergranular porosity
3300-3315		oolitic grainstone
3315-3320		wackestone
3320-3335		packstone
3335-3350		wackestone
3350-3430		wackestone to packstone; grainstone; mudstone

T161N, R79W, S21, SESW, N.D.G.S. No. 893

3820-3860		anhydrite; dolomitic mudstone; wackestone
3860-3895		oolitic grainstone with high solution moldic porosity
3895-3900		dolomitic mudstone; crinoidal wackestone
3900-3940		wackestone, with some solution and intergranular porosity
3940-4000		packstone

T161N, R81W, S15, NESW, N.D.G.S. No. 4844

4145-4220		no samples
4220-4316		packstone; wackestone; mudstone

T163N, R75W, S23, NESW, N.D.G.S. No. 503

		core chips
3400-3405		crinoidal, micritized grain wackestone; crinoidal micritized grain grainstone; brachiopod mudstone
3405-3410		crinoidal brachiopod micritized grain grainstone; argillaceous crinoidal brachiopod packstone (evidence of subaerial diagenesis)

T162N, R76W, S18, SESE, N.D.G.S. No. 1302

depth	T.S.	Description
3102-3125		buff to light brown mudstone (dolomitic, desiccation cracks, shaley laminated in parts, bioturbated, anhydritic) with some solution porosity
	3102	anhydritic mudstone
	3103.3	anhydritic mudstone with desiccation crack
	3103.5	laminated mudstone
	3103.8	anhydritic gastropod mudstone with anhydrite infilling moldic porosity
	3105	laminated mudstone
	3109	mudstone with high spherical solution porosity
	3111.5	mudstone with fenestral and moldic porosity, some of which is infilled with anhydrite
	3112.5	anhydrite mudstone
	3114	anhydritic mudstone
	3115	mudstone
	3116	mudstone
	3118	anhydrite
	3121	mudstone
	3123	fine-grained anhydritic mudstone

T163N, R77W, S2, SESW, N.D.G.S. No. 170

3067-3070		anhydrite interbedded with light gray mudstone (dolomitic) and anhydrite and interbedded with laminated mudstone
	3073	
3073-3083		anhydrite ("chicken wire) with interbeds of light gray mudstone (desiccation cracks and soft sediment deformation)
3083-3110		light gray to buff mudstone to wackestone with few interbeds of grainstone with solution and fracture porosity

depth	T.S.	Description
	3086	mudstone
	3087	burrowed micritized grain mudstone
	3089A	micritized grain crinoidal foraminifera coral grainstone with anhydrite infilling porosity
	3089B	same as above
	3090	same as above
	3091	mudstone with solution porosity
	3099	burrowed mudstone
	3105	micritized grainstone mudstone with high spherical moldic porosity
	3108	mudstone with high spherical moldic porosity
3110-3115		buff oolitic packstone to grainstone with some fracture porosity
	3110	oolitic grainstone
	3113	oolitic packstone
	3114	oolitic grainstone with good interparticle porosity
	3115	micritized grain grainstone overlain by oolitic grainstone
3115-3119		light gray mudstone to wackestone (burrowed)
	3117	fine-grained dolomitic mudstone
3119-3131		buff wackestone to packstone with few interbeds of grainstone
	3120	burrowed crinoidal foraminifera brachiopod packstone
	3121	micritized grain crinoidal brachiopod packstone
	3128	burrowed micritized grain brachiopod crinoidal wackestone
	3130	burrowed micritized grain brachiopod crinoidal wackestone with solution and interparticle porosity

depth	T.S.	Description
		sample chips
3131-3140		dolomitized mudstone
3140-3170		packstone to grainstone
3170-3190		grainstone with few mudstone chips
3190-3230		crinoidal coral, brachiopod wackestone to packstone

T164N, R77W, S33, NWNE, N.D.G.S. No. 961

depth	T.S.	Description
2976-2993		buff mudstone (dolomitic) with few interbeds of packstone (anhydrite infilling solution porosity) and anhydrite
	2976	bioturbated mudstone
	2992	anhydrite mudstone with desiccation cracks
2993-2998		buff to dark brown wackestone to packstone (oil stained) with solution porosity
	2996	dolomitic wackestone
2998-3003		brown dolomitic mudstone (slightly anhydritic) with solution porosity
	3000	dolomitic mudstone with secondary anhydrite infilling solution porosity
	3001	same as above
	3002A	anhydritic dolomitic mudstone
	3002B	same as above
3003-3025		brown grainstone (cycles of gradation from grainstone to mudstone, bioturbated oil stained from 3018.5-3025)
	3007A	bioturbated dolomitic mudstone
	3007B	crinoidal brachiopod coral micritized grain wackestone overlain by mudstone
	3011	burrowed dolomitic mudstone with solution porosity
	3018A	dolomitic crinoidal brachiopod micritized grain intraclast wackestone with high solution porosity
	3018B	same as above

T164N, R77W, S33, NESW, N.D.G.S. No. 1011

depth	T.S.	Description
2962-2984		light gray mudstone (dolomitic, bioturbated) with interbeds of anhydrite with fracture porosity (oil stained from 2973-2975)
	2964	interbedded mudstone and anhydrite
	2965	anhydritic mudstone
	2970	same as above
	2973	same as above
	2974	anhydrite crinoidal wackestone
	2979	anhydritic mudstone with some solution porosity
	2981	same as above
	2984	same as above
	2985	same as above
2984-2991		light gray to buff wackestone to packstone
	2986	crinoidal brachiopod foraminifera micritized grain packstone
	2987	crinoidal brachiopod foraminifera wackestone to packstone
	2988	
	2990	
		well cuttings
2991-3070		crinoidal brachiopod wackestone to packstone with a few chips of mudstone and grainstone

BURLEIGH COUNTY

T137N, R77W, S32, SESE, N.D.G.S. No. 756

4010-4070	anhydrite; dolomitic quartz silt mudstone
4070-4090	dolomitic mudstone; crinoidal brachiopod wackestone to packstone
4090-4100	packstone to grainstone; wackestone
4100-4120	packstone; wackestone
4120-4130	wackestone to packstone

LOGAN COUNTY

T136N R71W, S8, CNWSW, N.D.G.S. No. 1346

depth	T.S.	Description
2910-2930		clastic red siltstone with carbonate cement
2930-2940		quartz silt wackestone
2940-2950		clastic silt
2950-2980		mudstone
2980-2990		no samples
2990-3000		packstone with high spherical solution porosity
3000-3010		packstone
3010-3030		oolitic grainstone

T136N, R73W, S6, SWSE, N.D.G.S. No. 590

3250-3270		no samples
3270-3310		dolomitic mudstone
3310-3320		packstone
3320-3340		dolomitic mudstone
3340-3350		mudstone with some solution porosity; packstone
3350-3370		mudstone
3370-3380		mudstone; packstone
3380-3390		wackestone
3390-3400		mudstone
3400-3410		no samples
3410-3415		dolomitized mudstone

MCLEAN COUNTY

T146N, R81W, S10, NE, N.D.G.S. No. 22

5605-5630		anhydritic wackestone to packstone
5630-5640		wackestone to packstone oolite grainstone; anhydrite

depth	T.S.	Description
5640-5660		bioturbated wackestone; packstone
5660-5670		oolitic grainstone; wackestone
5670-5690		packstone; oolitic grainstone
5690-5700		argillaceous mudstone
5700-5720		oolitic grainstone
5720-5730		wackestone to packstone
5730-5740		oolitic grainstone
5740-5770		wackestone; mudstone

T146N, R82W, S32, SESW, N.D.G.S. No. 1516

depth	T.S.	Description
6210-6219		buff wackestone with thin interbeds of shale
	6212.5	crinoidal brachiopod micritized grain wackestone
	6213	same as above
	6218	same as above
	6219	same as above
6219-6234		light gray to dark gray mudstone to wackestone (burrowed) interbedded with shale
	6225A	burrowed dolomitic mudstone with pinpoint solution porosity
	6225B	same as above
	6225C	same as above
	6228	mudstone with good solution porosity
6234-6243		light gray to dark gray wackestone with interbeds of shale
	6237	crinoidal coral micritized grain packstone
6243		contact with Bottineau interval

MORTON COUNTY

T136N, R81W, S29, CNENW, N.D.G.S. No. 26

depth	T.S.	Description
4890-4900		anhydritic dolomitic mudstone with high solution porosity

depth	T.S.	Description
4900-4910		no samples
4910-4942		dolomitic mudstone, wackestone all chips have high solution porosity, some of which is infilled with anhydrite
4942-4960		oolitic grainstone with dolomite cement
4960-4970		oolitic grainstones; wackestone
4970-4980		no samples
4980-4990		grainstone
4990-5010		grainstone
5010-5020		grainstone

T139N, R86W, S30, SWSW, N.D.G.S. No. 133

6760-6790		anhydrite; wackestone; packstone
6790-6820		no samples
6820-6840		wackestone
6840-6870		no samples
6870-6880		wackestone; oolitic grainstone
6880-6910		wackestone to packstone

T139N, R90W, S27, NESW, N.D.G.S. No. 1620

7740-7760		anhydrite; dolomitic mudstone; wackestone
7760-7805		wackestone
7805-7840		oolitic grainstone
7840-7850		packstone
7850-7892		packstone; oolitic grainstone

PIERCE COUNTY

T152N, R74W, S23, SESE, N.D.G.S. No. 3920

3223-3238.5		anhydrite ("chicken wire") interbedded with dolomitic mudstone (iron stained)

depth	T.S.	Description
	3222	fine-grained dolomitic mudstone with high solution porosity
	3228.3	dolomitic mudstone with interbeds of anhydrite
	3230.5	anhydrite
	3233	anhydrite
	3234	laminated mudstone and anhydrite
	3234.5	quartz silt laminated mudstone
	3234.7	mudstone with anhydrite laminations
	3234.9	quartz silt laminated mudstone
	3738	anhydritic dolomitic mudstone
3238.5-3240		light gray mudstone (laminated, dolomitic)
	3240	dolomitic mudstone
3240-3240.5		light gray mudstone (dolomitic) with interbeds of anhydritic mudstone

T157N, R73W, S3, NWSW, N.D.G.S. No. 780

		core chips from samples
2652-2671		anhydrite ("chicken wire")
2671-2675		mudstone to wackestone (fine-grained, iron stained, anhydritic)
2675-2686		mudstone (burrowed, iron stained)

RENVILLE COUNTY

T161N, R55W, S13, SWNW, N.D.G.S. No. 815

5130-5163		mudstone
5163-5176		oolitic grainstone; wackestone to packstone; mudstone
5176-5195		wackestone
5195-5206		sparse wackestone
5206-5225		oolitic grainstone; mudstone to wackestone

depth	T.S.	Description
5225-5235		oolitic grainstone; wackestone
5235-5240		oolitic grainstone
5240-5280		wackestone; mudstone
5280-5285		wackestone to packstone
5285-5290		mudstone
5290-5325		wackestone to packstone; mudstone

SHERIDAN COUNTY

T146N, R74W, S16, SWSW, N.D.G.S. No. 735

3880-3920		anhydrite; dolomitic mudstone; wackestone to packstone
3920-3930		dolomitic mudstone
3930-3940		oolitic grainstone; skeletal grainstone; packstone
3940-3970		dolomitic mudstone; packstone; oolitic grainstone
3970-3980		grainstone
3980-4020		packstone

T147N, R75W, S1, NENE, N.D.G.S. No. 684

3805-3860		anhydrite; dolomitic mudstone
3860-3870		wackestone
3870-3880		mudstone
3880-3910		wackestone to packstone; anhydrite
3910-3920		wackestone to packstone
3920-3950		dolomitized mudstone; wackestone

SIOUX COUNTY

T148N, R76W, S15, NENE, N.D.G.S. No. 665

4040-4100		anhydrite; dolomitic mudstone; wackestone
4100-4130		mudstone; packstone

depth	T.S.	Description
4130-4160		wackestone to packstone
416004170		wackestone to packstone; mudstone
4170-4190		packstone

WELLS COUNTY

T146N, R68W, S8, NENE, N.D.G.S. No. 1211

2350-2400		anhydrite; mudstone with high solution porosity
2400-2410		wackestone
2410-2420		oolitic grainstone with good porosity
2420-2430		wackestone

T146N, R73W, S27, NENE, N.D.G.S. No. 207

3603-3615		oolitic grainstone; mudstone; wackestone
3615-3625		grainstone with dolomitic cement; packstone wackestone; mudstone
3625-3630		oolitic grainstone
3630-3680		wackestone to packstone

T147N, R73W, S16, SWSW, N.D.G.S. No. 1384

		core chips
3600-3616.5		anhydrite; packstone
		well sample
1616.5-3650		mudstone (bioturbated)
3650-3660		wackestone
3660-3670		wackestone (anhydrite infilling some solution porosity)
3670-3680		no samples
3860-3690		mudstone with high porosity; wackestone
3690-3700		grainstone; mudstone
3700-3710		no samples
3710-3730		grainstone; mudstone; wackestone; packstone

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