1979

Depositional environments and diagenesis of the Mississippian Bottineau interval (Lodgepole) in North Dakota

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DEPOSITIONAL ENVIRONMENTS AND DIAGENESIS OF THE MISSISSIPPIAN BOTTINEAU INTERVAL (LODGEPOLE) IN NORTH DAKOTA

by
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Bachelor of Science, University of Wisconsin, 1974

A Thesis

Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota

May
1979

This thesis submitted by Thomas J. Heck 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.

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ACKNOWLEDGMENTS

I would like to thank my committee members, Drs. Lee Gerhard, John Reid, and Frank Karner for their help in the preparation of this manuscript. I would also like to thank Dr. Timothy Cross for his help in the initial planning of this study. Dr. David Johnson critically read this manuscript and gave many helpful suggestions. Mr. Sidney Anderson was available for consultation on problems dealing with well log correlation. Mr. John Himebaugh also helped by discussing problems and making helpful comments on interpretations and procedures.

The North Dakota Geological Survey generously provided funding and the use of facilities. Further equipment and supplies were provided by grants to the Carbonate Research Laboratory at the University of North Dakota from the petroleum industry.

Finally, I would like to thank Mrs. Lorraine Rose for the typing of this manuscript and acknowledge my parents for encouraging me during the course of this study.

ABSTRACT

Bottineau interval rocks from the North Dakota part of the Williston Basin comprise a single marine transgression/regression cycle. Early Mississippian (lower Scallion subinterval) marine transgression from the restricted depositional environment of the Bakken Formation resulted in normal marine circulation. Six major facies were developed: (1) the central basin, (2) basin flank, (3) open shelf, (4) crinoidal mudstone, (5) gray shale, and (6) restricted shelf. Marine transgression continued until upper Scallion subinterval time, by which time the open shelf facies had already prograded over the gray shale and crinoidal mudstone facies.

Marine regression had begun by middle Bottineau interval (Virden subinterval) deposition. Three younger shallow water facies were developed along the margin of the basin: (1) the pelletal grainstone, (2) oolite grainstone, and (3) lagoonal. These facies prograded basinward over deeper water facies as marine regression continued until, by Flossie Lake subinterval time, these shallow water facies were being deposited in the central basin area. Bottineau interval sedimentation terminated with continued marine regression and a transition to deposition of shallower water Tilston interval sediments.

Two diagenetic provinces, basin and shelf, with different diagenetic histories, were identified in Bottineau interval rocks. Diagenetic processes were post- or pre-lithification events. Pre-

lithification processes included biologic activity, compaction, soft sediment deformation, pyrite replacement, cementation, and neomorphism. Biologic activity occurred early, both during and after deposition. Pyrite replacement, soft sediment deformation, precipitation of fringing cement, and microstylolitization occurred shortly after deposition. Later precipitation of equant and overgrowth cements prevented further microstylolitization in cement-lithified fabrics. All pre-lithification processes ceased once cementation and neomorphism had completely lithified the sediments.

Post-lithification processes included stylolitization, solution, fracturing, silicification, hematite replacement, dolomitization, and anhydritization. Stylolitization and fracturing began after complete lithification, as did silicification which produced chert nodules in the restricted shelf facies. This was followed by hematite replacement of matrix and allochems. Solution voids formed prior to, or during dolomitization as meteoric waters dissolved skeletal allochems. Anhydritization was the last event observed to have altered Bottineau interval rocks.

Areas of potential petroleum production exist from the L_2 subinterval in northwestern North Dakota, from structural traps resulting from salt solution of the Prairie Formation in north-central North Dakota, and from structural and stratigraphic traps along the erosional unconformity in eastern North Dakota.

INTRODUCTION

Purpose

Little petroleum has been discovered in Bottineau interval rocks in North Dakota compared to rocks of the same interval in Manitoba and Saskatchewan and to younger Madison Formation rocks in North Dakota. The purpose of this study is to identify the depositional environments and diagenetic history of Bottineau interval rocks in North Dakota and relate them to petroleum production.

Area of Study

The area involved in this study is approximately 53,000 square miles (135,000 square km) covering the western two-thirds of North Dakota (Figure 1); the subsurface extent of the Bottineau interval. No attempt was made to extend this study outside of North Dakota because of a lack of well control and difficulty in obtaining samples from bordering states and provinces.

Regional Setting

The Williston Basin is an intracratonic basin covering approximately 134,000 square miles (348,000 square km) in North Dakota, South Dakota, Montana, Manitoba, and Saskatchewan (Laird, 1956). Williston Basin rocks range in age from Precambrian to Recent with Mississippian rock thickness (Figure 2) ranging from over 2,500 feet (760 m) at the Mississippian depocenter to zero along the erosional unconformity in eastern North Dakota (Carlson and Anderson, 1965).

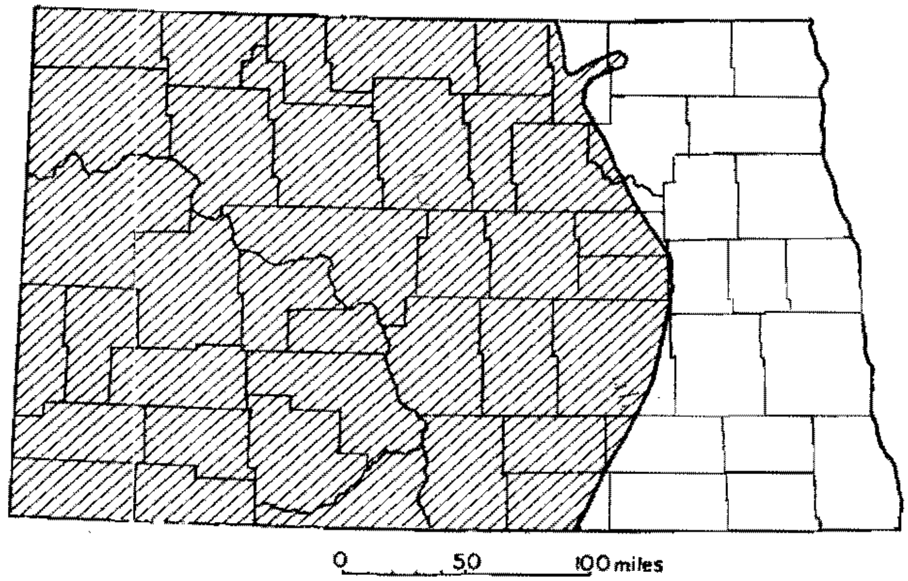


Fig. 1. Study area in North Dakota, showing approximate eastern limit of Bottineau interval rocks.

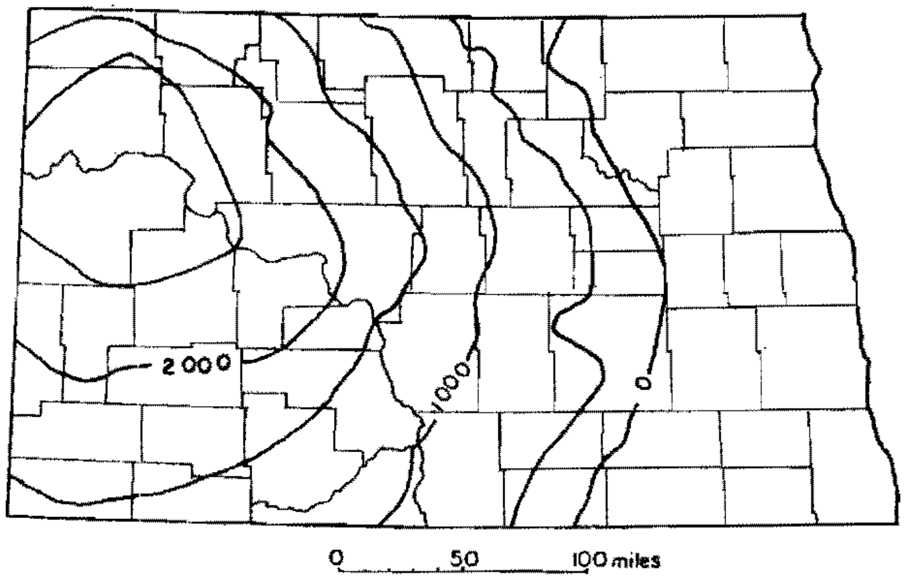


Fig. 2. Total Mississippian System thickness in North Dakota including the Madison, Kibbey, Otter, and Heath Formations (after Carlson and Anderson, 1965). Contour interval is 500 feet.

The major structural features in North Dakota are the Nesson and Cedar Creek Anticlines (Figure 3). Some minor structural features include the Stutsman, Foster, Burleigh, and Cavalier highs (Figure 3) of which only the Foster and Stutsman highs were active during Bottineau interval sedimentation (Ballard, 1963). Another structural feature is the Mandak Embayment located in southwestern Manitoba and north-central North Dakota (McCabe, 1961).

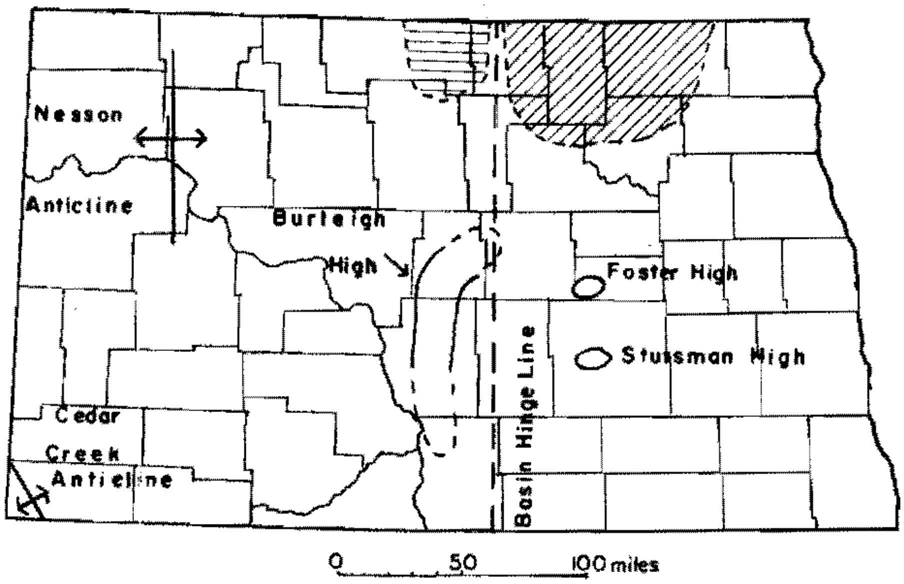
During lower Bottineau interval sedimentation the basin hinge line was located near the 100° meridian (Bjorlie, 1978). A slight compression of structure contours and a relatively uniform thickness for total Bottineau interval rocks can be observed in this area (Plates 1 and 2), indicating that the hinge line was located in this area during all of Bottineau interval time.

Stratigraphy

Underlying Strata

Bottineau interval rocks conformably overlie the upper shale unit of the Bakken Formation in northwestern North Dakota (Figure 4). As originally described by Nordquist (1953), the Bakken Formation consists of three onlapping units: a lower black radioactive shale, a middle calcareous siltstone to very fine grained sandstone, and an upper black radioactive shale.

During Upper Devonian-Lower Mississippian time major uplift and erosion occurred along the margins of the Williston basin contemporaneously with Bakken Formation deposition in the central basin area (Sandberg, 1964) which resulted in a slight angular unconformity between Bottineau interval rocks and the underlying Devonian



Area in which the Cavalier High migrated during the Paleozoic Era (after Ballard, 1963).

ManDak Embayment

Fig. 3. Location of Structural Features in North Dakota.

Plate 1. Isopach map of Bottineau interval rocks in North Dakota. Contour interval is 100 feet.

PLATE 1
PAGE 7

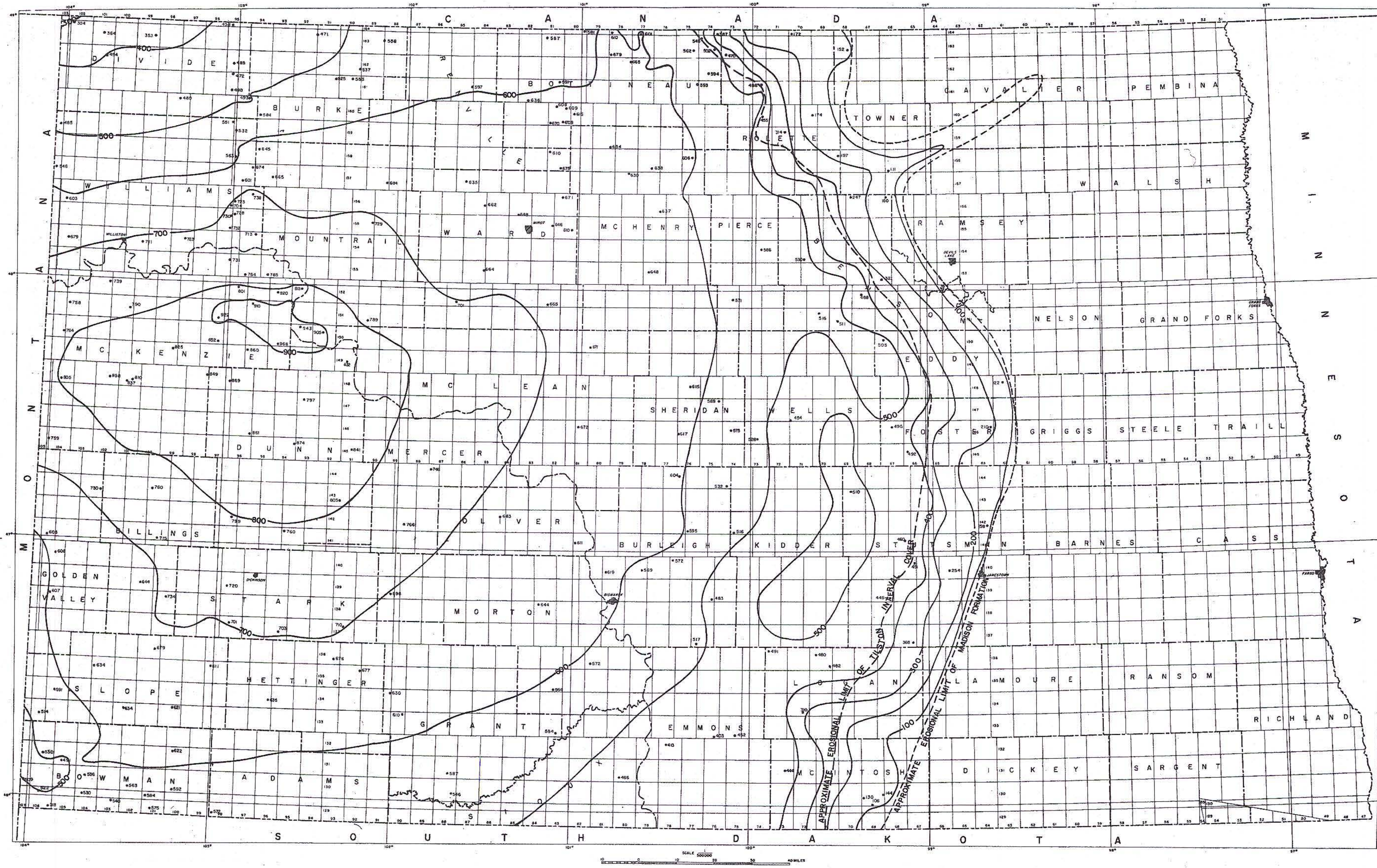
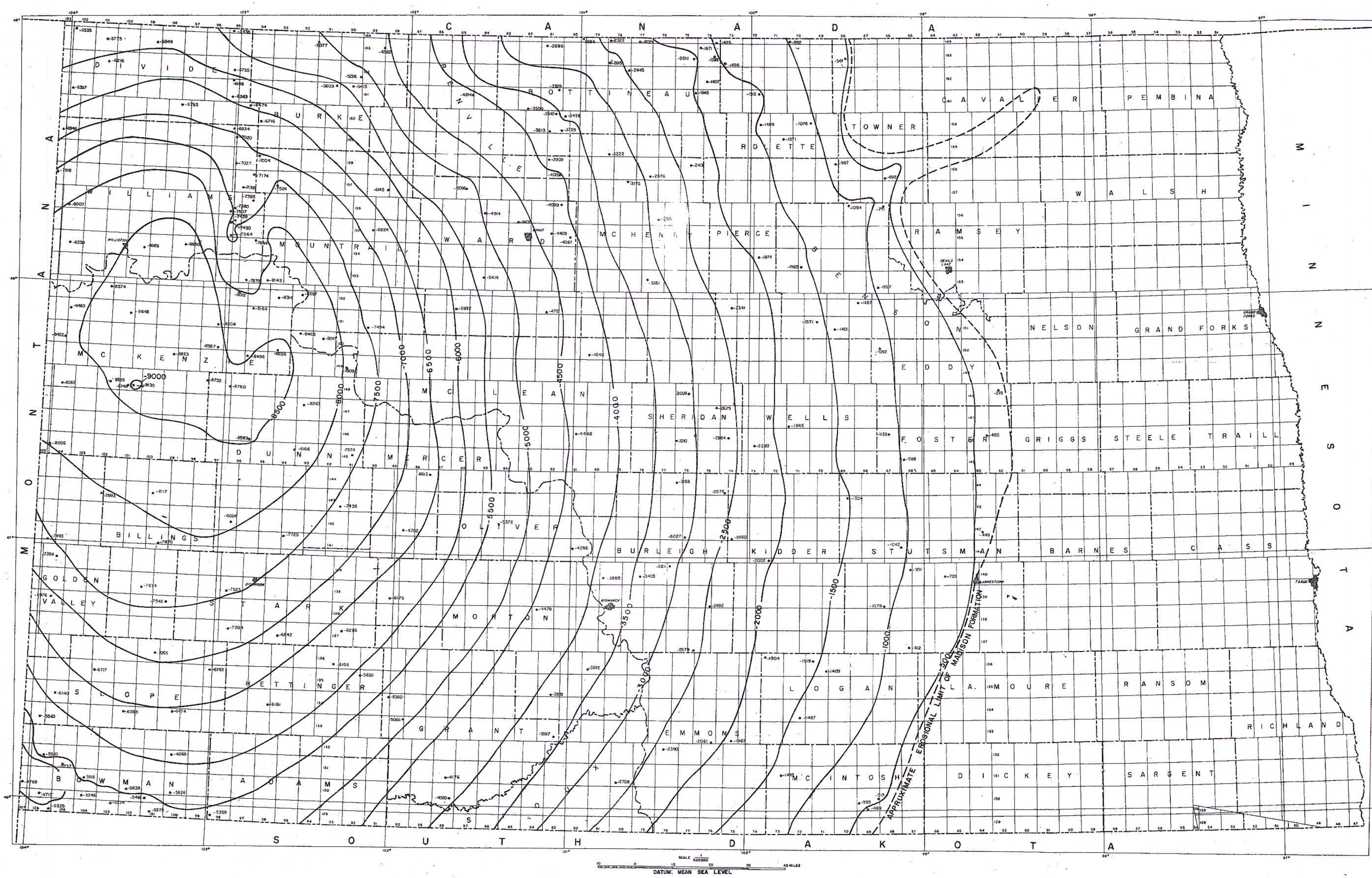


Plate 2. Structure contour map of the basal Bottineau interval in North Dakota. Contour interval is 500 feet.

PLATE 2
PAGE 9



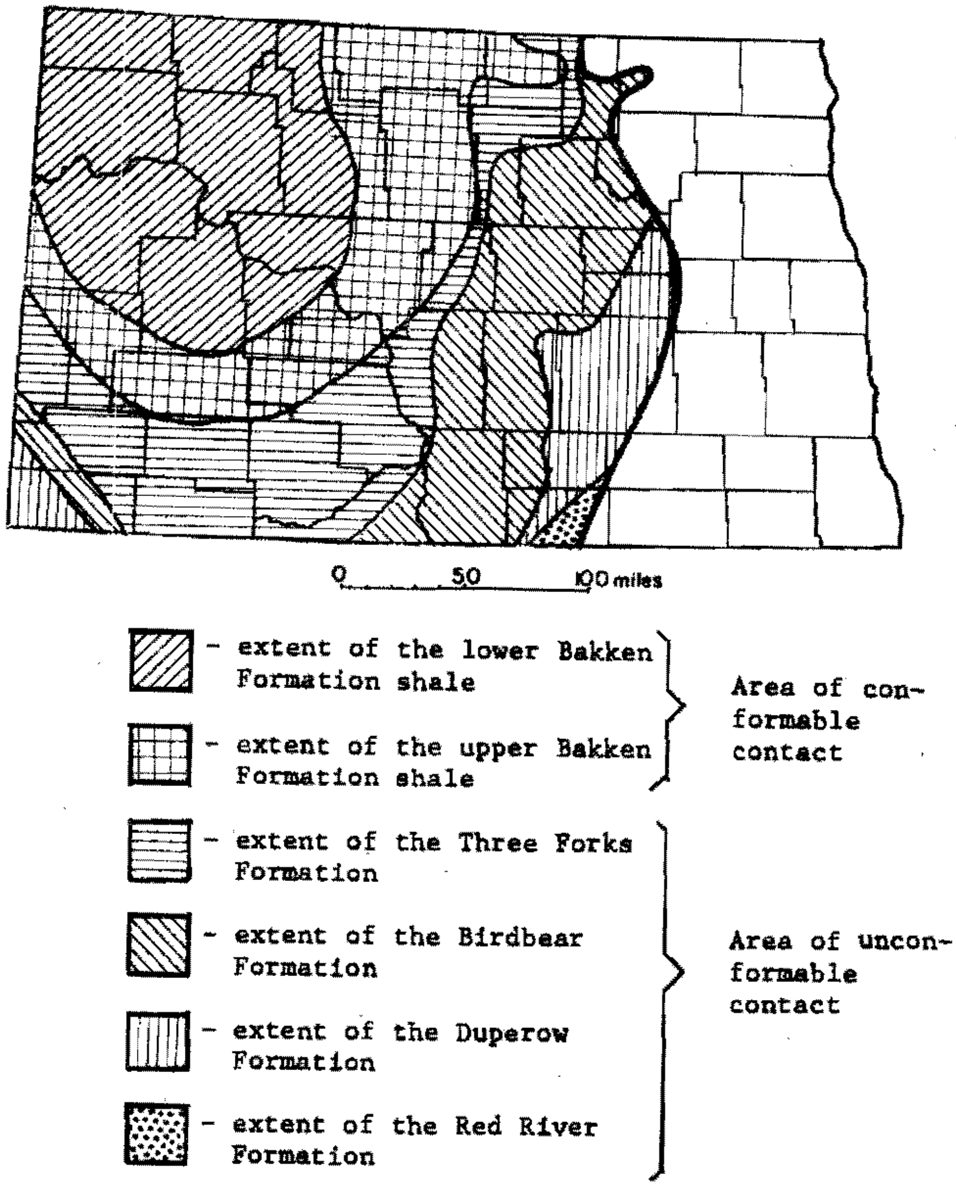


Fig. 4. Generalized subcrop map of strata underlying Bottineau interval rocks showing areas of conformable and unconformable contacts (after Carlson and Anderson, 1965).

strata (Figure 5).

Along the Cedar Creek Anticline Bottineau interval rocks unconformably overlie the Devonian Duperow Formation. This unconformity was the result of post-Bakken uplift and erosion on the anticline (Sandberg and Hammond, 1958). Sandberg and Hammond also report that post-uplift erosion removed variable amounts of Devonian strata concurrent with deposition of the Englewood Formation to the south. An early Mississippian marine transgression resulted in deposition of Bottineau interval sediments over the anticline.

Study of Carlson and Anderson's paper (1965, figs. 10-26) and mechanical logs reveals a more significant unconformity exists in the southeastern Bottineau interval subcrop. Here, Bottineau interval rocks overlie Ordovician rocks of the Red River Formation (Figure 4).

The uppermost surface of the Bakken Formation, where present, is considered to be the basal contact of the Bottineau interval (Figure 4). The upper shale unit of the Bakken Formation is a radioactive black shale and the contact is picked at the uppermost abrupt decrease in gamma ray counts (NDGS Well. No. 4725; depth 11,119; see Plate 3 for this and all subsequent well locations).

Where the Bakken Formation is absent, such as along the eastern and southern margins of the Williston basin in North Dakota, correlation is more difficult. In these areas the basal contact is picked at the unconformity between the Upper Devonian Three Forks Formation (NDGS Well No. 693, 5177), Birdbear Formation (NDGS Well No. 689; 3620), and the Duperow Formation (NDGS Well Nos. 287; 1933 and 3312; 7596), Finally, in the southeastern Bottineau interval subcrop area the underlying strata is the Ordovician Red River Formation.

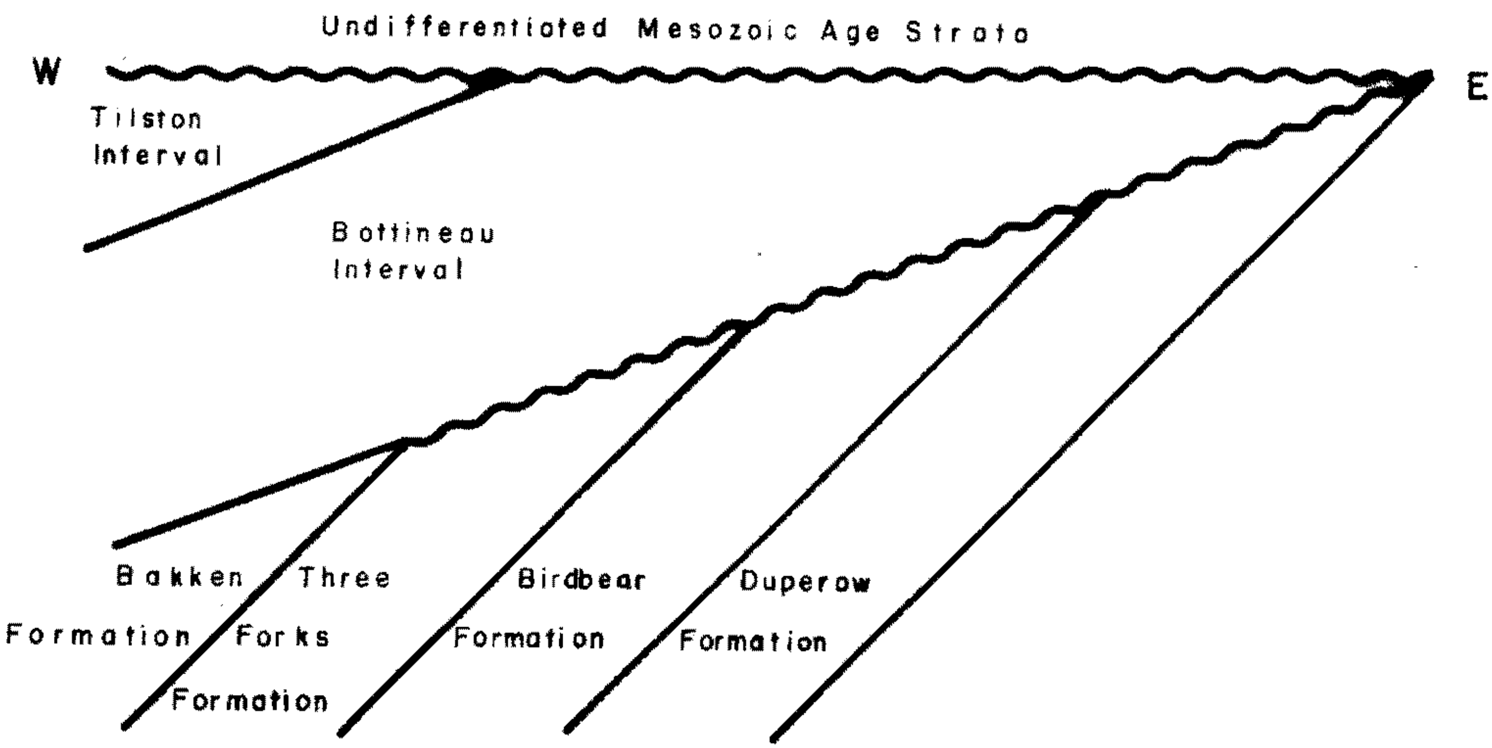


Fig. 5. Generalized E-W cross-section showing (1) angular unconformity between Bottineau interval and Devonian strata, (2) erosional unconformity between Mississippian and Mesozoic strata, (3) conformable contact between Bottineau interval and Bakken Formation strata. Not to scale.

Overlying Strata

The upper contact of the Bottineau interval varies, depending upon whether post-Mississippian erosion has removed the Tilston interval cover (Figure 5). Where the Tilston interval is present, a decrease in gamma ray log and SP-log curve values occurs. The SP log curve is gradational, with a series of staggered decreases (see Plate 3). The top of the Bottineau interval is picked at the lower, and generally greatest, decrease in SP curve value (NDGS Well No. 22, 5780). The gamma ray log curves exhibit a similar but lesser decrease and the contact is picked half-way between the maximum and minimum values observed (NDGS Well No. 693; 4565).

Where the Tilston interval is absent, the upper contact is picked at the lower increase in resistivity log values and/or a decrease in SP and gamma ray log curve values (NDGS Well No. 403, 2060).

Thickness

Bottineau interval rocks range in thickness from 900 feet (275 m) in the central basin area to zero along the erosional limit in eastern North Dakota (Plate 1). In western and central North Dakota Bottineau interval thickness is highly variable. In central North Dakota thickness changes are due, in part, to post-Mississippian erosion. McCabe (1961) postulated that on the basis of observed isopach gradients, Mississippian rocks once extended approximately 150 miles east of their present limit. Thickness variations in north-central North Dakota are apparently due to Devonian and Mississippian salt solution in the Middle Devonian Prairie Formation (Walker, 1957). Thickness changes in younger rocks have been reported over short distances along the solution edge of the Prairie Formation (Anderson and Hunt, 1964).

Thickness variations can also be seen in western North Dakota. Thinning over the crest of the Cedar Creek Anticline suggests that it was a positive feature during Bottineau interval sedimentation (Plate 1). This is supported by the presence of shelf sediments, consisting of oolitic and skeletal grainstones and packstones, in an otherwise basinal depositional setting.

There is no evidence that the Nesson anticline was positive during Bottineau interval sedimentation. Isopachs show no thinning over the crest of the anticline and sediments are basinal in depositional setting. Structural relief (Plate 2) observed along the crest of the anticline may be due to post-depositional movements. Laird and Folsom (1956) report that the crest of the anticline migrated approximately one mile (1.6 km) to the east between Mission Canyon and Greenhorn deposition. They suggest that intermittent basement faulting may be the mechanism of deformation.

Other thickness variations are interpreted to be the result of different rates of subsidence and sedimentation. During Mississippian time the depocenter of the Williston Basin was located in what is now west-central North Dakota (Carlson and Anderson, 1965). The greater accumulation of sediments in this area is the result of greater subsidence, coupled with high rates of sedimentation. Northwestern North Dakota was apparently a more stable area during this time. In this area Bottineau interval sediments thin to the northwest (Plate 1). The lesser sediment accumulation in this area may be due to less subsidence, less sedimentation, or a combination of both.

One small anomalous area of unusual structural relief is in McKenzie County (Plate 2). This area is the Red Wing Creek Field which has been interpreted to be an astrobleme, or meteorite impact crater, created during Jurassic time (Parson et al., 1975).

Methods of Study

This study is based on cores, cuttings, and well logs from the North Dakota Geological Survey's Core and Sample Library and well log files at Grand Forks, North Dakota. Thin sections, acetate peels, and core slabs were prepared on equipment purchased from petroleum industry grants for the Carbonate Studies Laboratory at the University of North Dakota. Calcite determination was based on Alizarin Red "S" staining, after a technique developed by Friedman (1959). Further mineralogical and cementation studies were made using a Cathodoluminescence unit at the Department of Geology, University of North Dakota, and examination of thin sections and acetate peels stained with Alizarin Red "S" and potassium ferricyanide according to procedures described by Evamy (1963). Cores, cuttings, acetate peels, and thin sections were classified according to Dunham's (1962) classification.

Twenty four cores, which vary in stratigraphic position and length, were studied from Bottineau interval rocks. Most of the available core is located in the northeastern Bottineau interval subcrop with the remainder being scattered throughout the state (Figure 6). Core descriptions (appendix C) were made using a hand lens and

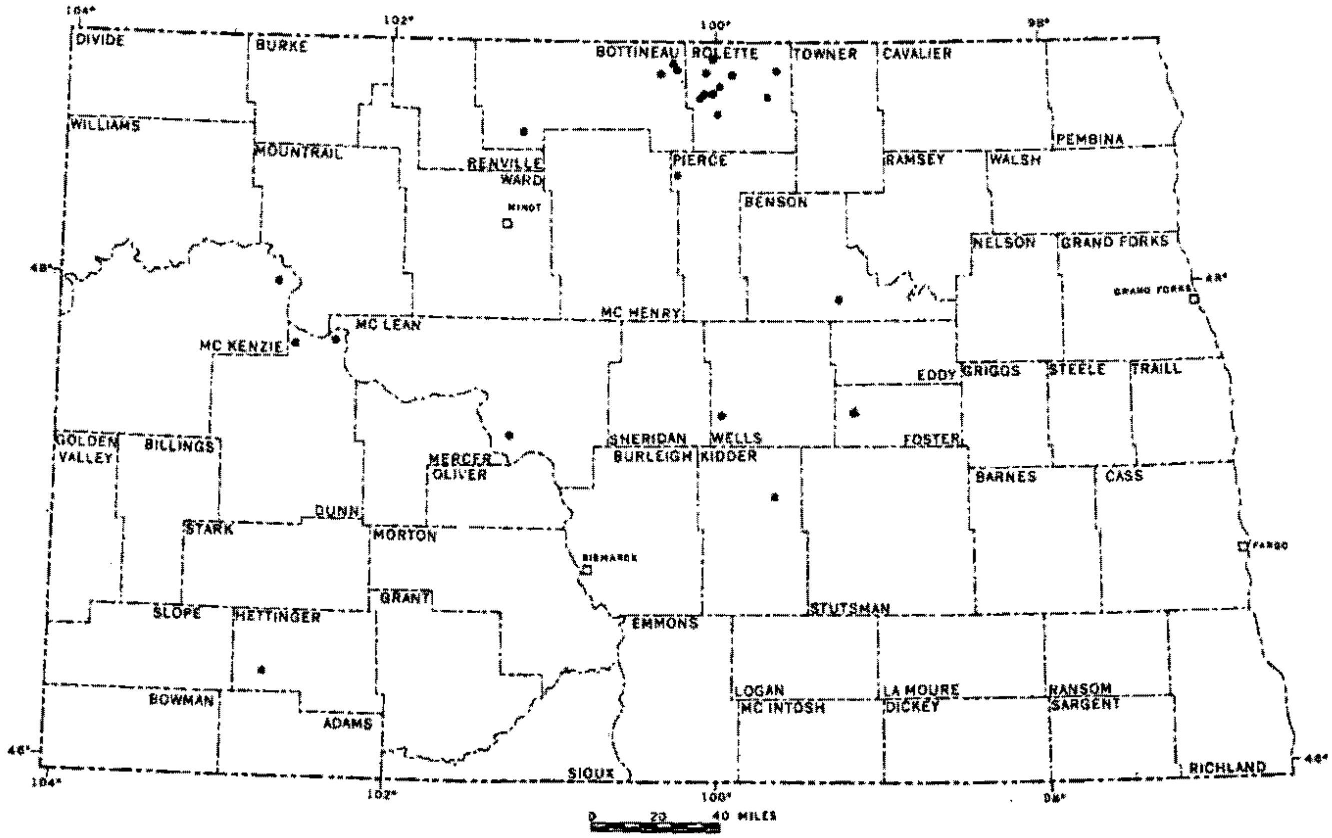


Fig. 6. Location of studied wells with Bottineau interval core in North Dakota (see appendices A and C for precise locations and descriptions).

microscopic examination of slabbed surfaces.

Cuttings, however, are available for most wells drilled in North Dakota. From samples, general reconnaissance was made to determine areas of interest for study in greater detail (Figure 7). A binocular microscope was used for sample description (appendix D); transmitted light was used for viewing wet chips and reflected light for dry chips.

Over 400 well logs from locations scattered throughout the state were studied to determine thickness, structural relief, and correlation of Bottineau interval rocks (appendices A and B).

Previous Work

The name Madison Group was first used by Peale (1893) who divided the Carboniferous strata of Montana into the Madison and Quadrant Formations (table 1). He indicated that good exposures of these formations

TABLE 1

MADISON FORMATION TERMINOLOGY

<table>
<tr><th colspan="2">Peale 1893</th><th colspan="2">Weed 1899</th><th colspan="2">Collier & Cathcart 1922</th><th colspan="2">Sloss & Hamblin 1942</th><th colspan="2">Smith 1960</th></tr>
<tr><td rowspan="3">MADISON FORMATION</td><td>Jaspery Limestone</td><td rowspan="3">MADISON FORMATION</td><td>Castle Limestone</td><td rowspan="3">MADISON GROUP</td><td rowspan="2">Mission Canyon Formation</td><td rowspan="3">MADISON GROUP</td><td rowspan="2">Mission Canyon Formation</td><td rowspan="3">MADISON FORMATION</td><td>Charles Facies</td></tr>
<tr><td>Massive Limestone</td><td>Woodhurst Limestone</td><td>Mission Canyon Facies</td></tr>
<tr><td>Laminated Limestone</td><td>Paine Shale</td><td>Lodgepole Formation</td><td>Lodgepole Formation</td><td>Lodgepole Facies</td></tr>
</table>

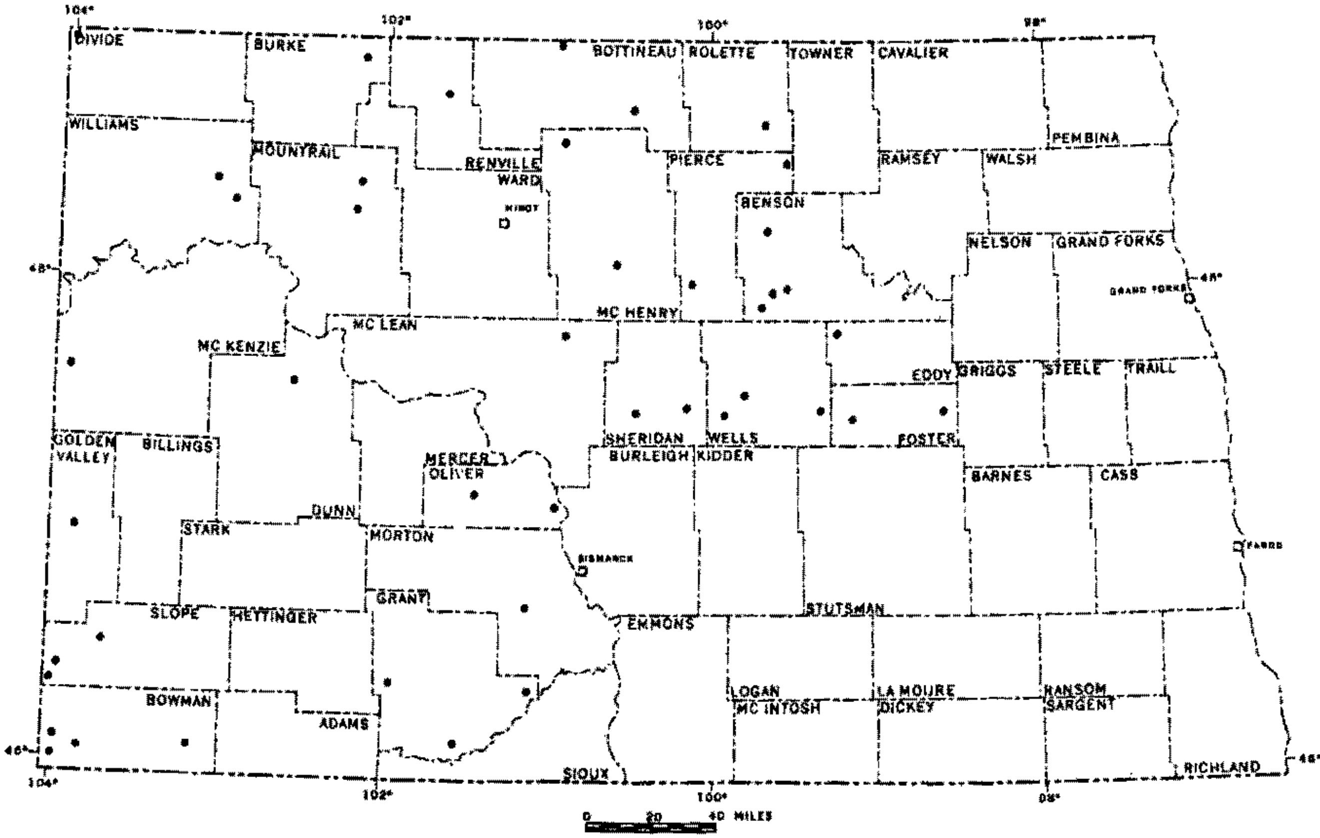


Fig. 7. Location of studied wells with cuttings in North Dakota (see appendices A and D for precise locations and descriptions).

are found in the central Bridger Range near Three Forks, Montana, but failed to designate a type section. Peale also divided his Madison Formation into three units: a lower laminated limestone, a middle massive limestone, and an upper "jaspery" limestone (Peale, 1893).

Weed (1899) considered the type section of the Madison Formation to be in the Madison Range of Montana but also failed to designate a type section. He also divided the Madison Formation into three units, calling them the lower Paine Shale, middle Woodhurst Limestone, and upper Castle Limestone.

Collier and Cathcart (1922) later elevated the Madison Formation to group status and named the included formations the Lodgepole and Mission Canyon after canyons of the same names in what they considered to be the type section of the Madison Group, the Little Rocky Mountains of Montana. Collier and Cathcart's terminology was used by Sloss and Hamblin (1942), who considered Weed's Castle Limestone to be the faunal and lithologic equivalent of Collier and Cathcart's Mission Canyon Formation. The Paine Shale and Woodhurst Limestone were not mappable as formations so Sloss and Hamblin proposed that they be considered members of the Lodgepole Formation. They also considered the type section of the Madison Group to be in the Little Rocky Mountains but failed to designate a type section.

Holland (1952) designated a type section for the Madison Group on the north bank of the Gallatin River near Logan, Montana, and Knechtel, Smedley, and Ross (1954) proposed a type section for the Lodgepole Formation in the Little Rocky Mountains, Montana. They also agreed with Holland that the type section of the Madison Group was near Logan

Montana. However, Holland; Knechtel, Smedley, and Ross; and other workers failed to give complete locations, faunal data, and/or descriptions of the sections in which they were working. Sando and Dutro (1974) did further field studies on the type sections, reestablishing previous type sections and detailing all missing data for the Madison Group and Lodgepole Formation type sections. In addition, they proposed and described type sections for the Paine Shale and Woodhurst Limestone members of the Lodgepole Formation.

Despite the above literature which, since Collier and Cathcart's paper (1922), describes the Madison as a group, this study will follow the current North Dakota Geological Survey and refer to the Madison as a formation. The Lodgepole, Mission Canyon, and Charles will be considered as facies of the Madison Formation. This terminology is used because Madison rocks were originally described as a formation (Peale, 1893) and it is more convenient for work in the North Dakota part of the Williston Basin because of the complex intertonguing relationship of the Mission Canyon and Charles facies (S. B. Anderson, N.D.G.S., Verbal Communication, 1979).

The Madison Formation in North Dakota has been subdivided into informal units called intervals, which are based on laterally continuous mechanical log marker horizons. Fuller (1956) divided the Madison Group into units using thin areally extensive anhydrite beds in southeastern Saskatchewan. He considered these marker beds to be nearly time-parallel and correlative over wide areas. The Saskatchewan Geological Society (1956) redefined the marker horizons and named the units "Beds." These beds were named, in ascending order, the Souris Valley, Tilston, Frobisher-Alida, Midale, and Poplar (table 2).

TABLE 2

MADISON FORMATION SUBDIVISION TERMINOLOGY

Fuller 1956				Saskatchewan Geological Society 1956		Smith 1960	
MADISON GROUP	CHARLES EVAPORITES		Poplar Beds	MADISON GROUP	Poplar Beds	MADISON FORMATION	Poplar Interval
	MADISON LIMESTONE	UPPER	Ratcliffe Beds		Ratcliffe Beds		Ratcliffe Interval
			Hastings-Frobisher Beds		Midale Beds		
			Forget-Nottingham Beds		Frobisher-Alida Beds		Frobisher Alida Interval
			M. C. 1 Limestone		Tilston Beds		Tilston Interval
		LOWER			Souris Valley Beds		Bottineau Interval

Fuller's marker bed concept was also accepted by the North Dakota Geological Survey but his marker beds were considered unsuitable for correlation in North Dakota (Smith, 1960). Smith subsequently chaired a committee which redefined the units on the basis of two basin-wide marker horizons. The committee divided the Madison Formation into five intervals, the Bottineau, Tilston, Frobisher-Alida, Ratcliffe, and Poplar. The Smith Committee also reclassified the Lodgepole, Mission Canyon, and Charles as facies, rather than formations of the Madison.

Various workers in the Virden-Roslea area of Manitoba have proposed local systems of subdividing the Lodgepole Formation. Stanton (1956) proposed a more regional system for correlation (table 3) although even his units are applicable only in the eastern marginal area of the Williston Basin. He proposed that the Lodgepole Formation be divided

TABLE 3

BOTTINEAU INTERVAL TERMINOLOGY

<table>
<tr><th colspan="2">Stanton
1956</th><th colspan="2">McCabe
1963</th><th colspan="2">NDGS, this report</th></tr>
<tr><td rowspan="4">LODGEPOLE FORMATION</td><td>unnamed</td><td rowspan="4">LODGEPOLE FORMATION</td><td>Flossie Lake Member</td><td rowspan="4">BOTTINEAU INTERVAL</td><td>Flossie Lake subinterval</td></tr>
<tr><td>Whitewater Lake Member</td><td>Whitewater Lake Member</td><td>Whitewater Lake subinterval</td></tr>
<tr><td>Virden Member</td><td>Virden Member</td><td>Virden subinterval</td></tr>
<tr><td>Scallion Member</td><td>Scallion Member</td><td>Scallion subinterval</td></tr>
</table>

into three members: the Scallion, Virden, and Whitewater Lake. He also noted the presence of younger Lodgepole sediments but did not name them. McCabe (1963) proposed that this previously unnamed upper unit be called the Flossie Lake member of the Lodgepole Formation.

The above terminology has been informally accepted for use by the North Dakota Geological Survey (S. B. Anderson, N.D.G.S., Verbal Communication, 1978). In this report the names of these units are used but they are considered as subintervals of the Bottineau interval.

FACIES DESCRIPTIONS

Introduction

During Bottineau interval sedimentation a pattern was developed similar to that of the present day Bahama Banks. A sequence of facies was developed which ranged from relatively deep water deposits in the central basin to shoal, shelf, and lagoon sediments along the basin margin. Six facies were developed during lower Scallion time and will be described from deepest water to shallowest water depositional environment. Three younger facies, developed during Virden time, also will be described from deepest to shallowest water depositional environment.

Central Basin Facies

The central basin facies consists of dark gray to black skeletal packstone pods in thinnly bedded dark gray to black mudstones and wackestones (Figure 8). Irregular thin argillaceous laminations are abundant and core samples break both along these laminae and randomly throughout the core. Thin (1-2 mm) chips flake off these break surfaces making core reconstruction difficult. A few thin (50-75 mm) black shale beds are found randomly distributed within this facies. Pyrite is abundant; vertical burrows, horizontal feeding traces, and flecks of organic material are common (Figure 9). Small scale current bedding is rare; no large scale features were observed.

This facies was deposited in the central area of the Williston Basin throughout Bottineau interval sedimentation (Figure 10; see also

Fig. 8. Photomicrograph of the contact between lower skeletal packstone and upper skeletal mudstone. Plane polarized light. Thin section number 793-50.

Fig. 9. Photomicrograph of burrows in mudstone. Note the flattened shape, darker color, and finer grain size of burrows compared to the surrounding rocks. Plane polarized light. Thin section No. 793-4.


2 mm


2 mm

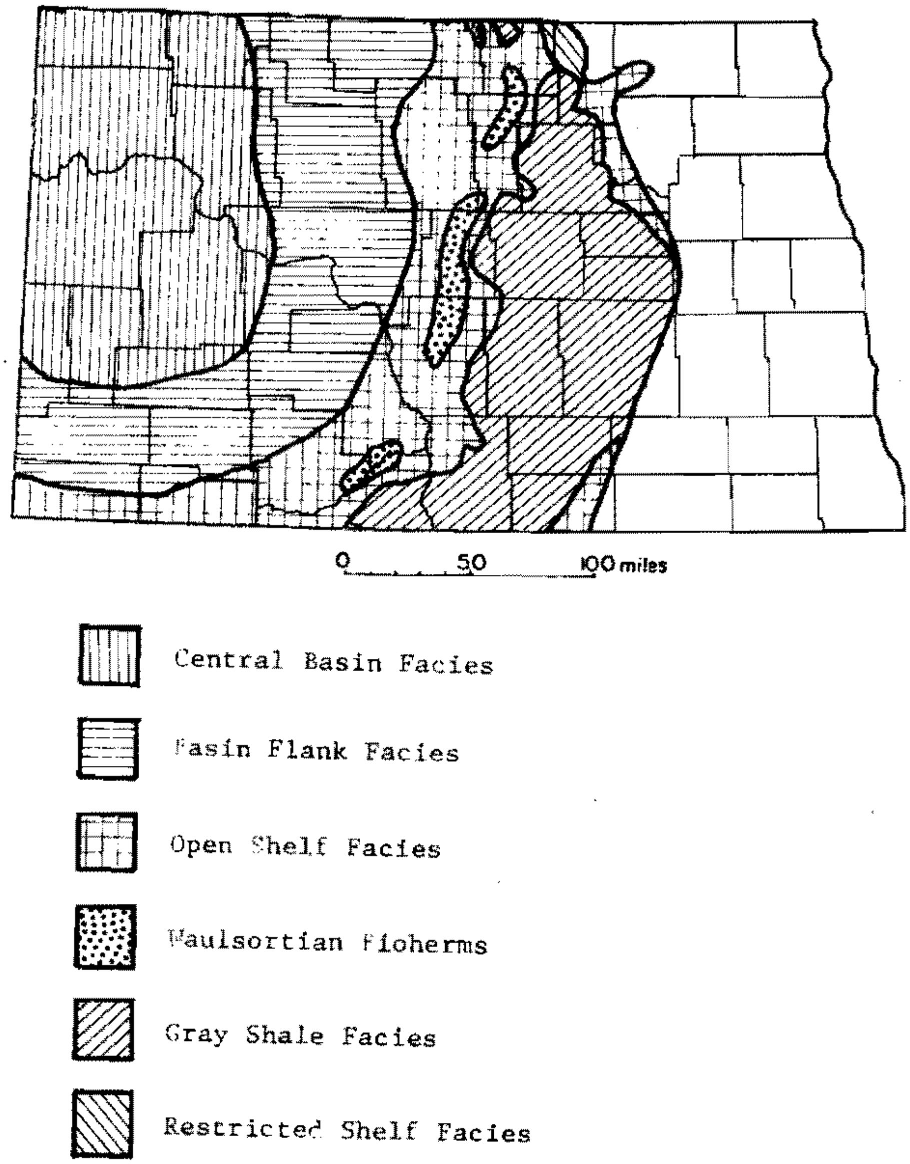


Fig. 10. Facies distribution during lower Scallion subinterval time.

Figures 17 and 19). Based on (1) tectonic setting, (2) observed lithology, (3) observed fauna and faunal distribution, (4) bedding, and (5) a similarity to documented deep water carbonates, deposition is interpreted to have occurred in the deepest waters during Bottineau interval sedimentation.

During this time the depocenter was in west-central North Dakota where the greatest sediment accumulation presently exists (Plate 1). Gallup and Hamilton (1953) report that the Williston Basin was connected to a geosyncline in western Montana and southeastern Idaho by the Central Montana Trough. Andrichuk (1955) suggested that this trough was mildly unstable during the Mississippian Period and that a basinal environment existed in northeastern Montana and northwestern North Dakota. Smith (1972, 1977) and Nordquist (1953) noted increased Lodgepole Formation (Bottineau interval) thicknesses in the central Montana area. Nordquist's (1953, fig. 6) isopach closely approximates the thicknesses observed in this study although he did not extend his study far into North Dakota. Maximum Bottineau interval thicknesses occur in northeastern McKenzie County and this area therefore is interpreted to have been the depocenter during Bottineau interval sedimentation. This area is also interpreted to have been less stable than the Central Montana Trough because of the greater sediment accumulation in the depocenter area. The basal Montana trough rocks have been interpreted to be deep water in origin (Smith, 1977), as have rocks from the central basin facies (Wilson, 1969).

During the Upper Devonian, deposition of marine sediments was continuous in western North Dakota. Deposition of the Bakken

Formation occurred in a restricted environment and within the Bakken Formation the three units conformably onlap, indicating continuous deposition. Madison Formation deposition began with an initial marine transgression onto the craton from the restricted environment of the Bakken Formation (Carlson and Anderson, 1965). Normal marine circulation, which was continuous throughout the Bottineau interval, gradually became restricted during later Madison deposition. Evaporites, which formed first on the northeastern flank of the Williston Basin, gradually became more extensive and extended basinward until upper Madison Formation rocks were composed largely of evaporites (Carlson and Anderson, 1965). Continuous deposition of the Upper Devonian to upper Madison rocks in western North Dakota and the increased evaporite deposition and basinward migration during upper Madison time, indicate that western North Dakota was a negative area throughout this time. From the tectonic setting described above and on the basis of previously discussed physical characteristics, the central basin facies is interpreted to have had a deep water origin.

Rocks from the central basin facies are uniformly dark colored lime mudstones and wackestones with interbeds and intercalations of shale and argillaceous limestone. These thin-bedded rocks are interbedded with relatively thick homogeneous lime mudstones or argillaceous limestones. Sloss (1969) states that beds from deep water carbonates usually can be traced over wide areas but, due to a lack of core and well log coverage, beds from this facies could not be traced. But, observed rock coloration and bedding are similar to documented deep water carbonates (Smith, 1977; Yurewicz, 1977).

A sparse fauna, consisting of crinoid columnals, whole bryozoans and ostracods, and whole and broken brachiopods, was observed in rocks from this facies. Examination of core and samples revealed that lateral and vertical changes occur in faunal distribution. Laterally, as the basin flank facies is approached, fossil density and the number of whole *in situ* fossils increases. Similarly, an increase in fossil density was observed in samples from the upper 100-200 feet (30-60 m) of central basin facies rocks. The lateral change is interpreted to be the result of more favorable life conditions present higher up the slope and down-slope transportation of fossils. The vertical change is interpreted to be the result of shoaling during upper Bottineau interval marine regression which changed depositional environment parameters, such as salinity, oxygen content of the water, temperature, and turbidity. The observed faunal assemblage is similar to those described by Smith (1977) and Yurewicz (1977) from documented deep water carbonates.

An alternate interpretation is that central basin facies rocks are shallow water deposits. Sloss (1969) suggested that many of the sedimentary structures and regional relationships exhibited by rocks from the basal Lodgepole Formation in south-central Montana can be characteristic of shallow water carbonates. Wilson (1969) replied that his interpretation of a deep water origin for Lodgepole rocks was for more negative areas, such as western North Dakota. A deep water depositional environment for central basin facies rocks is preferred because of the tectonic, lithologic, faunal, and bedding characteristics discussed above.

Basin Flank Facies

The basin flank facies consists of medium to light gray fine grained skeletal packstones and wackestones (Figure 11) interbedded with argillaceous bioturbated mudstones. Pyrite is present, but is not as abundant as in the central basin facies. Whole brachiopods are common, as are horizontal feeding traces found in the argillaceous mudstones (Figure 12). Thin irregular laminations are also present in the more argillaceous interbeds. McCabe (1961) reports that accumulations of argillaceous sediments are common in areas intermediate to shelf and basin. This appears to be true for Bottineau interval rocks in north-central North Dakota because an areally extensive shale bed was observed in both core and well logs (Figure 13). The extent of this shale cannot be determined precisely because as the shale approaches zero thickness the marker becomes indistinguishable from normal background radioactivity on the gamma ray log.

The basin flank facies was deposited between the relatively deep waters of the central basin facies and the shallower waters of the shelf, shoal, and lagoonal facies (Figure 14). The increased abundance of _in situ_ fauna indicates that the environment was more hospitable to life than the central basin facies. This facies is interpreted to have been deposited in waters below normal wave base but above storm wave base.

Crinoidal Mudstone Facies

The crinoidal mudstone facies is light gray to cream colored cherty dolomitic mudstone deposited at or near the shelf break (Figures 10 and 14). Although core was not available from this facies,

Fig. 11. Photomicrograph of argillaceous skeletal packstone overlying skeletal wackestone. Plane polarized light. Thin section No. 38-5026B.

Fig. 12. Photomicrograph of burrows (B) in an argillaceous mudstone interbed which underlies skeletal packstone. Note silica replacement of skeletal allochems (A). Plane polarized light. Thin section No. 38-5019.


1 mm

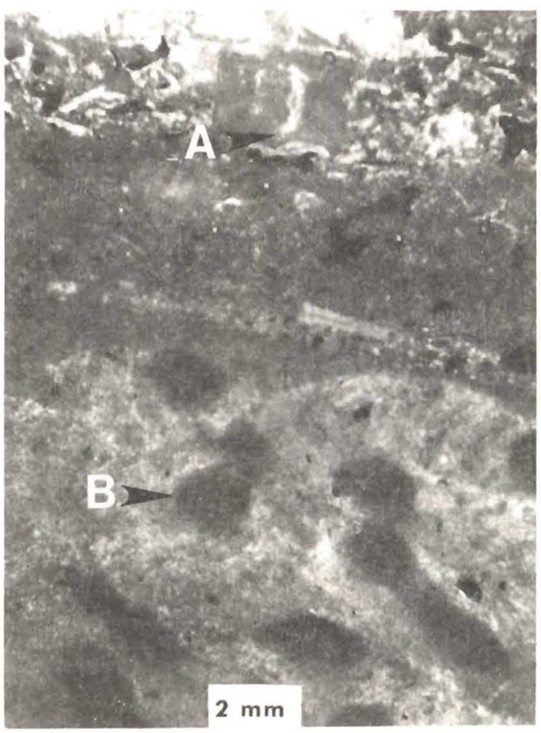
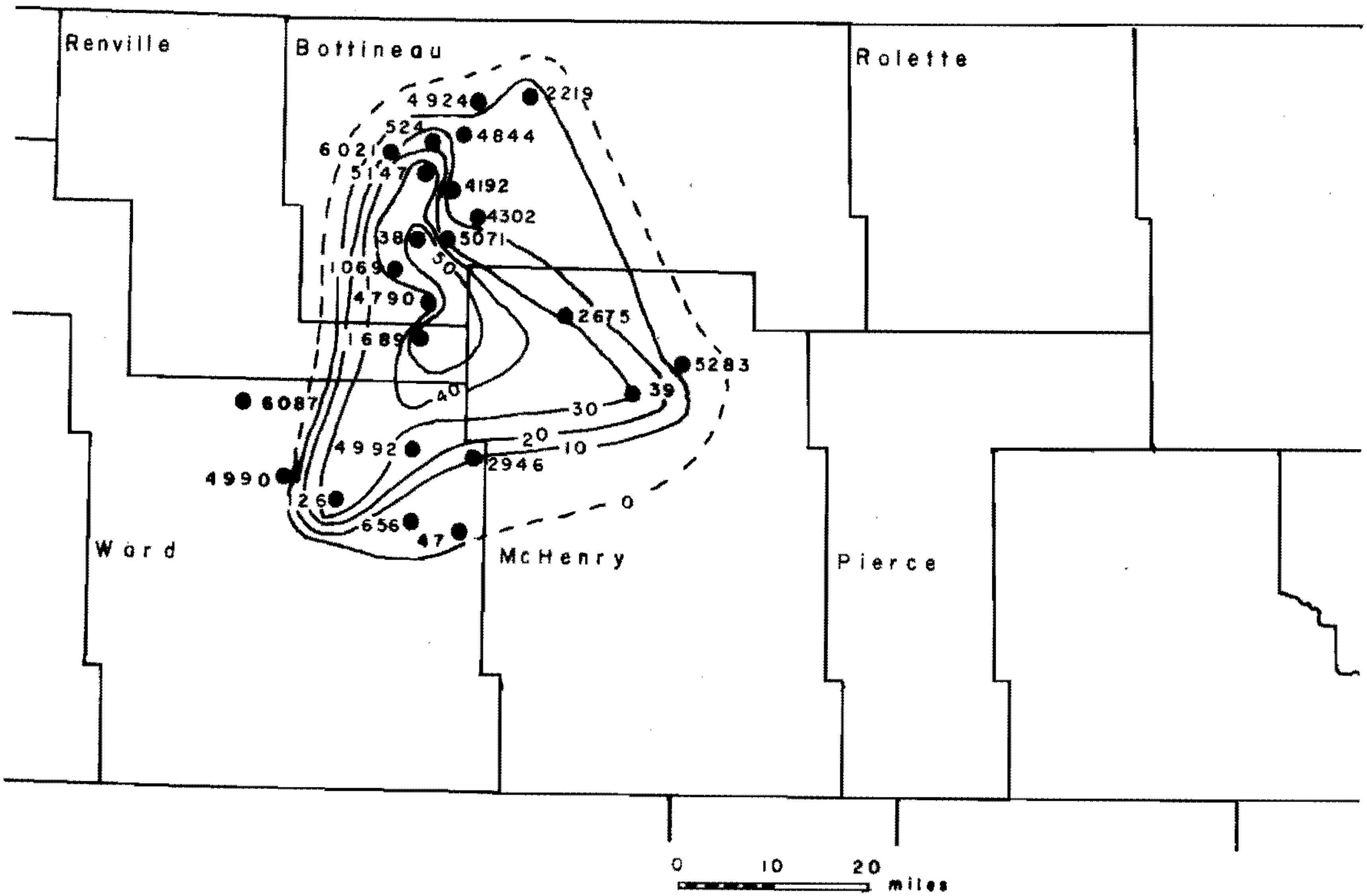

A
B
2 mm

Fig. 13. Thickness and areal extent of shale unit in north-central North Dakota. Dashed contour represents the approximate zero edge of the shale.


Renville
Bottineau
Rolette
Ward
McHenry
Pierce
4924
2219
524
4844
6021
5147
4192
4302
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1069
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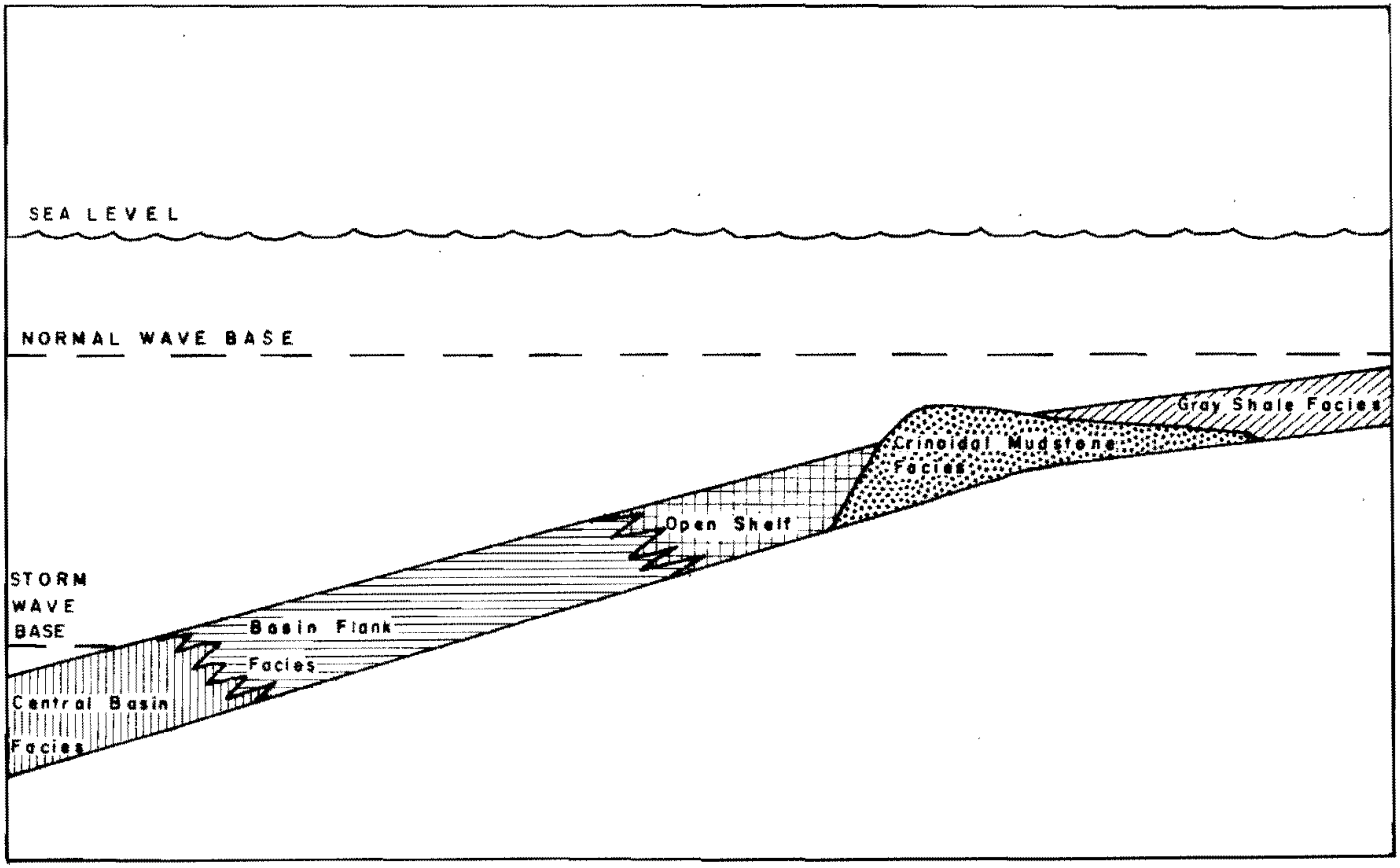


Fig. 14. Schematic diagram showing the lateral relationship between facies during Lower Scallion subinterval time.

cuttings exhibit irregular and blocky shape, react slowly to acid, and have no discernible bedding. Crinoid columnals are the most abundant fossil remains; bryozoan debris is also present but less abundant.

This facies was interpreted to be a Waulsortian bioherm complex by Bjorlie (1978) for the following reasons: (1) Waulsortian bioherms have the same faunal and matrix constituents (crinoids, bryozoans, and mud), (2) this facies is located at the shelf break, as are other reported bioherms, and (3) this facies is of equivalent age and stratigraphic position to bioherms studied in central Montana by Smith (1972) and Stone (1972).

> Waulsortian bioherms are "massive lime mudstone containing scattered crinoid and bryozoan fragments and forming lens-like buildups and mounds, constitutes a distinctive and ubiquitous facies in Lower Carboniferous . . . strata throughout the northern hemisphere. The rocks of such buildups takes the name Waulsortian, from a village in the Dinant basin, south of Namur in Belgium." . . . In regional paleotectonic patterns . . . . Waulsortian mounds and lenses appear chiefly as an intermediate (shelf margin) facies between geosynclinal basins and shelf deposits which were formed in open marine circulation (Wilson, 1975).

The following is summarized from Wilson (1975). The classic composition of bioherms is crinoid and bryozoan debris floating in a mud matrix. Waulsortian bioherms are generally located in clear open marine waters, away from coastal influences, at the shelf break. Sediments vary both basinward and shoreward, depending upon the amount of calstic sediment influx. Waulsortian bioherms generally grade rapidly into more basinal facies and gradually into shelf facies. Waulsortian bioherms have been reported in Montana (Smith, 1972; Stone, 1972), England (Parkinson, 1957), Ireland (Lees, 1961), and other locations.

In addition to similar composition and location, Bjorlie (1978) noted that Waulsortian bioherms in North Dakota show similar relationships to laterally equivalent facies. That is, they grade rapidly into basinal facies and gradually into shelf facies.

Gray Shale Facies

The gray shale facies, or Carrington and Routledge Shales as they were originally described by Ballard (1963) and Stanton (1956), is found shoreward of the crinoidal mudstone facies (Figure 10) and the Carrington Shale is partially onlapped by the bioherms in central North Dakota (Bjorlie, 1978). The following description is summarized from a study by Bjorlie (1978): the gray shale facies varies in color from dark gray in the basal part to red-brown in the upper part. Pyrite is scattered throughout the facies and macrofossils are rare. A thin limestone bed can be recognized on mechanical logs in the upper third of the shale through part of the shale subcrop. Clay-size sediments comprise 60-70% of the shale and all but a trace of the remainder is silt-size. The clay-size fraction is nearly 100% illite while the silt-size fraction is primarily quartz, feldspar, calcite, and dolomite.

Bjorlie (1978) interpreted this facies to have been deposited in a restricted lagoonal environment because of its position shoreward of the crinoidal mudstone facies, because of the pyrite found throughout this facies, and the dark color in the basal part of the shale. The red-brown color in the upper part of the shale was interpreted to be the result of post-depositional oxidation of the sediments.

The crinoidal mudstone facies apparently acted as a barrier to circulation and reduced currents enough to allow the deposition of fine-grained sediments. The source of these fine-grained sediments was interpreted to be the older Paleozoic and Precambrian rocks exposed to the north and northeast (Bjorlie, 1978).

Several embayments in the shale facies (Figure 10) were interpreted to be either distributary channels or rivers flowing into the basin from the exposed craton to the east (Bjorlie, 1978). These channels may have carried clastic sediments into the basin. Bjorlie (1978) also noted the presence of a thin sand and shale unit west of the crinoidal mudstone facies in the basin flank facies and interpreted this unit to be the result of fluvial transport of clastic sediments by these channels.

Open Shelf Facies

The open shelf facies is composed of interbedded lithologies which vary from laminated mudstone to skeletal packstone (Figures 15 and 16). The rocks are generally light gray to buff and hematitic mottling is common, especially around voids. Moldic porosity has been developed in some scattered beds, but pinpoint and intergranular porosity is more common. Chert commonly replaces fossils and matrix.

This facies was deposited both basinward and shoreward of the Waulsortian bioherms (Figure 10) in areas where restriction of circulation by the bioherms was limited and where deposition of the gray shale facies was prevented. These areas existed near the strandline, in areas where the intermittent bioherm distribution allowed normal marine circulation and basinward of the bioherms.

The interbedded lithologies of this facies are interpreted to be the result of the patchy distribution and migratory behavior of benthic

Fig. 15. Photomicrograph of brachiopod packstone. Plane polarized light. Thin section No. 659-3287.

Fig. 16. Photomicrograph of the contact between skeletal packstone and mudstone. Dark colored material is hematite which has replaced matrix along the contact. Plane polarized light. Thin section No. 659-3324.


.5 mm


1 mm

organisms, salinity, clastic influx, and bottom topography. Laporte and Imbrie (1964) indicate that changes in these variables are more important in controlling sediment distribution than are overall marine conditions. The generally high percentage of fine-grained sediments is indicative of either low to moderate currents, water depth below effective wave base, or sediment trapping by organisms.

Later and more extensive marine transgression onto the craton submerged the gray shale and crinoidal mudstone facies (Figure 17) and may have been the principal reason why deposition of these facies ceased. The open shelf facies is interpreted to have prograded over the gray shale and crinoidal mudstone facies both during and after upper Scallion subinterval marine transgression when the Bottineau interval sea reached its maximum extent.

Restricted Shelf Facies

The restricted shelf facies consists of interbedded light gray to buff skeletal mudstone to wackestone and irregularly laminated red-yellow crinoidal mudstone. The crinoidal mudstone interbeds are generally 1.3-10 cm thick and are comprised of numerous thinner laminations (Figure 18). These laminae drape over crinoid columnals and are darker in color due to a higher concentration of argillaceous sediments. The skeletal wackestones contain crinoids as the dominant faunal component, but brachiopods and gastropods are also found. The wackestone interbeds are thicker, generally 7.5-30 cm, with no observable internal bedding. Moldic and vuggy porosity has been developed in some beds and anhydrite has discontinuously filled some of these voids, especially in vuggy porosity. Chert is abundant, replacing both matrix and

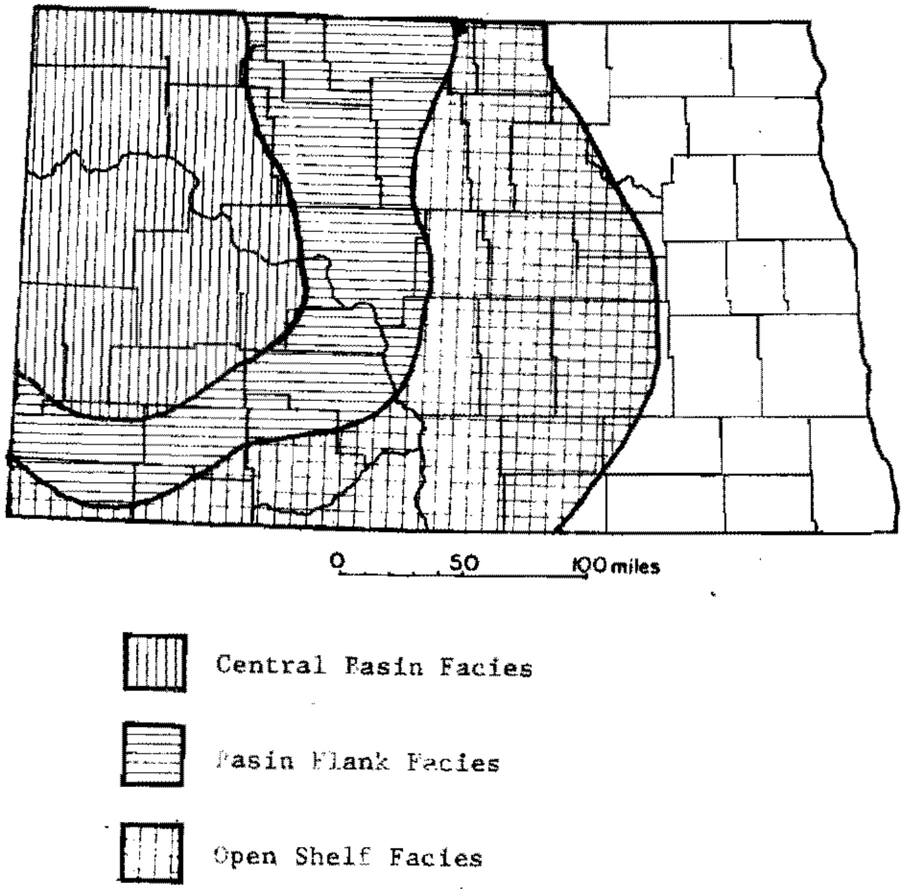


Fig. 17. Facies distribution during upper Scallion subinterval time.

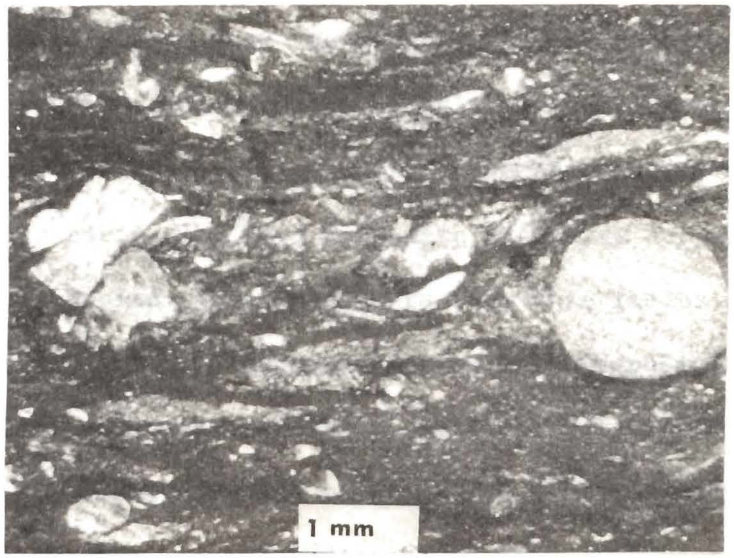


Fig. 18. Photomicrograph of crinoidal wackestone. Note compaction laminations draping crinoid columnals. Plane polarized light. Thin section No. 615-2614.

skeletal allochems; individual nodules greater than 25 cm long have been observed.

The restricted shelf facies is interpreted to have been deposited on a restricted platform near the margin of the basin (Figure 10). The areal extent of this facies cannot be delineated precisely because of poor well control. Its position along the erosional unconformity indicates that this facies may have been more extensive but was eroded during post-Mississippian time. Sediments from this facies are interpreted to have undergone periodic exposure during which deposition of red-yellow crinoidal mudstones occurred. Wave-washed skeletal allochems were carried in, deposited, and later buried by other sediments. The concentration of argillaceous sediments in thin laminae is the result of the deposition of fine-grained sediments during exposure. Unequal erosion removed some of these laminae and deposited more skeletal allochems. Periodic submergence occurred and deposited marine sediments, consisting of skeletal wackestones, over the intertidal sediments. Although these sediments are marine in origin, a restricted platform can be inferred because of the sparse fauna.

Pelletal Grainstone Facies

The pelletal grainstone facies consists of light to medium gray pelletal and skeletal muddy grainstones and packstones deposited shelfward of the basin flank facies during middle and upper Bottineau interval sedimentation (Figure 19). In core, three types of bedding can be observed: (1) finely laminated, (2) massive bedded, and (3) an intermediate type with characteristics of both end members. In thin section, some of the pellets appear to be micritized skeletal grains rather than

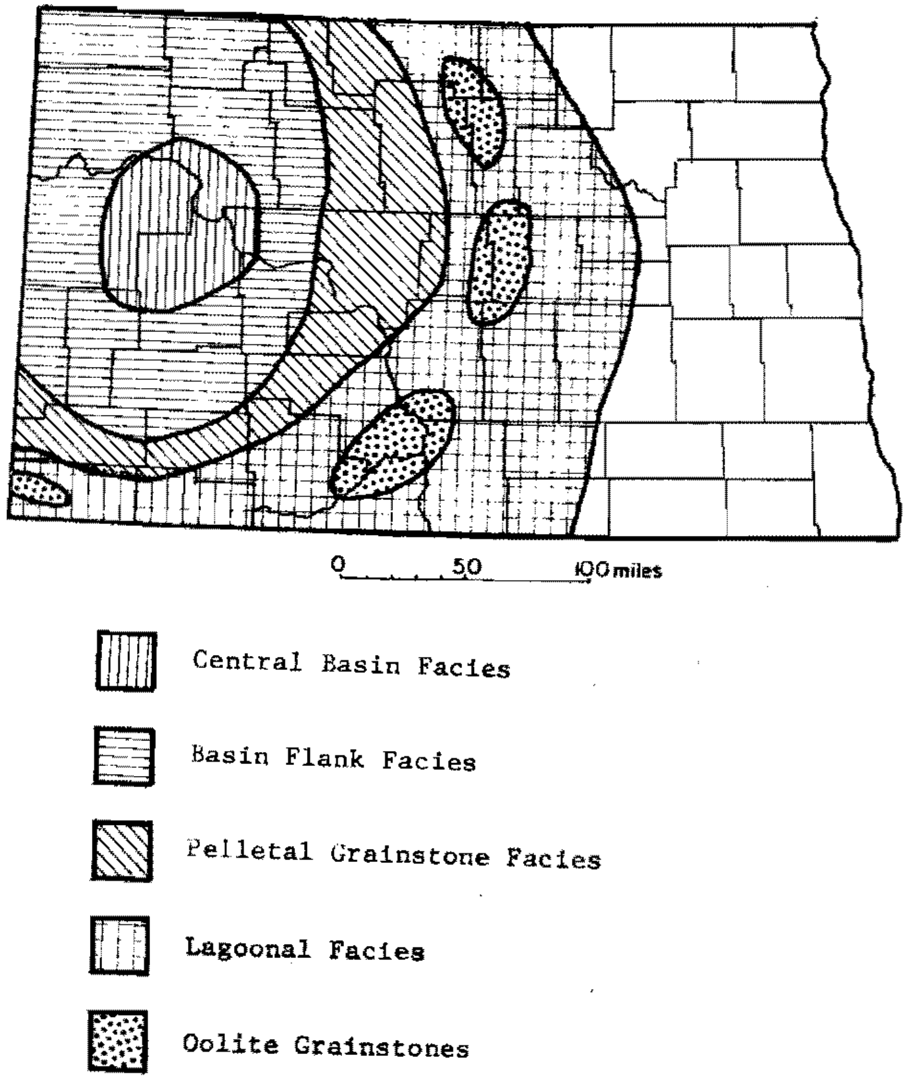


Fig. 19. Facies distribution during Virden and Whitewater Lake subinterval time.

aggregates of clay-size carbonate (Figure 20). Mollusk remains have been recrystallized but the shape and position of the shells have been preserved by the concentration of pellets, matrix, and fossil debris along the original shell edges. Mud intraclasts are common, especially in the massive bed units.

A shallow water depositional environment is postulated for this facies because of the common micritization of grains, which occurs most abundantly in water less than 60 feet (18 m) (Swinchatt, 1969). Supporting evidence for a shallow water origin is the well washed, fossiliferous, and bedded character of rocks from this facies. This facies, in middle and upper Bottineau interval rocks, is well developed in the areas flanking the central basin and is indicative of gradual marine regression and/or infilling of the basin by successively shallower water sediments. Supporting evidence for the infilling/marine regression during this time is the increase in unbroken in situ fossils in the upper 100-200 feet (30-60 m) of central basin facies rocks. In addition, the grainstone fabric of these rocks, in open marine environments, normally should contain a mud matrix because winnowing does not occur in deeper waters to remove the mud. However, the high spar content of this facies is indicative of greater current action. Basins with low gradients frequently have little or no current action because of energy attenuation by friction (Keulegen and Krumbein, 1958). To deposit grainstone fabrics, agitation is necessary to winnow out fine-grained sediments; bottom friction supplied the necessary agitation. In addition, Keulegen and Krumbein report that there is little breaker section at the shelf edge because of this energy loss. When the low

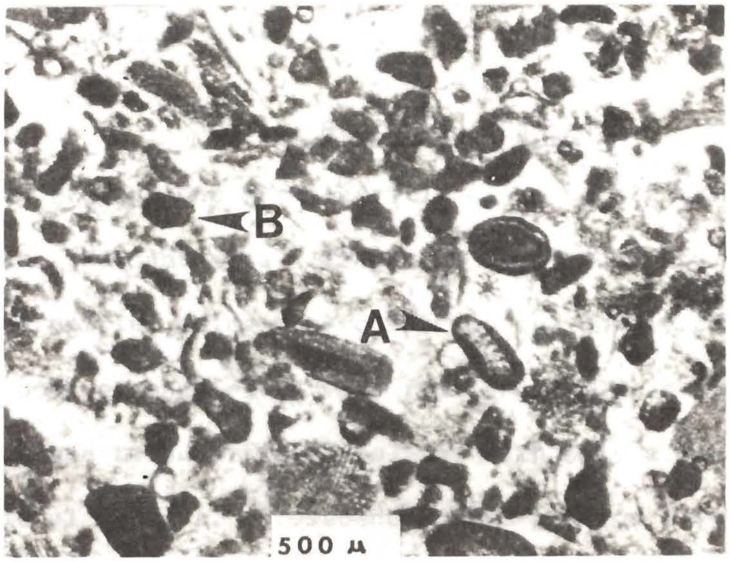


Fig. 20. Photomicrograph of peloidal skeletal grainstone showing grain with micritized rim and a skeletal center (A) and a true pellet (B). Plane polarized light. Thin section No. 1516-7.

gradient of the Williston Basin and the accompanying lack of high energy breakers at the shelf edge are considered, the absence of organic framework buildups, which require high energy and an upwelling of nutrient-rich waters from basinal areas to grow, is explained.

Oolite Grainstone Facies

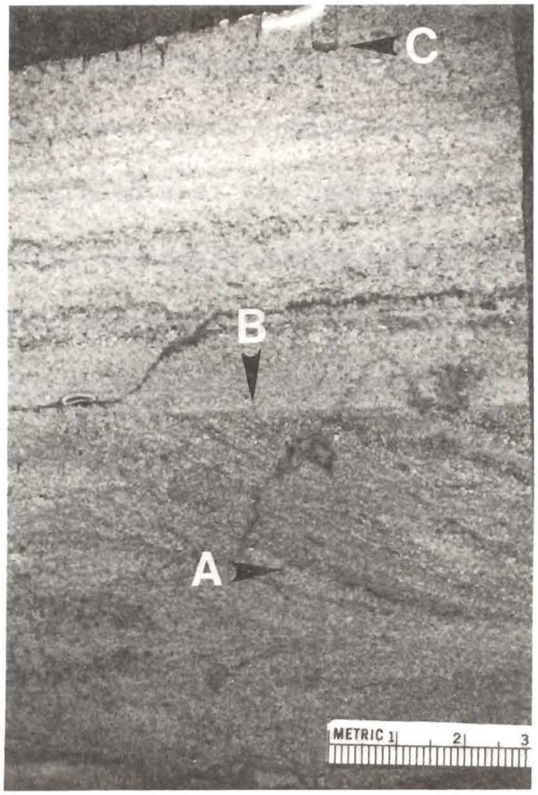
Oolite grainstones are generally cream to off-white in color and from coarse to fine sand-size. They vary from poorly to well indurated, with higher porosities being more common in the poorly indurated oolite bodies. The oolites themselves vary from true oolites with numerous concentric laminae to superficial oolites with only a few thin laminae around a skeletal nucleus. Crossbedding and erosional surfaces can be observed within a given body and intraclasts also can be observed (Figures 21 and 22). These oolite bodies range in thickness from two to thirty feet (0.6-9 m) but well control was insufficient to determine the precise areal extent of these bodies. The contact with over- and underlying strata is generally gradational.

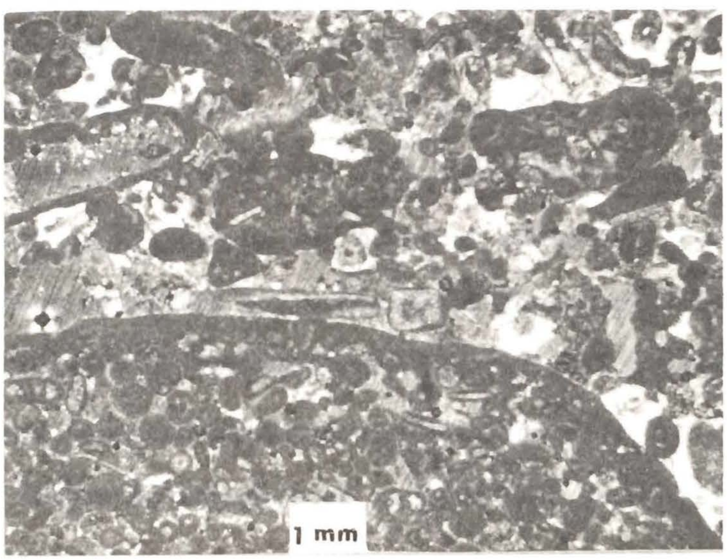
Oolite bodies in Bottineau interval rocks are interpreted to have formed in highly agitated shallow waters near the shelf break (Figure 19). Evidence of agitation is the well-washed and well-sorted character of the oolites and the generally high degree of rounding observed in the nuclei of superficial oolites. No other evidence for a shallow water origin was observed.

The oolite shoals are found in middle Bottineau interval rocks almost to the exclusion of other Bottineau interval strata. A migratory behavior for these shoals can be inferred from the gradational shoal contacts. The apparent absence of oolite shoals in upper Bottineau interval

Fig. 21. Photograph of cross-bedded oolites (A), truncation surface (B), and stylolite (C). Core slab is from N.D.G.S. Well No. 927, depth 3259.

Fig. 22. Photomicrograph of oolite intraclasts surrounded by second generation oolites. Crossed nicols. Thin section No. 274-3321B.


C
B
A
METRIC 1 2 3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rocks may have been the result of either oolite migration or a loss of necessary temperature, salinity, and chemical conditions. Infilling of the basin was continuous throughout middle and upper Bottineau interval time and the shallower water sediments of the pelletal grainstone facies gradually prograded over the deeper water basin flank facies. Oolite shoals migrated basinward during middle Bottineau time, prograding over deeper water sediments into the central basin area (Figure 23).

However, due to poor well control in the area marginal to the basin center where the oolite shoals would appear, no evidence for the migration of oolite shoals into the central basin area was observed.

Lagoonal Facies

The lagoonal facies is a complex of several interbedded lithologies: (1) skeletal packstones and grainstones, (2) laminated pelletal muddy grainstones, and (3) argillaceous mudstones and wackestones (Figures 24 and 25). The first two lithologies vary in color from cream to light red and orange, while the mudstone/wackestone lithologies are generally variegated purples, yellows, and reds. Iron staining is common. Bedding is variable, and soft sediment deformation is common, especially between grainstone and mudstone contacts. Heavy dark hematite replacement of matrix is common along these contacts. Bioturbation traces are rare in the mudstones and pelletal grainstones and, if present, are obscured in skeletal grainstones.

This facies is interpreted to have been deposited in an open platform or lagoonal environment shoreward of the oolite grainstone facies (Figure 19). It occupies approximately the same position on the shelf as the open shelf facies and is similar in lithology. The

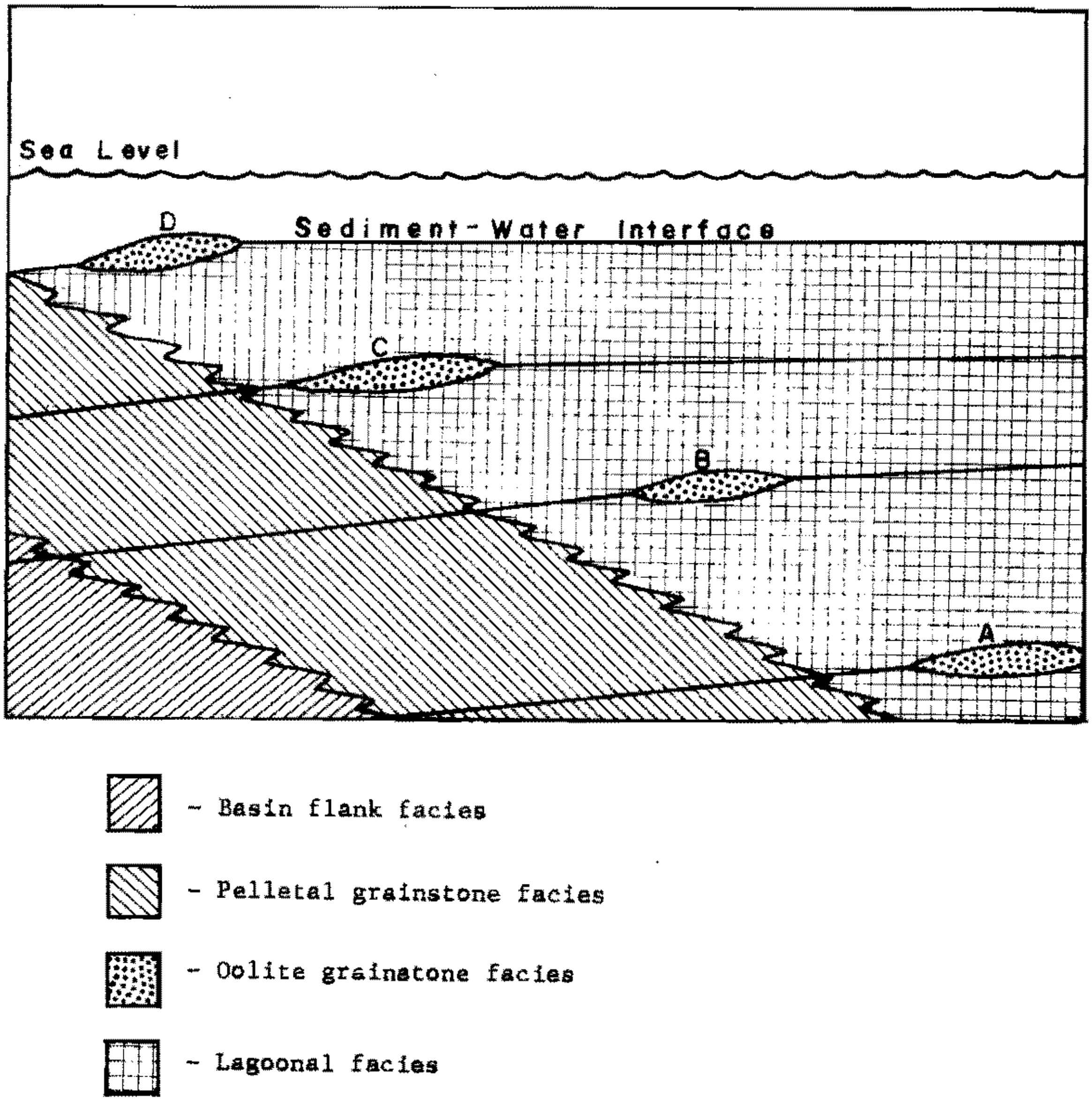
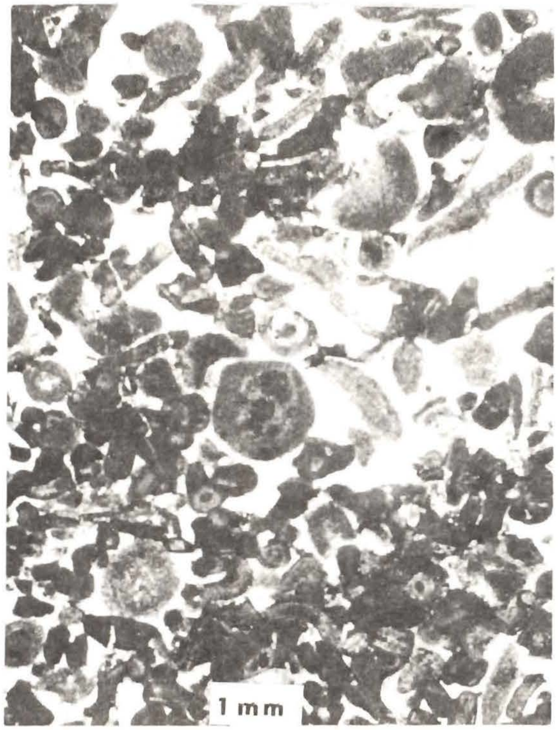


Fig. 23. Schematic diagram showing basinward migration of oolite shoals.

Fig. 24. Photomicrograph of skeletal grainstone. Plane polarized light. Thin section No. 83-2740.

Fig. 25. Photomicrograph of skeletal grainstone over mudstone with sharp contact (A) and syntaxial overgrowth (B). Plane polarized light. Thin section No. 83-2702.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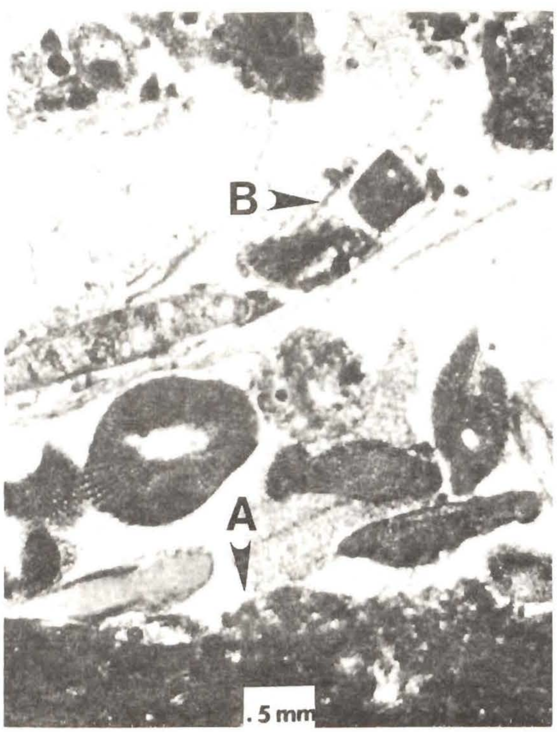

B
A
.5 mm

major difference between these facies is the energy/water depth conditions that existed during deposition. The lagoonal facies was deposited in shallower water and/or higher energy conditions than the open shelf facies. Evidence for this difference is the greater abundance of grainstones and the lesser amount of fine-grained sediments in rocks from the lagoonal facies.

Interpretation

During uppermost Devonian and lowermost Mississippian time a restricted environment occupied the central part of the Williston Basin resulting in deposition of the black shales and calcareous siltstone of the Bakken Formation (Figure 4). Gradual marine transgression resulted in the onlapping relationship between the three units of the Bakken Formation (Carlson and Anderson, 1965).

Lower Bottineau interval (Scallion subinterval) sedimentation began when continued marine transgression onto the craton resulted in normal marine circulation basinward of the crinoidal mudstone facies and restricted circulation shoreward of the crinoidal mudstone facies. Six major facies were developed during lower Bottineau interval sedimentation (Figure 10): (1) dark gray to black irregularly laminated crinoidal mudstone/wackestone (central basin), (2) medium to light gray argillaceous skeletal packstone/wackestone, (3) light colored cherty skeletal wackestone/packstone (open shelf), (4) crinoidal mudstone (at or near the shelf break), (5) gray shale (restricted environment shoreward of the crinoidal mudstone facies), and (6) restricted shelf (along the marginal areas of the basin).

Later and more extensive marine transgression restored normal marine circulation shoreward of the shelf break environment. As the result of this transgression the open shelf facies prograded over the crinoidal mudstone and gray shale facies (Figure 17).

By the beginning of middle Bottineau interval sedimentation (Virden and Whitewater Lake subintervals) a gradual marine regression, coupled with facies progradation into the basin, had already begun. This change in sea level is reflected in the development of three younger facies (Figure 19): (1) medium to dark gray argillaceous pelletal skeletal grainstone (shallow open shelf), (2) oolite grainstone (as shoals at or near the shelf break), and (3) light colored argillaceous cherty pelletal skeletal mudstone to grainstones (shoreward of the oolite shoals).

During middle Bottineau interval time sedimentation was variable. The amount of argillaceous sediment within the Virden and Whitewater Lake subintervals is the basis for their being subdivided into upper and lower units (Stanton, 1956); in both subintervals the upper unit is nonargillaceous compared to the lower unit. In addition, each of these subintervals has been described as cyclical. Each cycle started with basal oolite shoals and skeletal grainstones (Stanton, 1958). These cycles were observed in Bottineau interval rocks of North Dakota as well as in Canada where they were originally described.

Zakus (1967) reports that the upper Bottineau interval (Flossie Lake subinterval) sedimentation may be a continuation of the cyclical pattern of Middle Bottineau interval sedimentation because an influx of argillaceous sediments can be observed in basal Flossie Lake rocks, similar to those occurring in middle Bottineau interval rocks. However, he also reports that the cycle may not be as complete because the oolite shoals in middle Bottineau interval rocks are missing. The missing oolite shoals may be the result of either a change in depositional environment, such that oolites could not form, or the oolite shoals migrated into the basin center as marine regression and/or basin infilling continued. The latter explanation is preferred for the following reasons: (1) shallow water muddy grainstones overlie deeper water central basin and basin flank facies rocks, and (2) the increase in fossils in the upper 100-200 feet (30-60 m) of central basin facies rocks. Both observations are indicative of basin shoaling. The cessation of oolite formation as the result of a change in depositional environment is unlikely as overlying Tilston interval and younger Madison Formation rocks contain abundant oolite bodies. However, well control for the area in which oolite shoals are interpreted to have migrated is missing and this interpretation cannot be proved.

Bottineau interval sedimentation closed with marine regression and/or basin infilling with continued shoaling. A transition from the deeper water Bottineau interval rocks to the shallower water rocks of the Tilston interval indicates that deposition was continuous (Himebaugh, 1979).

DIAGENESIS

Introduction

Various definitions of diagenesis have been used in the literature but no general agreement has been reached. Diagenesis, as used in this study, refers to all processes which affected Bottineau interval sediments between deposition and the present.

Chilinger, Bissel, and Wolf (1967) suggest that, within a given carbonate unit, different diagenetic histories may result from local and regional changes in environmental and post-depositional conditions. Similarly, study of Bottineau interval rocks indicates that two diagenetic provinces can be distinguished: shelf and basin (table 4).

The shelf diagenetic province comprises the crinoidal mudstone, gray shale, open shelf, restricted shelf, and lagoonal facies. In general, the rocks from these facies are light orange and pink, contain micritized grains, abundant calcite cements, most of the replacement silica and all of the replacement hematite, and underwent the most extensive dolomitization and anhydritization.

The basin diagenetic province comprises the central basin and basin flank facies. Rocks are dark, fine grained, burrowed, contain most of the observed pyrite, and have been only partially dolomitized.

The pelletal grainstone facies is interpreted to be transitional between the two diagenetic provinces. It resembles the basin diagenetic province in color and in the fact that pyrite rather than

TABLE 4

DIAGENETIC PROCESSES AND FEATURES OBSERVED TO OCCUR IN THE BASIN AND SHELF PROVINCES

	Basin	Shelf
burrows	x	x
micritization	A	*
soft sediment deformation	A	x
compacted burrows	x	x
fringing cement	x	+
outgrowths	x	*
equant cement	x	*
micrite	x	x
microspar	*	*
stylolites	x	x
microstylolites	*	*
fractures	x	x
ferroan dolomite	x	*
iron-free dolomite	x	A
ferroan dolomite cement		+
anhydrite	x	*
pyrite	*	+
hematite	A	*
chert nodules	A	x
silica replaced allochems	x	*

A = absent
+ = rare
x = common
* = abundant

hematite is the dominant replacement iron mineral. It resembles the shelf diagenetic province in that it contains abundant calcite cement and micritized allochems. The boundary between provinces is interpreted to exist within this facies but precise boundaries cannot be determined.

Diagenetic processes which altered Bottineau interval rocks are further divided into pre- and post-lithification events. Pre-lithification diagenetic processes were those which occurred before cementation and neomorphism lithified the sediments. Post-lithification diagenetic processes occurred after the sediment was lithified.

In the following sections each diagenetic process observed to have altered Bottineau interval rocks is described for the diagenetic province(s) in which it occurs and is classified as either pre- or post-lithification processes; mechanisms and the time of occurrence will be discussed, as data permit. The diagenetic processes will be discussed in their approximate order of occurrence.

Biologic Diagenesis

Biologic processes were important in the pre-lithification modification of Bottineau interval sediments. Observed textural and structural features which indicate biologic activity in the shelf diagenetic province include burrows, micritized grains, and fecal pellets. In the basin diagenetic province burrows were the only observed evidence for *in situ* biologic activity. Although burrows occur in both diagenetic provinces, they are most easily identified in the basin diagenetic province. In this province, burrows appear as elliptical to subcircular structures that differ in color and grain size from the surrounding rocks (Figure 9). Burrows are darker and finer grained, not having been significantly altered by diagenetic processes. In contrast, shelf diagenetic province burrows are less distinct. Burrows in fine grained sediments are subcircular structures which are frequently rimmed with hematite (Figure 26). In coarse grained rocks evidence of bioturbation is not readily identifiable.

Other evidence of biologic activity is the presence of pellets and/or peloids. Pellets are small (less than one mm in diameter) subspherical aggregates of clay-size carbonate sediments deposited as fecal material by sediment ingesting organisms moving through the sediment (Figure 20). Fecal pellets were formed before lithification and, for pellets to be preserved, either hardening of the pellets or rapid burial is required.

Peloids are grains which resemble pellets but are of uncertain origin (Bathurst, 1971). Peloids observed in Bottineau interval rocks are interpreted to have formed by micritization of skeletal grains. Micritization is the boring of skeletal grains by endolithic algae, fungi, and bacteria which results in a rim or envelope of micrite around the periphery of the grain. In extreme cases micritization can result in the complete conversion of skeletal grains to micrite. Bathurst (1966) reports that endolithic algae coat grain surfaces and bore into them forming tubules. Upon death and decomposition of the algae, some of the tubules are filled with micrite. With intermittent agitation to expose fresh surfaces to algal activity and numerous repetitions of the boring, a micrite rim or envelope is formed.

Some incipient peloids have an outer coating of micrite with the interior of the peloids still having a skeletal fabric (Figure 20). With continued micritization entire grains may be micritized and form peloids. Bathurst (1971) and Taylor and Illing (1969) report that the

Fig. 26. Photomicrograph of a burrow in a mudstone filled by overlying packstone. Note oolitically coated grain in burrow (A). Crossed nicols. Thin section No. 274-3339.

formation of peloids by micritization may be common in modern sediments; Bathurst further suggests that many peloidal sediments may be micritized carbonate sands.

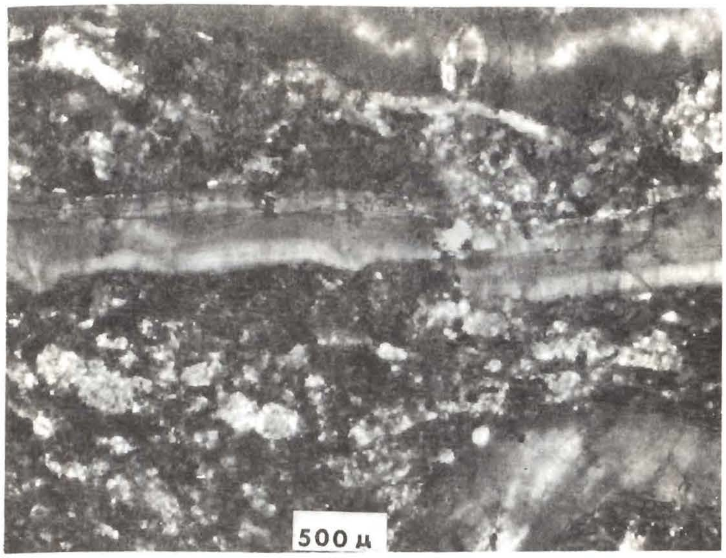
Compaction

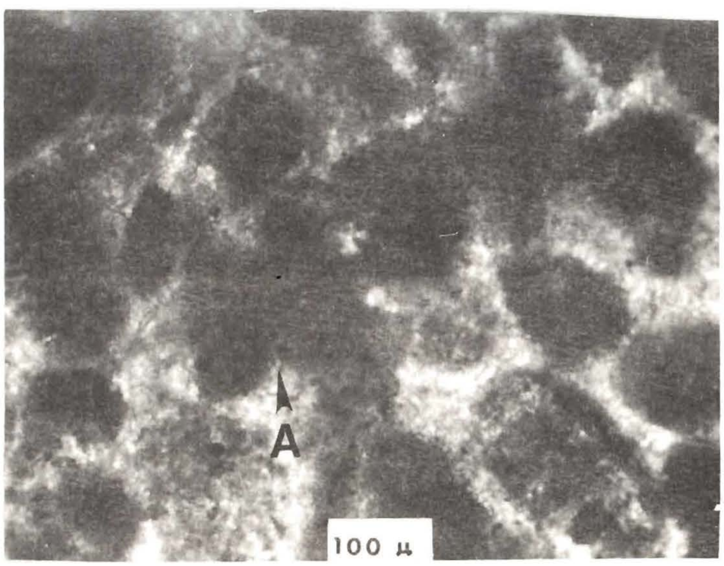
Numerous references to the uncompacted character of fine grained carbonate sediments have been made on the basis of the presence of unbroken fossils (Pray, 1960; Ginsburg, 1957). Shinn et al. (1977) compacted a core of modern sediment to approximately one-fifth its original length and compared the compacted sediment with an ancient sample. They noted that whispy laminae, slightly flattened burrows, and unbroken fossils were present in both cores. This led them to suggest that compaction in carbonate sediments may be more common than previously supposed.

Shelf diagenetic province rocks contain the following compaction features: broken skeletal allochems in both mud and grain supported fabrics (Figure 27), pelletal sediments in which pellet boundaries have begun to coalesce (Figure 28), slightly flattened burrows, and microstylolites (Figure 29). Broken skeletal allochems are indicative of compaction before lithification. Coalescence of pellets must begin before pellets are completely indurated and the sediment completely lithified. Burrows are assumed to have been circular at the time of formation and the flattening indicates that some compaction occurred. Microstylolites must form before complete lithification because skeletal allochems must be mobile in the sediment in order for microstylolites to form (Bathurst, 1971).

Fig. 27. Photomicrograph of broken brachiopod in a mud supported fabric. Crossed nicols. Thin section No. 754-2699.

Fig. 28. Photomicrograph of pellets which have begun to coalesce (A). Plane polarized light. Thin section 1516-6.


500 µ


A
100 µ

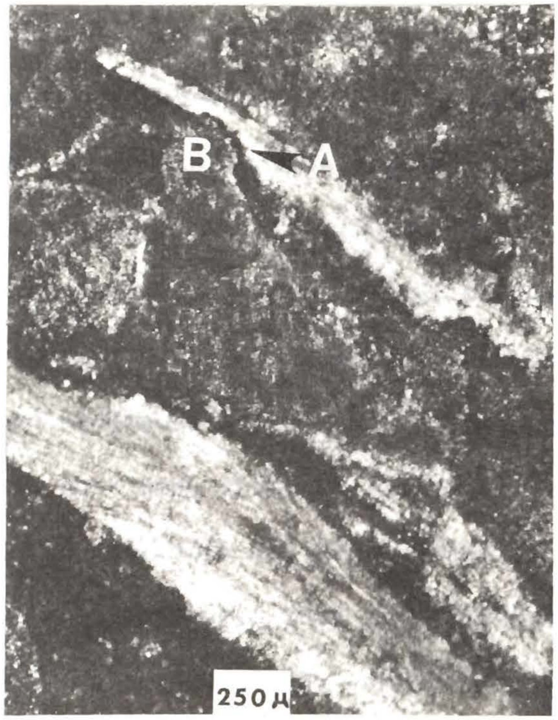


Fig. 29. Photomicrograph of microstylolite (A) where crinoid (B) has penetrated a brachiopod. Crossed nicols. Thin section No. 274-3271B.

Basin diagenetic province rocks contain less evidence of compaction. Burrows are flattened (Figure 9) which indicates that some compaction occurred as does the presence of microstylolites. Young (1973) concluded that fine grained sediments from his study were deposited as "soupy" sediments and underwent considerable compaction. Modern fine grained sediments contain approximately 60% void space of which most is lost in the first foot (30 cm) of burial (Ginsburg, 1957). Post-depositional compaction of fine grained sediments is interpreted to have occurred in Bottineau interval rock from North Dakota because modern fine grained sediments contain such high porosities before compaction and because Bottineau interval sediments contain low porosities.

Compaction of sediments may be important also in forming new fabrics. Dunham (1962) suggested that some packstone fabrics are not depositional but may be the result of compaction of wackestone fabrics. The extent to which compaction modified Bottineau interval sediments by creating new fabrics is unknown but probably was minor.

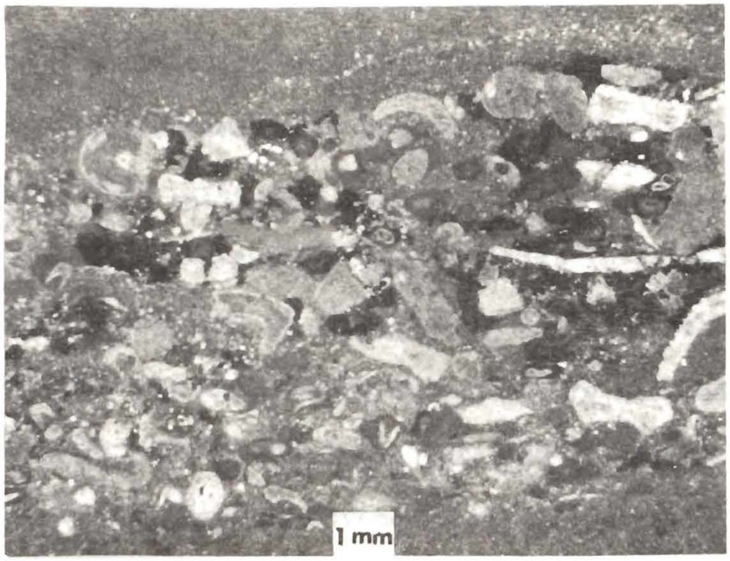
Soft Sediment Deformation

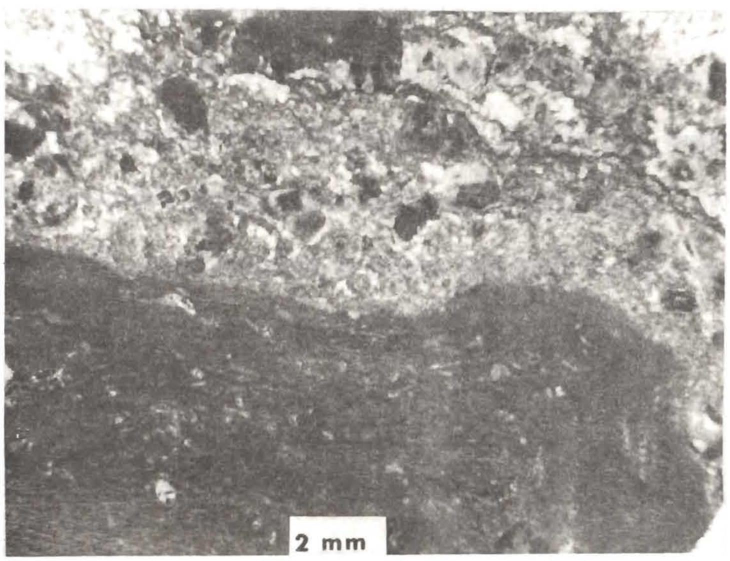
A common sedimentary structure in shelf diagenetic province rocks is the occurrence of small pillows or pods of skeletal packstones and wackestones enclosed in micrite (Figure 30). Load structures, or irregularly shaped bulges of interpenetrating micrites and grainstones are also common (Figure 31).

Pillows vary from a few centimeters to over five centimeters in diameter and are subcircular to elliptical in cross section. The margins of pillows are frequently gradational with the surrounding sediment and are discontinuously stained and replaced by hematite.

Fig. 30. Photomicrograph of a packstone pillow in micrite. Plane polarized light. Thin section 955-3422.

Fig. 31. Photomicrograph of a load structure where packstone and mudstone fabrics are interpenetrating. Plane polarized light. Thin section No. 83-2670.


1 mm


2 mm

These structures are interpreted to have formed by sediments with greater density sinking into less dense sediments.

Structures similar to pillows, observed in Bottineau interval rocks, were formed experimentally by Kuenen (1958). A sand layer was deposited over a clay layer and, after a shock was applied, pillows of sand sank into the clays. The shock results in a loss of sediment coherency allowing the sand to sink because of its greater density. Kuenen reports that the application of a shock is necessary to start sediment movements. Howard and Lohengrel (1969) suggested earth tremors as a possible shock mechanism; movements along underlying Precambrian faults may have induced a shock strong enough to form similar structures in Bottineau interval sediments.

Load structures form when sand is deposited on thixotropic muds; unequal loading results in sand bodies sinking into the clays (Reineck and Singh, 1975). Continued loading could result in separation of the sand into pillows which would then sink into the clay. Pillows formed in this manner would not require a shock to lose coherency and may have formed in Bottineau interval rocks.

Cementation

Cementation, as used in this study, is the passive precipitation of authigenic minerals in void spaces. Minerals observed to occur as cements are calcite, anhydrite, and dolomite. Calcite is the most common cementing mineral in Bottineau interval rocks.

Calcite cements were observed in both diagenetic provinces but are most common in the shelf diagenetic province. Calcite cements occur in three forms: (1) syntaxial overgrowths, (2) equant cement, and

(3) fringing or drusy cement. Bathurst (1971, pp. 417-419) presents 17 criteria used in this study for the recognition of calcite cements. Some of the more commonly occurring are: (1) an increase in crystal size away from grain margins, (2) numerous enfacial angles in triple junction boundaries, (3) micrite rims which have not been neomorphosed, (4) spar forming on grain surfaces which are free of carbonate mud, and (5) two or more generations of cement.

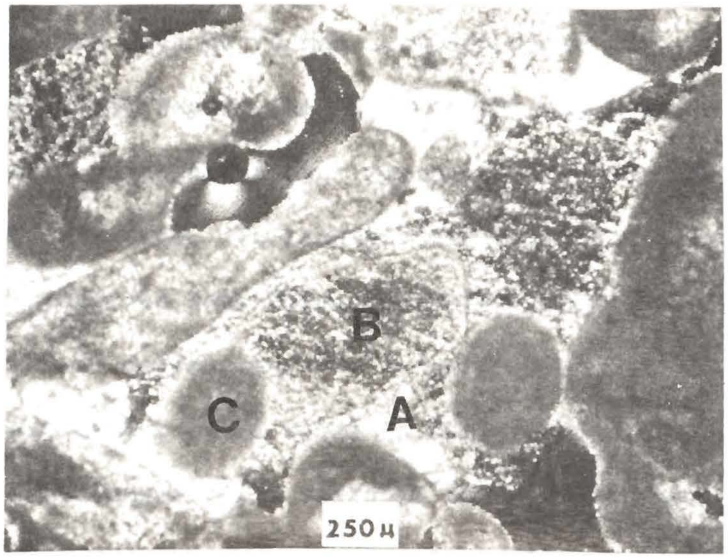
A syntaxial overgrowth is cement that has precipitated in optical continuity with the allochem over which it has grown. Echinoid debris, consisting mainly of crinoid columnals, commonly exhibit overgrowths in Bottineau interval rocks (Figure 24). Folk (1965) has reported that overgrowths also can form on skeletal allochems such as brachiopods and trilobites.

Echinoid fragments consist of a framework of small tubules which form a single crystal of calcite exhibiting unit extinction. Overgrowth formation consists of a partial to complete infilling of internal voids as well as the formation of external overgrowths which are elongated parallel to the C-axis (Evamy and Shearman, 1965). The shape of individual overgrowths and the boundaries between adjacent overgrowths is dependent upon the orientation and distance separating the host allochems. Where overgrowths are well developed they tend to fill all available pore space (Lucia, 1962).

Overgrowths in Bottineau interval rocks can be observed in both well-washed carbonate sands and in micritic rocks. Overgrowths in carbonate sands frequently make up the bulk of the cement and may enclose other allochems in a poikilitic fabric (Figure 32). In carbonate muds overgrowths are smaller, less well developed, and rarely intergrown.

Fig. 32. Photomicrograph of an overgrowth (A) on a crinoid columnal (B) has enclosed another crinoid columnal (C) in a poikilitic manner. Thin section No. 274-3321B.

Fig. 33. Photomicrograph of equant cement which increases in crystal size away from a brachiopod shelf (A) which was also earlier coated by fringing cement (B). Thin section No. 38-5043.


B
C
A
250 µ


B
A
500 µ

Some controversy exists over the process of overgrowth formation in fine-grained sediments. Bathurst (1958) suggested that they are a replacement feature formed by solid-state grain growth. Evamy and Shearman (1965) report that overgrowths observed in their study formed by early cementation that was halted by later deposition of fine-grained sediments. In fine-grained Bottineau interval sediments, overgrowths appear to have formed by early cementation that was later halted by renewed deposition.

Equant cement fills voids in Bottineau interval rocks. For example, equant cement fills skeletal voids, voids between overgrowths, solution voids, and other openings. Generally, an increase in crystal size occurs away from void surfaces and most voids containing equant cement are completely filled (Figure 33). An exception to this is along stylolites where isolated crystals of equant cement can be observed.

The third, and least abundant cement type, is fringing or drusy cement. Fringing cement occurs as intergrown elongate crystals of calcite with their long axis perpendicular to allochem surfaces which completely cover some allochems (Figure 33).

A general sequence of cement precipitation can be determined from observed textural relationships. Fringing cements are found coating allochem surfaces, indicating formation early in diagenesis (Powers, 1962). Overgrowths also were observed to enclose fringing cements, indicating precipitation at a later time. Folk (1965) has suggested that overgrowths form either earlier or faster than other spar cements. This is in agreement with Evamy and Shearman (1965) who reported that overgrowths may be synsedimentary. Equant cements occur filling void spaces between overgrowths indicating a still later time of precipitation. Moberly (1973) and Alexandersson (1972) have noted equant cement fills skeletal voids, such as bryozoan zooecium, early in diagenesis of modern sediments. As most skeletal voids are filled, an early precipitation can be inferred for all cements. However, Young and Greggs (1975) suggested that at least some of the equant cement formed from the release of calcite from post-lithification stylolitization. Calcite released from stylolitization cannot be shown to have occurred in Bottineau interval rocks but may have formed isolated equant calcite crystals along the plane of stylolites. A final consideration of cementation is that more than one generation of cement exists. Evamy (1963) and Evamy and Shearman (1965) reported that variations in ferrous iron concentration within the crystal lattice can be observed by staining with potassium ferricyanide. Bathurst (1971) noted that changes in Mn^{2+} and Fe^{2+} concentration can be observed by using luminescence petrography. Changes in calcite composition are interpreted to reflect changes in pore water composition which appear as colored bands under the cathode luminescence unit. Both staining and luminescence petrography were used to determine if more than one generation of cement is present in Bottineau interval rocks. Staining produced no results but in several samples two generations of cement in overgrowths were noted using luminiscence petrography. The rare occurrence of two generations of cement can be interpreted in two ways: (1) as a change in pore fluid composition without a halt in precipitation or (2) precipitation of the first generation was halted, pore fluid composition changed, and a later generation of cement was precipitated. Both processes can result in the same fluorescence pattern under the cathode luminiescence unit and no distinction is possible.

Neomorphism

Neomorphism is a general term for the conversion of aragonite to calcite and the recrystallization of a sediment when the exact process cannot be determined (Folk, 1965). Folk also states that neomorphism involves the transformation of an older crystal to a new crystal, which can be the same mineral or a polymorph with a different size, shape, or orientation but it cannot be a void filling. Neomorphism is particularly applicable to ancient sediments where the original sediment composition is unknown.

The mineralogy of Bottineau interval sediments at the time of deposition is unknown but generalizations can be made. Young (1973) postulated a comminuted skeletal origin for the carbonate muds in his study area. The most common skeletal allochems in Bottineau interval rocks are crinoids, brachiopods, bryozoans, ostracods, and mollusks. Chave (1964) reports the mineralogy of modern allochems which has been reproduced in table 5. In addition, Purdy (1968) and others, have reported that modern oolites are aragonitic in composition. The mineralogy of Bottineau interval allochems is assumed to have been the same as their modern equivalents. Destruction of skeletal allochems is interpreted to have resulted in a sediment composed of an unknown mixture of high-Mg calcite, calcite, and aragonite. The term meomorphism then, is preferred when describing the conversion of aragonite to calcite and recrystallization in both diagenetic provinces because the original Bottineau interval sediment composition can be inferred only.

TABLE 5

MINERALOGY OF MODERN SKELETAL ALLOCHEMS
(AFTER CHAVE, 1964)

	Aragonite	Aragonite & Calcite	Calcite	High Mg Calcite	Mg-Calcite & Aragonite
Algae	X		X	X	
Crinoids				X	
Brachiopods			X	+	
Bryozoans				+	X
Mollusks					
Gastropods	X	X			
Pelecypods	X	X	X		
Cephalopods	X			+	
Ostracods			X	+	

X=common occurrence
+=rare occurrence

Folk (1965) and Bathurst (1971) describe three phases of neomorphism in fine-grained sediments (table 6). They suggest that these phases form by a growth process which involves the transformation of a sediment varying in crystal size and mineralogy to a sediment which is more uniform in mineralogy and crystal size. Microspar and micrite are common in Bottineau interval rocks.

Some examples were observed of recrystallization, and aragonite converting to calcite, in allochems from Bottineau interval rocks. Aragonite converting to calcite can occur in two ways: solution/reprecipitation, or *in situ* conversion (Bathurst, 1971; Dodd, 1966).

TABLE 6

NEOMORPHIC PHASES OF CALCITE
(AFTER FOLK, 1965 AND BATHURST, 1971)

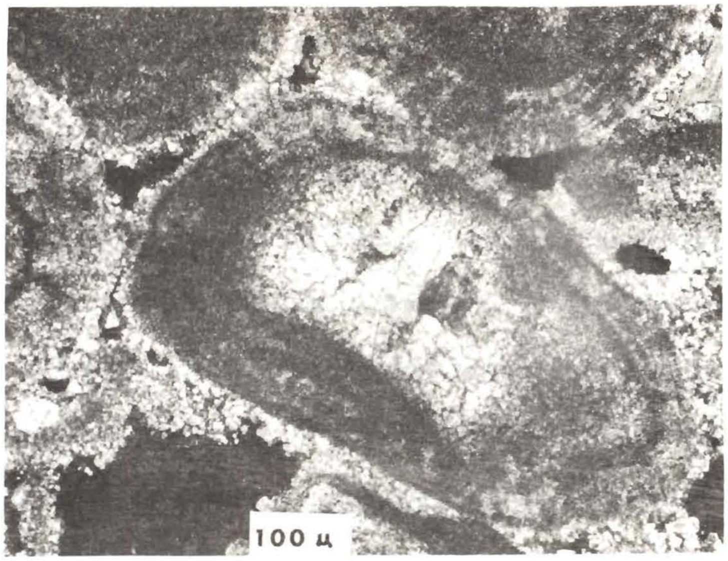
Phases	Crystal Size
Micrite	1-4 microns
Microspar	4-31 microns
Pseudospar	Greater than 31 microns

Recrystallization is most noticeable in oolites, where it appears to be a gradational process. Some oolites are unaffected while others have been partially to wholly recrystallized to equant calcite. Recrystallization occurs primarily in the nucleus of the oolite or as a concentric zone within the laminae of the oolite coatings (Figure 34). Recrystallization may have occurred either prior to or after the aragonite in the oolites was converted to calcite by *in situ* conversion. No textural relationships were observed to specify the time of recrystallization.

Solution/reprecipitation conversion of aragonite to calcite is common in Bottineau interval rocks. This process can occur in either lithified or unlithified sediments (Bathurst, 1964) but was observed to have occurred only in lithified Bottineau interval sediments. Collapse structures and the presence of sediment in the space that was originally occupied by the allochem are evidence for solution of allochems before lithification. These features were not observed in Bottineau interval rocks. Evidence for post-lithification solution

Fig. 34. Photomicrograph of an oolite with recrystallized center. Crossed nicols. Thin section 274-3225.

Fig. 35. Photomicrograph of solution/reprecipitation conversion of aragonitic gastropod to equant calcite crystals. Crossed nicols. Thin section No. 615-2485.


100 μ


250 μ

and reprecipitation includes the preservation of the original allochem shape without inclusions of matrix (Figure 35). Solution/reprecipitation involves the complete removal of the original skeletal material leaving a void which is later filled by calcite cement (Dodd, 1966).

In situ conversion of aragonite to calcite does not involve a void stage. This process differs from solution/reprecipitation in that internal allochem structures can be seen as relict (Bathurst, 1971; Dodd, 1966). In situ conversion in Bottineau interval rocks occurs only in oolites where concentric laminations are still visible (Figure 36). Dodd (1966) states that, from samples he studied, the time of conversion could not be determined but it could have occurred either before or after lithification. The time of in situ conversion could not be determined for Bottineau interval rocks.

Solution

Solution features occurring in both diagenetic provinces include stylolites, microstylolites, and solution voids. Stylolites and microstylolites require pressure solution for their formation (Bathurst, 1971). Solution voids occurred from the dissolution of skeletal allochems and matrix and were relatively undeformed.

Microstylolites are most readily observed in thin section because of their small size (usually less than one cm in length). They occur as boundaries between skeletal allochems which have interpenetrated leaving an irregular contact surface (Figure 29). Microstylolites frequently have a concentration of insoluble residue along the contact surface. The shape of the microstylolites is the result of different solubilities of stressed allochems at the points of contact (Bathurst, 1971).

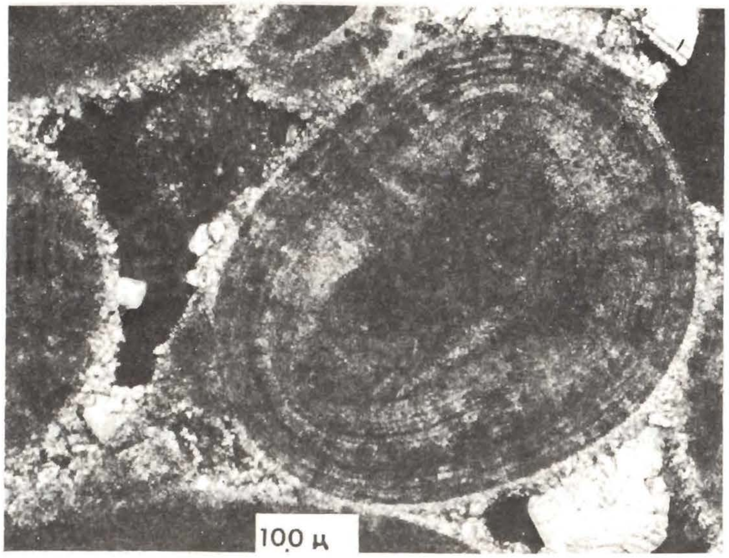


Fig. 36. Photomicrograph of in situ conversion of aragonite to calcite with preserved oolite laminae. Crossed nicols. Thin section No. 274-3225.

Microstylolites occur in all fabrics where two or more allochems have come into contact.

In both thin section and core, stylolites appear as irregular surfaces approximately parallel to bedding which generally cut completely through a given sample. Stylolites cut across both allochems and bedding, and a considerable concentration of insoluble residue along the stylolite contact surface is common. In cores where considerable relief can be observed in the stylolite, the sides of interpenetrating columns are grooved.

Stylolites form by the application of a stress, which is usually vertical from overburden pressure. Where solubility differences exist in the stressed rocks, a process similar to grain-to-grain pressure solution in microstylolites will dissolve the more soluble part of the rock (Bathurst, 1971). The less soluble rock will penetrate into voids left by the solution of more soluble rocks and an irregular surface will result from lateral variations in solubility along the plane of the stylolite.

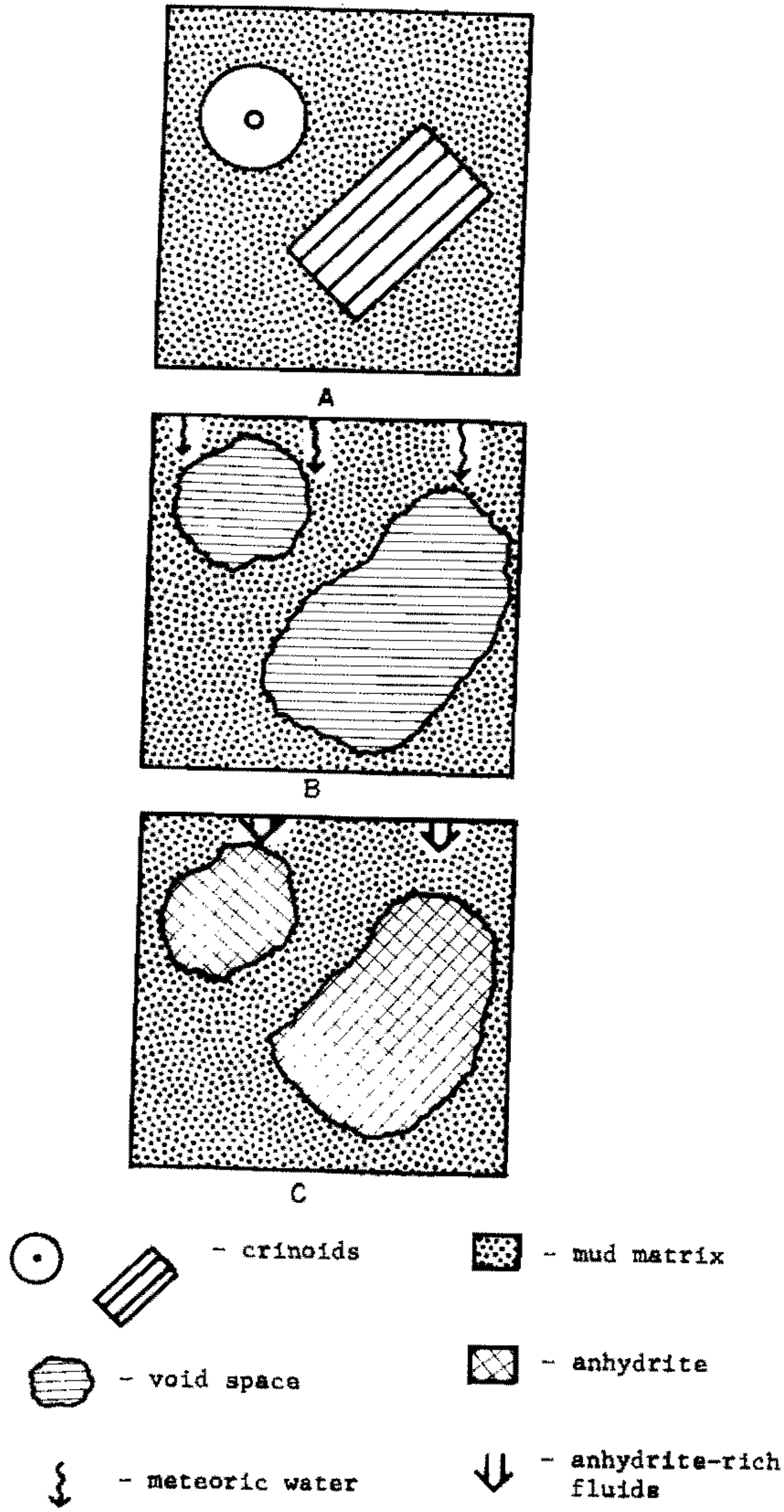
Pressure solution may also be important for the development of impermeable zones and as a source of calcite for cementation. Bathurst (1971) reported that the amplitude between adjacent columns in stylolites represents the minimum amount of carbonate that has been dissolved. Dissolved carbonate may be removed in two ways: (1) along the stylolite in the water film which exists between interpenetrating columns or (2) parallel to the major stress axis. Harms and Choquette (1965) have demonstrated an increase in porosity away from stylolites. They suggest that this is a result of calcite precipitating away from the area of maximum stress. A loss in porosity and permeability results, and, when coupled with the concentration of insoluble material along the stylolite, an impermeable barrier may result.

Bathurst (1971) suggested that carbonate that has been dissolved by pressure solution need not reprecipitate immediately once a stress free-area has been reached. Rather, it can be carried for an indeterminate distance before precipitation. Young (1973) suggested that calcite transported away from stylolites may form some of the calcite cements observed in his study. The amount of calcite derived in this manner that is available for cementation cannot be determined but may have formed the small amount of equant calcite observed along stylolites in Bottineau interval rocks.

Solution voids have been observed only in the shelf diagenetic province and are most commonly found near the pre-Mesozoic disconformity. Most voids are subspherical, less than two cm in maximum dimension. These voids are commonly filled by anhydrite. Some solution voids are interpreted to have formed from crinoid columnals (Figure 37). Neomorphism of fine grained matrix, which varied in mineralogical composition, resulted in a new matrix of relatively stable low magnesium calcite and left crinoid columnals relatively unaltered. Later, during the infiltration of meteoric waters during dolomitization, crinoids were preferentially dissolved, leaving voids. Post-dolomitization infilling by anhydrite cement followed.

Solution of Bottineau interval rocks apparently was a multistage process. Microstylolites must form before complete lithification because grain-to-grain contacts occur only if grains are mobile during

Fig. 37. Sequence of formation of anhydrite-filled solution voids. Crinoids were deposited in mud and lithified (A). Infiltration by meteoric waters dissolved the crinoid columnals (B) leaving a void. Anhydrite-rich fluids infiltrated and precipitated anhydrite in the voids (C).


A
B
C
- crinoids
- mud matrix
- void space
- anhydrite
- meteoric water
- anhydrite-rich fluids

compaction (Bathurst, 1971). Fringing cements, which formed early in diagenesis, will not halt microstylolitization but will be dissolved along with the more soluble allochem.

In Bottineau interval rocks, stylolites cut across matrix, allochems, and cements, indicating formation after lithification. Stresses are transmitted through a variety of rock constituents and stylolites form a larger scale feature than microstylolites because more points of pressure solution exist. Young (1973) has suggested that stylolitization was not a single event but occurred more than once during diagenesis. Because stylolites were observed in a number of different lithologies and cross-cutting relationships between stylolites were not observed in this study, more than one stylolitization event cannot be shown to have occurred.

Solution voids are interpreted to be related to dolomitization when fresh waters infiltrated Bottineau interval rocks and dissolved crinoid columnals and matrix. No textural evidence other than solution voids being filled by anhydrite cement was observed to support this interpretation.

Fracturing

Vertical fractures were observed in both diagenetic provinces. The size of fractures varied from approximately 1-25 cm and were filled with either calcite or anhydrite. Anhydrite-filled fractures were observed only in the shelf diagenetic province while calcite-filled fractures were observed in both provinces. In thin section, the cements appear as an interlocking mosaic of equant calcite or equant to tabular anhydrite.

Fracturing is a post-lithification event. Allochems, cements, and matrix were observed to be cut by fractures (Figure 38). Young (1973) suggested that fracturing was related to salt solution-induced stresses. However, fractures were observed in areas where no salt solution has occurred, indicating that some other mechanism(s) caused the fracturing. One mechanism would be the later subsidence in the Williston basin. Bottineau interval rocks are overlain by later Mississippian and younger marine sediments. Later subsidence, to admit marine waters into the basin, might have induced sufficient stresses to cause fracturing.

Movement of the Nesson Anticline also may have resulted in localized fracturing. Laird and Folsom (1956) reported that the crest of the anticline moved approximately one mile (1.6 km) to the east between Mission Canyon and Greenhorn deposition and suggested intermittent basement fault movements as the mechanism. Basement fault movements along the anticline, and in other localities, may have caused some of the fracturing observed in Bottineau interval rocks.

The extent to which any of these mechanisms were responsible for fracturing cannot be determined. Neither can an exact time of fracturing be given. Fracturing is a post-lithification event but, due to the possible intermittent nature of these mechanisms, a single event cannot be proved. Rather, fracturing may have occurred at several times.

Replacement

Calcite which has been replaced by other minerals can be observed throughout Bottineau interval rocks. The most common replacement minerals are dolomite and anhydrite with accessory silica, hematite, and pyrite.

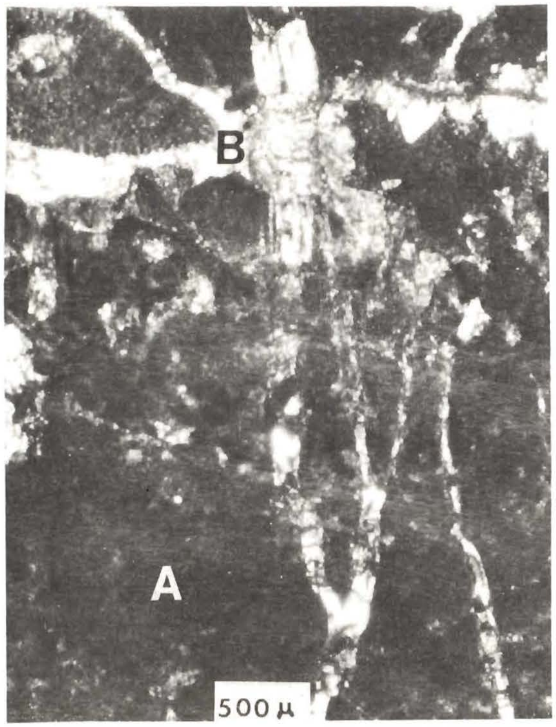


Fig. 38. Photomicrograph of a calcite-filled fracture cutting across an intraclast (A) and cement (B). Crossed nicols. Thin section No. 1516-4.

Dolomite

Dolomite occurs in two forms in Bottineau interval rocks: as small subhedral to euhedral rhombs associated with fine grained rocks and as a coarse void-filling cement in a carbonate sand body. Dolomite rhombs are common in rocks of both diagenetic provinces while void filling dolomite cement has been observed in only one sample from the shelf diagenetic province.

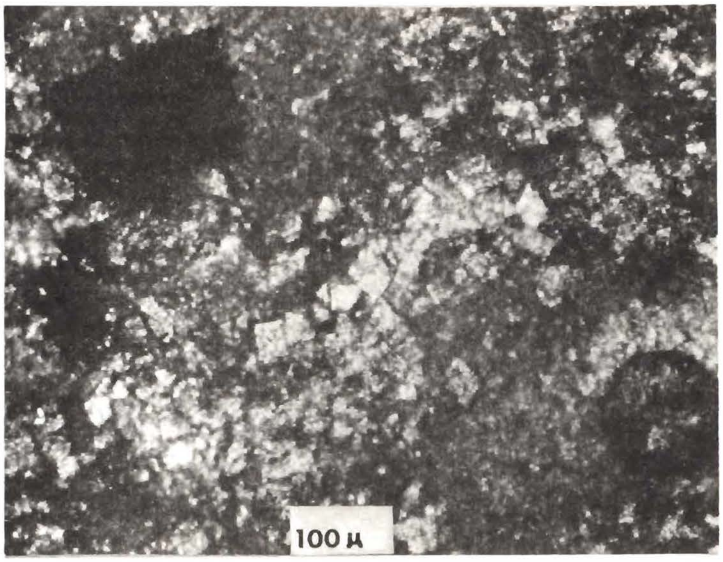
Staining was the major tool used to determine thin section mineralogy. A mixture of Alizarin Red "S" and potassium ferricyanide was used which permitted the identification of two dolomite types: ferroan and iron-free dolomite. Iron-free dolomite remains clear while ferroan dolomite appears light blue to turquoise after staining (Evamy, 1963, 1969). Rocks from the shelf diagenetic province contain only ferroan dolomite while those from the basin diagenetic province contain both ferroan and iron-free dolomite.

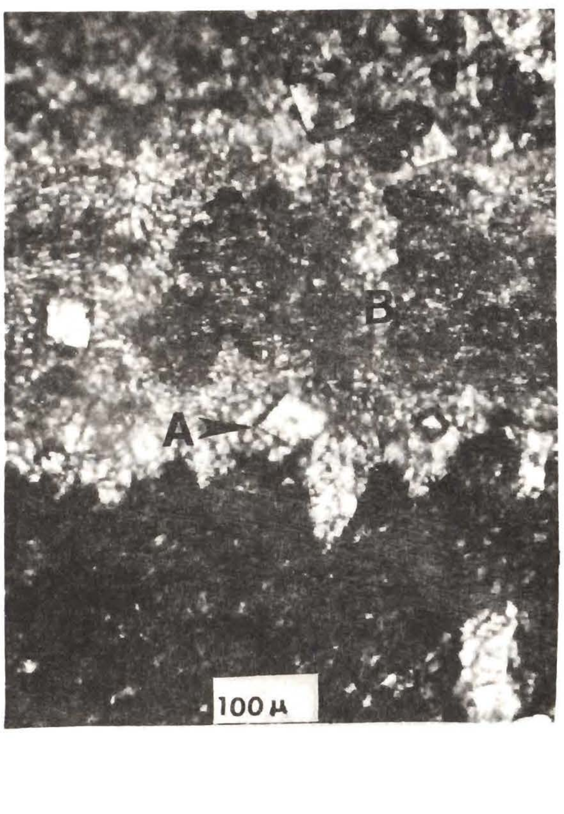
Dolomite in the shelf diagenetic province occurs as rhombs, generally less than 50 microns in diameter, in fine grained rocks (Figure 39). Dolomite-replaced cements and skeletal allochems are rare but are present along the contact between dolomitized sediments and skeletal sands (Figure 40).

McCabe (1961) and Young (1973), in their studies of Mississippian shelf rocks in Canada, noted a relationship between the thickness of dolomitized rocks and the thickness of overlying Mesozoic rocks. Where Mesozoic rocks are thick, dolomitized rocks are thin, and *vice versa*. Inadequate core and sample coverage along the Bottineau interval subcrop prevented confirmation of this relationship in North Dakota.

Fig. 39. Photomicrograph of dolomite rhombs in mudstone from the shelf diagenetic province. Crossed nicols. Thin section No. 2537-2063.

Fig. 40. Photomicrograph of dolomite rhombs (A) which replaced overgrowth cement around a crinoid columnal (B) at extinction. Crossed nicols. Thin section No. 2537-2070.


100 μ


B
A
100 μ

Dolomite in the basin diagenetic province occurs as disseminated rhombs less than 25 microns in diameter (Figure 41). Two dolomite types were observed, ferroan and iron-free. The amount of dolomite is difficult to determine because the dark color of basin rocks masks stain colors. However, dolomite can be observed along the edges of thin sections where rock chips are thinnest or by grinding thin sections to 35 microns.

Dolomite most commonly occurs in fine grained rocks and is interpreted to be the result of selective dolomitization. The amount of dolomite varies from a few disseminated rhombs to complete dolomitization of matrix.

Murray and Lucia (1967) reported that dolomite associated with fine grained rocks may be related to three controls: (1) a higher percentage of soluble carbonate minerals may be found in fine grained sediments than in coarse grained sediments, (2) the greater surface area of fine grained sediments may provide more locations for nuclei in a given volume of sediment, and (3) the permeability of fine grained sediments may be equal to that in coarse grained sediments. They could not measure the permeability of fine grained sediments from their study at the time of dolomitization, but they suggested that permeability may have been as great in fine grained sediments as in coarser grained sediments. They based this on the fact that compaction and cementation in fine grained sediments may have been offset by the early and rapid precipitation of overgrowths in the coarse grained sediments. These controls cannot be shown to have affected Bottineau interval sediments but may have been important in the selective dolomitization observed.

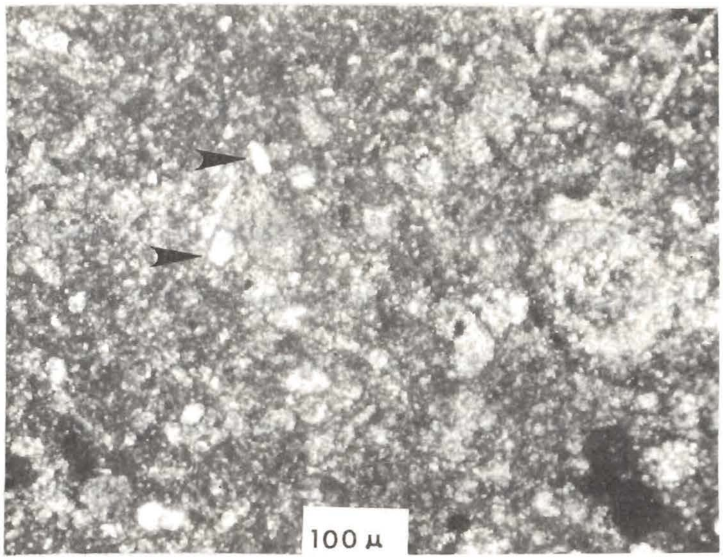


Fig. 41. Photomicrograph of disseminated dolomite rhombs in mudstone from the basin diagenetic province. Crossed nicols. Thin section No. 2172-10,141.

Another possibility for the source of selective dolomitization of fine grained sediments may be the presence of clay minerals in the sediments. Kahle (1965) suggested that clay minerals may be a source of magnesium for dolomitization. Clay minerals can remove magnesium from sea water in two ways: (1) ion exchange between magnesium and other cations (Kahle, 1965), and (2) the addition of magnesium to clays in the form of $Mg(OH)_2$ (Russell, 1970). Post-depositional chemical reactions may release the magnesium from the clays which then would be available for incorporation into dolomite.

Other possible sources of magnesium for dolomitization, besides that suggested by Kahle are: cannibalism of overlying rocks, recrystallization of high magnesium calcite to low magnesium calcite, and infiltration of hypersaline brines.

McCabe (1961) suggested that Bottineau interval rocks extended 150 or more miles east of their present erosional limit. Younger Mississippian rocks may have extended over Bottineau interval rocks but to what extent is unknown. Between Mississippian and Jurassic time Bottineau interval rocks were exposed to subaerial weathering which eroded Madison Formation rocks to their present limit. During erosion, magnesium normally would be released into solution from calcite, dolomite, and argillaceous sediments. Infiltration of magnesium-rich fluids into Bottineau interval rocks could occur and result in dolomitization. Cannibalism of pre-existing sediments is another possible source of magnesium (Goodell and Garman, 1969).

Folk (1965) considers the change of high magnesium calcite to low magnesium calcite a form of recrystallization. Staining has shown that some of the high magnesium calcite crinoids have been recrystallized to low magnesium calcite in shelf diagenetic province rocks. Recrystallization released magnesium into solution which was incorporated into cements or dolomite.

Infiltration of hypersaline brines is another source of magnesium. Young (1973) used Adams and Rhodes' model of seepage refluxion as his model of dolomitization. In this model, hypersaline brines form from high rates of evaporation on the shelf. Continued inflow of normal marine waters replaces the evaporated water and dissolved ions are concentrated in the remaining water. Because of their higher density, brines flow down gradient until stopped by a barrier where they infiltrate the underlying sediments. If anhydrite and aragonite were precipitated before infiltration the Mg/Ca ratio would be raised high enough to cause dolomitization. Folk and Land (1975) state that the Mg/Ca ratio must exceed 5-10:1 before dolomitization will begin. Young suggested that the precipitation of bedded anhydrites in the Jurassic Amaranth Formation of Manitoba removed enough calcium to raise the Mg/Ca ratio to the necessary levels.

Young's model of dolomitization by seepage refluxion may be applicable to rocks in Manitoba when the relationship between thickness of overlying strata and dolomitized strata is considered, but, in North Dakota, dolomitization by seepage refluxion cannot be conclusively proved. Instead, Folk and Land's (1975) model of dolomitization by brine and fresh water mixing is preferred because no overburden/dolomitized strata relationship can be proved to exist. In the absence of this relationship dolomitization by brine-fresh water mixing can occur more readily. In their model (Figure 42), subsurface

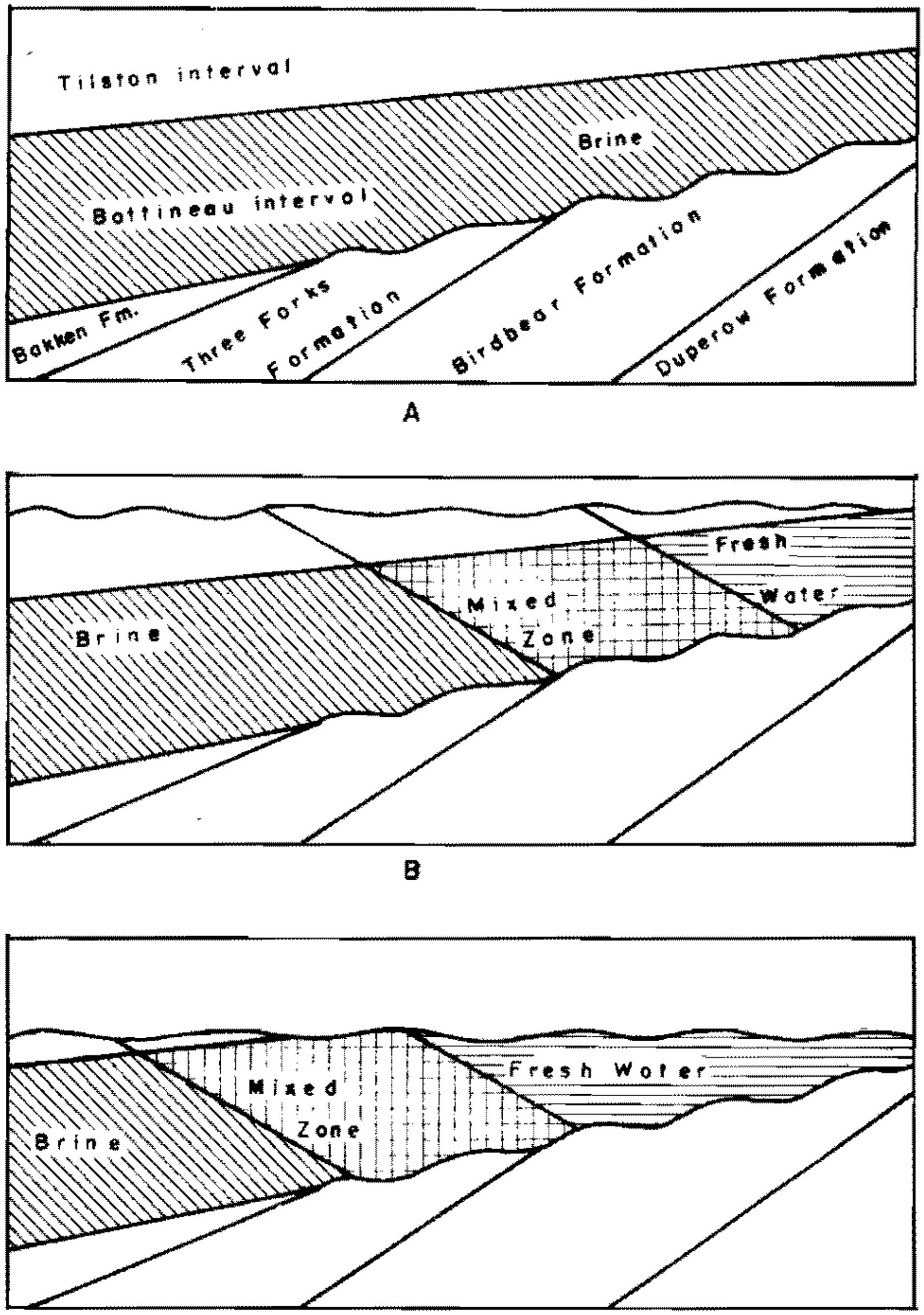


Fig. 42. Brine-fresh water mixing model of dolomitization. (A) Brine filled Bottineau interval rocks prior to erosion. (B) Fresh water infiltrated during erosion forming a fresh water zone and a mixed zone where dolomitization occurred. (C) The zones migrated basinward with continued erosion.

brines are mixed with fresh water and dilution of the brine occurs. The Mg/Ca ration remained high because the amount of Mg and Ca added to the system is small when compared to the brine's original content. With high Mg/Ca ratios at the new lowered salinities, dolomitization readily began because the rates of crystallization required for dolomitization were reduced. Further, more magnesium may have been added from one or more of the previously described sources.

Carlson and Anderson (1965, figs. 26-34) show that Madison Formation rocks are unconformably overlain by the Triassic Spearfish Formation in northeastern North Dakota, and the Jurassic Piper Formation in southeastern North Dakota. Bottineau interval rocks could have been covered by pre-Triassic and pre-Jurassic rocks, but either these were eroded off and were never deposited. In either case, erosion occurred along the Madison Formation subcrop during this time. During this erosional period, fresh water would have had ample time to infiltrate and mix with formation fluids and cause dolomitization.

The single observed occurrence of dolomite cement in shelf diagenetic province rocks is unusual (NDGS Well No. 83, depth 2697). It occurs filling the void between overgrowths and, upon close examination, no evidence of a replacement origin was noted (Figure 43). Apparently, local conditions were such that dolomite cement could precipitate but what these conditions were is unknown. Choquette (1971) suggested that dolomite cements may be more common than previously supposed but that they have been mistakenly identified as calcite.

Dolomitization in the basin diagenetic province is less extensive than in the shelf diagenetic province. Dolomite occurs

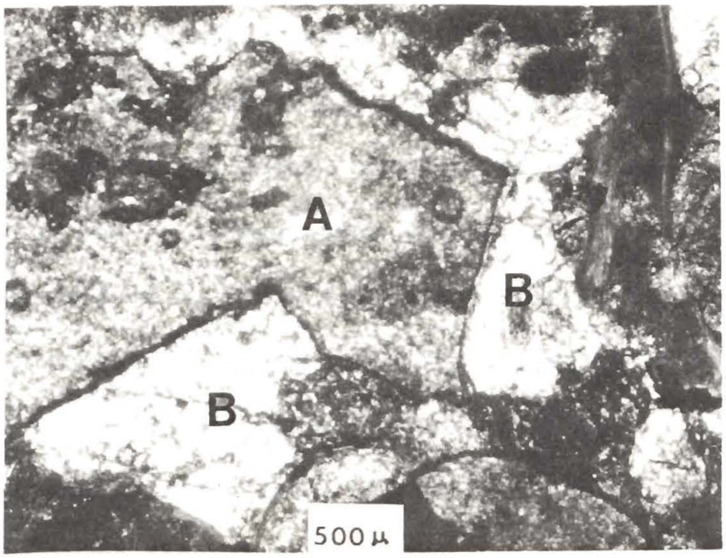


Fig. 43. Photomicrograph of ferroan dolomite cement (A) filling the space between overgrowths (B). Crossed nicols. Thin section No. 83-2697.

disseminated throughout fine grained basin rocks but was not observed to replace allochems or cement. The different manner in which dolomite occurs is interpreted to reflect a different mode of dolomite formation. Basin rocks are finer grained, more argillaceous, and less permeable than shelf rocks. The lower permeability of the rocks excludes mixing of fluids as the dolomitizing agent. Rather, dolomitization is interpreted to be the result of magnesium transported into the basin by clay minerals, as suggested by Kahle (1965) and Russell (1970). Post-depositional processes, such as ion exchange, released magnesium from clays and the magnesium was then incorporated into dolomite. Additional magnesium may have been available from the recrystallization of high magnesium calcite. The disseminated nature of the dolomite reflects the lesser amount of magnesium available in these finer grained rocks. The occurrence of iron-free dolomite indicates that either sufficient iron was not available for incorporation into the dolomite or that iron-free dolomite occurred as a separate dolomitization event.

Dolomitization, based on textural relationships, was a late diagenetic event. Dolomite replaces both cements and matrix, indicating a post-lithification time of replacement. Dolomite is also present as inclusions in anhydrite, indicating formation prior to anhydrization. The formation of iron-free dolomite in the basin diagenetic province cannot be distinguished as a separate event. Two possibilities exist; either iron-free dolomite formed as a separate event or insufficient quantities of iron were available for incorporation into the dolomite.

Ferroan dolomite cement is interpreted to have precipitated simultaneously with replacement dolomite in fine grained rocks. This interpretation is based solely on the similar composition of the cement and replacement dolomite. Further study may result in the discovery of more ferroan dolomite cements in Bottineau interval rocks.

Anhydrite

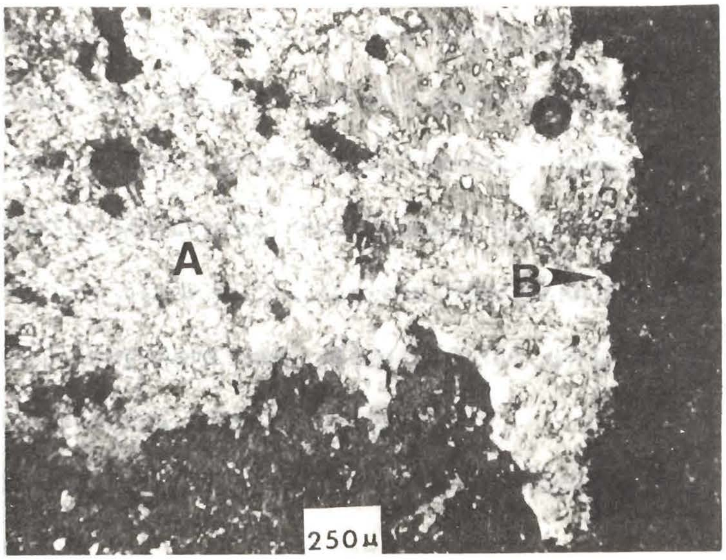
Anhydrite was observed in two forms in shelf sediments: (1) as void-filling cement and (2) replacing both matrix and allochems. Gradations between these two types of anhydrite can be observed.

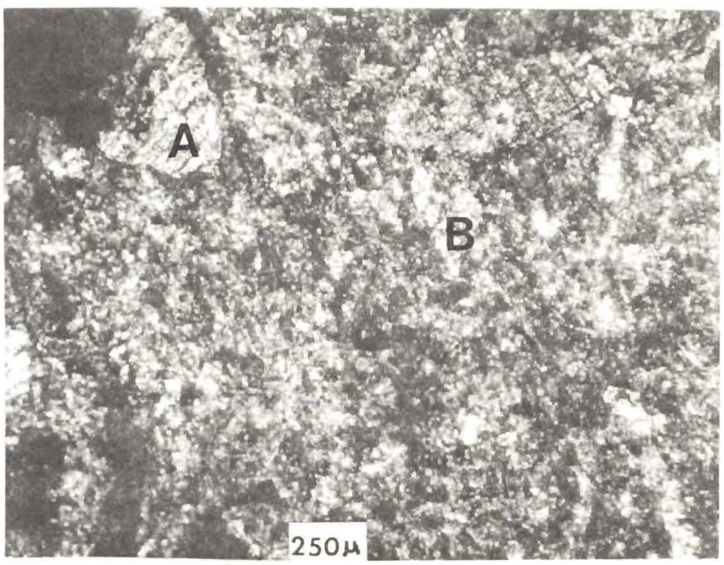
Void-filling anhydrite is free of inclusions and can be observed filling skeletal voids, solution voids, and fractures (Figure 44). Crystal shape varies from a single crystal, conforming to the shape of the void, to a mosaic of equant to tabular crystals; crystal length varies from 10-250 microns.

Replacement anhydrite occurs as an aggregate of randomly oriented crystals that cut across matrix, allochems, and cements. Inclusions of carbonate sediments are common (Figure 45), especially near the contact with unreplaced matrix, which is evidence of a replacement origin (Murray, 1964). Murray also suggested that most replacement anhydrite is derived from the solution of overlying bedded anhydrites. Young (1973) suggested two sources for anhydrite observed in his study: precipitation from hypersaline brine or the dissolution of bedded anhydrite. Young suggested that any model of dolomitization and anhydritization must explain the thickness relationship between overburden and dolomitized strata. To account for this relationship, Young suggested that hypersaline brines were formed during deposition of the Middle Jurassic Amaranth Formation in what is now southern Manitoba, and that the brines infiltrated the rocks and dolomitized them. He suggested that the brine composition could change with time and later precipitate

Fig. 44. Photomicrograph of void filled by anhydrite cement (A-light area). Note the sharp contact between the cement and the surrounding darker matrix (B). Crossed nicols. Thin section No. 615-2575.

Fig. 45. Photomicrograph of a remnant crinoid columnal (A) surrounded by replacement anhydrite (B). Crossed nicols. Thin section No. 917-2637.


A
B
250µ


A
B
250µ

anhydrite. He gave an alternate source of anhydrite-rich fluids, the dissolution of overlying bedded anhydrites. He suggested that the source was the evaporites from the overlying upper Amaranth Formation which infiltrated and anhydritized the underlying rocks (Young, 1973). An anhydrite source other than Middle Jurassic evaporites is the dissolution of bedded anhydrites from younger Madison Formation rocks. Evaporites, such as those which cap the overlying Tilston interval Himebaugh, 1979), may have been dissolved and infiltrated Bottineau interval rocks, causing anhydritization.

Anhydritization, based on textural relationships, was the last diagenetic process to alter Bottineau interval rocks. The presence of dolomite inclusions in anhydrite indicates that anhydrite formed after dolomitization.

Silica

Calcite which has been replaced by silica can be observed in both diagenetic provinces but is most common in the shelf diagenetic province. Silica primarily replaces skeletal allochems, consisting mainly of crinoids and brachiopods. Two forms of silica were observed, spherulitic chalcedony and microcrystalline quartz. These two forms preferentially replace certain skeletal allochems. Spherulitic chalcedony replaces brachiopods while microcrystalline quartz replaces crinoids. Silica also occurs as nodules, replacing both skeletal allochems and matrix in the restricted shelf facies in the extreme northeastern subcrop area in North Dakota (Figure 10).

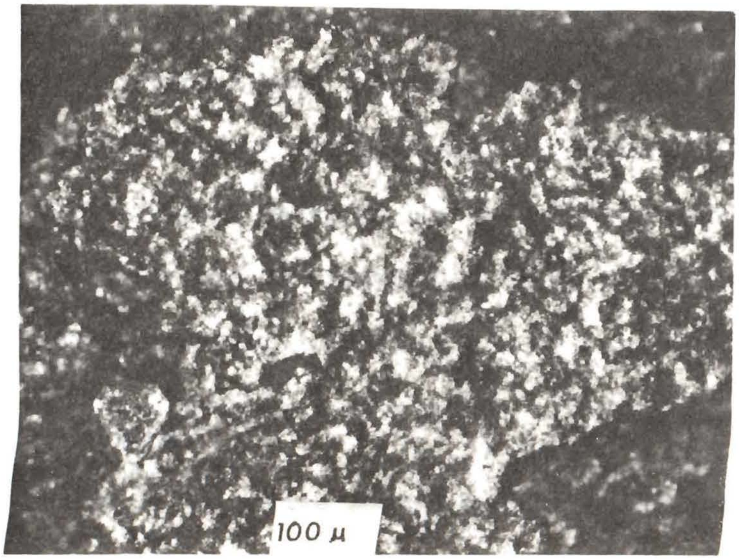
Microcrystalline quartz is the most common form of silica. In thin section, microcrystalline quartz appears colorless to light brown and consists of a mosaic of interlocked crystals, less than 200 microns in diameter (Figure 46). Because of the small size of the crystals and their different orientations, microcrystalline quartz exhibits no discernible extinction pattern but goes extinct in a random pattern. Microcrystalline quartz commonly occurs around the lumen of crinoic columnals and, as the degree of silicification increases, moves outward until the entire columnal is replaced. Microcrystalline quartz occurs rarely in brachiopods and appears as patches within the shell.

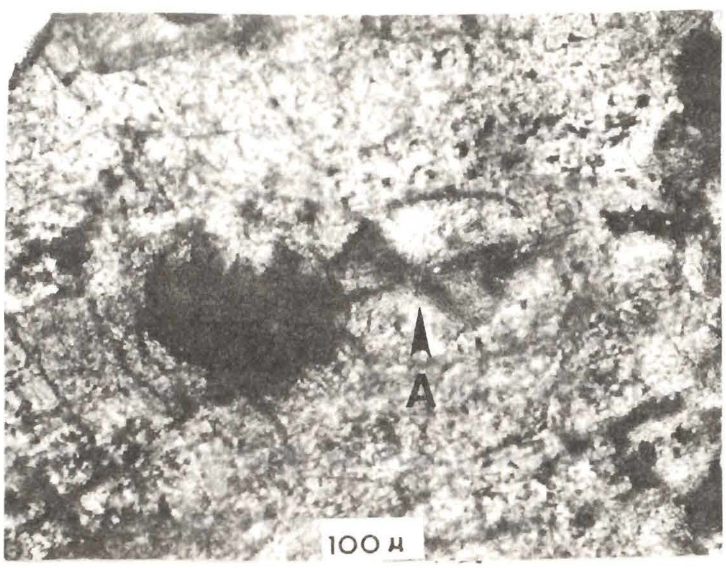
Spherulitic chalcedony occurs as individual or groups of individual spherulites and occurs most commonly in brachiopods (Figure 47). Spherulites are generally less than one cm in diameter and appear light brown under polarized light. Spherulites also appear fibrous and, when a section is cut through the center of a spherulite, a pseudouniaxial cross can be seen under crossed nichols. Intergrown spherulites mutually interfere, creating complex interference patterns.

Chert nodules are the only observed exception to silica replacement occurring in skeletal allochems. Chert nodules are irregular bodies which vary from several cms to over 20 cm in their longest dimension. In core, nodules are white to variegated red and purple and color bands are common. Fractures, which appear similar to shrinkage cracks, are common and can be several centimeters in length. In thin section, nodules exhibit the same coloration as core samples; this coloration partially masks interference colors. Staining with Alizarin Red "S" reveals that silicification is incomplete, as numerous remnants of calcite can be observed in both allochems and matrix. Hematite staining is common, especially along the margins of nodules and fractures.

Fig. 46. Photomicrograph of microcrystalline quartz. Note the random extinction pattern shown by individual crystals. Thin section No. 110-3449D.

Fig. 47. Photomicrograph of spherulitic chalcedony. Note the pseudouniaxial cross (A) exhibited by the spherulite. Crossed nicols. Thin section No. 659-3305.


100 μ


A
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Van Tuyl (1918) presented several characteristics of replacement silica. Two of the more commonly observed in Bottineau interval rocks are: (1) partial to complete replacement of matrix and fossils and (2) preservation of depositional fabrics. Banks (1970) observed that gradational boundaries between nodules and the surrounding matrix is indicative of replacement. Based on the above characteristics silica in Bottineau interval rocks is interpreted to be of replacement origin instead of a detrital origin.

Possible Silica Sources

A frequently cited silica source is the solution of siliceous hard parts, such as sponge spicules, from sediments (Land, 1976). Study of available core and samples gave no indication of sufficient populations of silica-producing organisms to derive the necessary amounts of silica observed in Bottineau interval rocks.

An alternate source would be the weathering of Precambrian shield rocks which are exposed to the north and east. Loughnan (1960) reports that silica is released from the weathering of silicate minerals. Transportation into the basin could either be by ground water or fluvial transport. Bien et al. (1958), reported that much of the silica transported into the Gulf of Mexico is either adsorbed on or co-precipitated by colloids or suspended matter. Dapples (1967) noted that siliceous sediments are often associated with fine grained terrigenous sediments. A transport mechanism similar to that observed by Bien et al. is interpreted to have occurred. Settling of silica-rich fine grained sediments occurred near the margin of the basin. Later reactions with formation fluids released the silica from colloids and suspended matter, and replacement of calcite occurred. Deposition of all the fine grained siliceous sediments did not occur near the basin margin; some was transported throughout the basin. Later reactions with formation fluids replaced calcite with silica throughout the basin. Other sources, such as organically produced silica, may account for some of the observed silica but probably was minor.

The time of silicification can be determined from textural relationships. Inclusions of calcite were observed in chert nodules and the rare replacement of calcite cement indicates that replacement occurred after cementation and lithification. Hematite staining around fractures within nodules and around the margins of nodules indicate that silicification predated hematite replacement.

Young (1973) suggested that two periods of silicification occurred. He suggested that an early period of silicification of skeletal allochems that was followed by a later period of matrix replacement. He cites the presence of dolomite inclusions in nodules as evidence for a later period of silicification. But dolomite was not observed as inclusions in nodules from Bottineau interval rocks in North Dakota.

Hematite

Hematite occurs only in the shelf diagenetic province where it stains and replaces skeletal allochems, matrix, and cements. Hematite was observed concentrated along fractures, pores, burrows, allochem margins, stylolites, and bedding planes.

Hematite is most common in fine grained rocks and imparts the variegated red, yellow, and purple colors to the rocks. Most calcareous sands are lightly stained to yellow and orange.

Hematite occurs as individual grains, aggregates of grains, and as a film around voids and fractures (Figure 48). Individual grains appear dark red while aggregates are opaque. Hematite films appear as a faint reddish discoloration of the rock. Individual grains are generally less than 10 microns in diameter while aggregates form bands which can be up to one cm thick. The occurrence of hematite within skeletal allochems and cutting across allochems and matrix demonstrates a replacement origin.

The abundant hematite requires a significant volume of iron being transported into the basin. Two possible mechanisms were discussed by Young (1973). First of all sediments in his study area were unconformably overlain by Jurassic redbeds; iron-rich fluids may have infiltrated through fractures. In North Dakota, Bottineau interval rocks are overlain by either the Triassic Spearfish Formation or Jurassic ferruginous rocks (Carlson and Anderson, 1965). Young observed that this method would not adequately explain how fine grained sediments contain most of the observed hematite. He further noted that the permeabilities of these fine grained sediments may not have been sufficient to account for the presence of hematite by infiltration.

Secondly, Young suggested that the association of fine grained sediments and hematite may indicate that solution of iron oxides from clay minerals occurred. The amount of hematite observed is too great

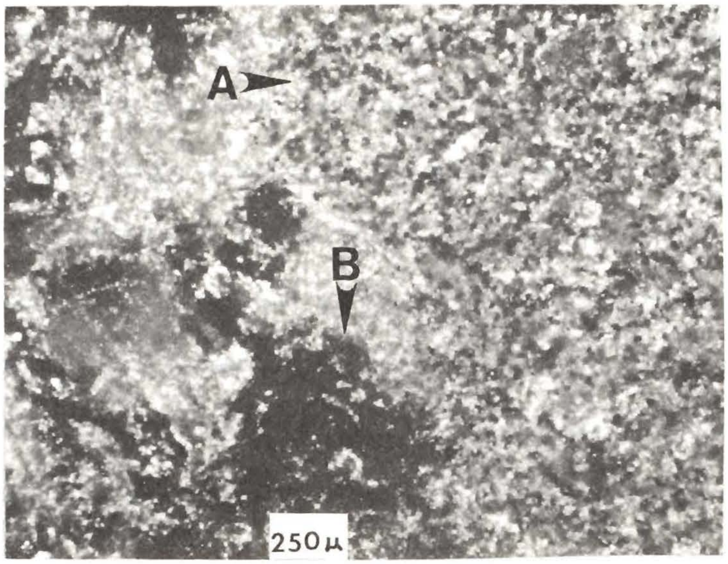


Fig. 48. Photomicrograph of replacement hematite showing individual grains (A) and clusters of grains (B). Plane polarized light. Thin section 3083-2721.

to be accounted for in this manner. The majority of fine grained sediments in Bottineau interval rocks were deposited in the deeper water central basin where iron minerals consist of iron sulphides and those deposited in shelf areas may not have contained enough iron oxides to produce the observed hematite. Young's first idea, that iron infiltrated through fractures, is preferred in this study because, as suggested by Murray and Lucia (1967), the permeability of fine grained sediments may have been as great as coarse grained sediments because compaction and cementation in fine grained sediments may be offset by the early and rapid precipitation of overgrowths in coarse grained sediments. Permeabilities of the two sediment types may have been nearly equal.

Hematite replacement is interpreted to be a late diagenetic event. Hematite can be observed replacing matrix, cement, and skeletal allochems. Hematite also occurs rimming the margins of some chert nodules and staining fractures within nodules, indicating formation after silicification. Hematite was not observed to replace dolomite or anhydrite, indicating formation prior to dolomitization and anhydritization.

Pyrite

Pyrite is abundant in rocks from the basin diagenetic province where it occurs replacing skeletal allochems and matrix. Pyrite also occurs in the shelf diagenetic province but is limited to a single occurrence in Benson County, North Dakota, well number 2537.

Pyrite occurs as individual subhedral to anhedral crystals which appear brassy in cores and opaque in thin section (Figure 49).

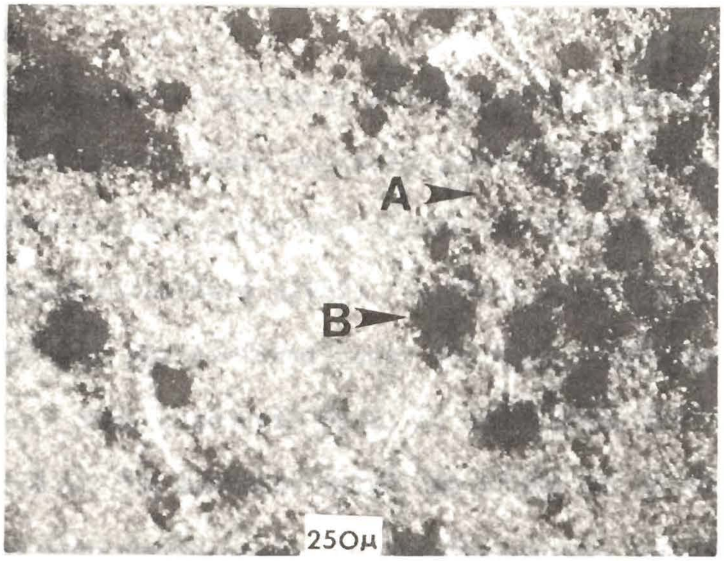


Fig. 49. Photomicrograph of replacement pyrite showing individual grains of pyrite (A) and clusters of grains (B). Plane polarized light. Thin section No. 793-29.

Pyrite also occurs as aggregates of intergrown crystals replacing skeletal allochems. Individual crystals seldom exceed 50 microns in diameter while aggregates seldom exceed one centimeter in their longest dimension.

Bryozoans are the skeletal allochem most commonly replaced by pyrite, followed by crinoids, ostracods, and brachiopods. Pyrite also occurs concentrated along stylolites and microstylolites.

Emory and Rittenberg (1952), in their study of California basins, report that pyrite forms under reducing conditions and negative Eh values. They also note that, if conditions are favorable, pyrite can form at the sediment-water interface but pyrite more commonly forms at some depth below the sediment-water interface.

Pyrite was observed concentrated along microstylolites, indicating that, as microstylolites form prior to complete lithification, pyrite also formed before complete lithification. Because most pyrite replaces skeletal allochems, other textural and structural relationships were not observed and a more precise determination for the time of formation cannot be made.

Summary

Diagenetic processes in Bottineau interval rocks can be divided into pre- and post-lithification events. Pre-lithification processes frequently interacted, making distinction as separate events difficult. Post-lithification processes appear as separate and distinct events, with the possible exception of dolomitization. Figure 50 shows the relative time framework of diagenetic processes as they affected Bottineau interval rocks.

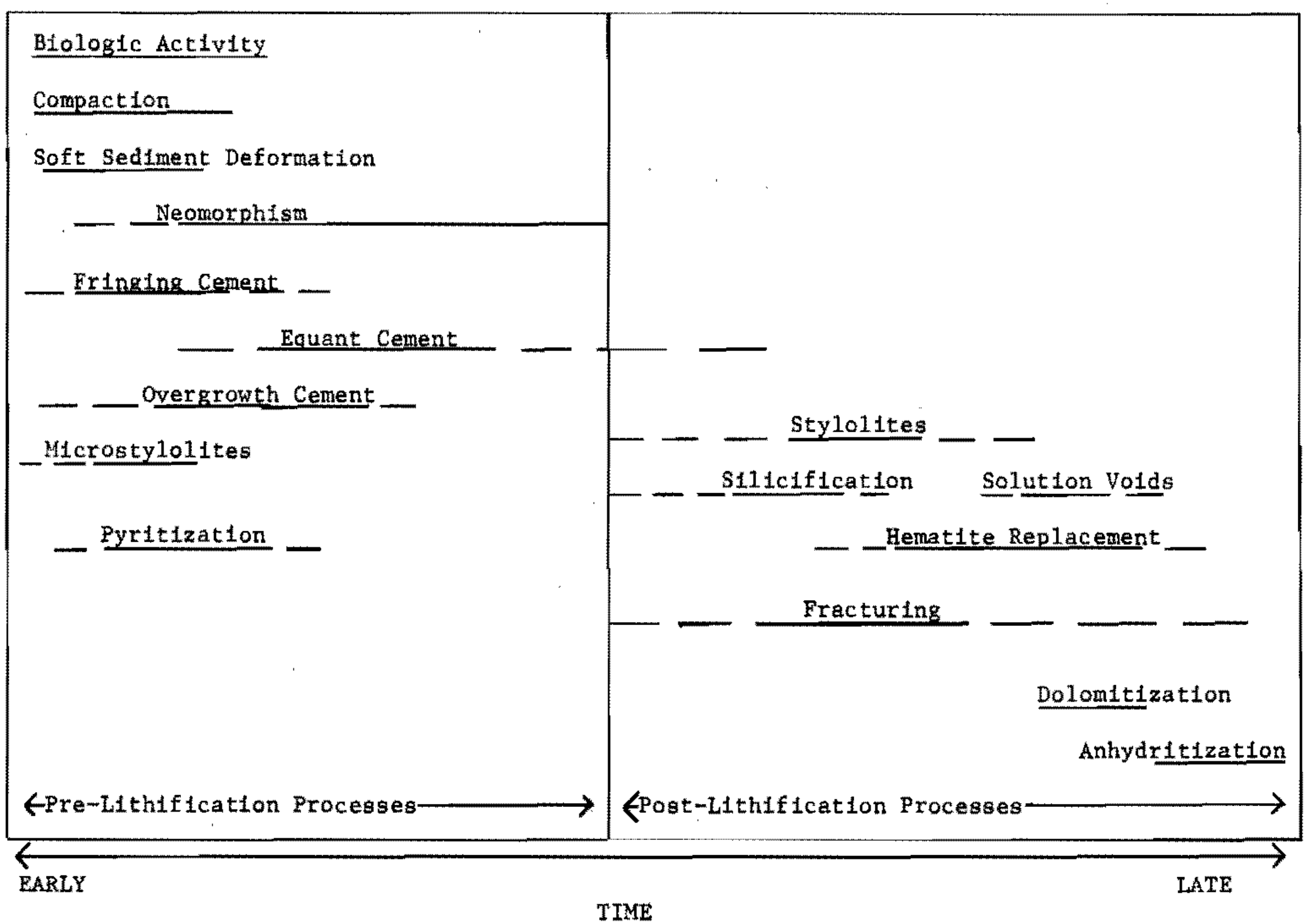


Fig. 50. Relative time of occurrence of diagenetic processes in Bottineau interval rocks.

Pre-lithification processes include biologic activity, compaction, soft sediment deformation, pyrite replacement, cementation, microstylolitization, and neomorphism. Biologic activity occurred early, both during and after deposition. Pyrite replacement and soft sediment deformation occurred shortly after burial. Fringing cements formed prior to microstylolitization without halting the process. Later cements, such as equant and overgrowth cements, halted microstylolitization in cement-lithified fabrics. All pre-lithification processes, with the possible exception of equant cement precipitation, ceased after cementation and neomorphism had completely lithified the cement.

Post-lithification processes include solution, fracturing, silica and hematite replacement, dolomitization, and anhydritization. Stylolites and fractures could form any time after lithification is complete and stresses are induced. The time(s) when these events occurred cannot be determined and they may have occurred more than once. Silicification occurred after lithification, followed by hematite replacement. Solution voids are interpreted to have formed prior to, or during, dolomitization as a result of the solution of skeletal allochems by meteoric waters. Anhydritization is the last process observed to have altered Bottineau interval rocks.

PETROLEUM POTENTIAL

Bottineau interval rocks do not produce oil in North Dakota. In Manitoba, production from the Virden and Whitewater Lake subintervals has been established along the erosional unconformity and accounts for most of Manitoba's production (McCabe, 1959). Several areas of potential production may exist in North Dakota.

In northwestern North Dakota a porosity zone was observed in Bottineau interval rocks (Figure 51) and was called the L_2 subinterval by Carlson and Anderson (1966). They reported that the L_2 subinterval is generally 80-100 feet (24-30 m) thick in their study area but that it appears to pinch out to the south and to the northwest. The areal extent of this subinterval has not been mapped. Petroleum was discovered in this subinterval in the Calvert-Cater No. 1 well from the interval 9221-9226. However, the well was shut in and completed higher in the Madison (Carlson and Anderson, 1966). This discovery indicates a potential for further production from this subinterval.

Harms and Choquette (1965) have reported a relationship between stylolites and porosity. They noted an increase in porosity away from stylolites. Reduced porosity along stylolites may act as a barrier to oil migration and direct oil into updip stratigraphic traps (Figure 52).

An areally extensive shale bed is present in north-central North Dakota in the area of the Devonian Prairie Formation salt solution (Figure 13). Structural relief, formed from salt solution prior

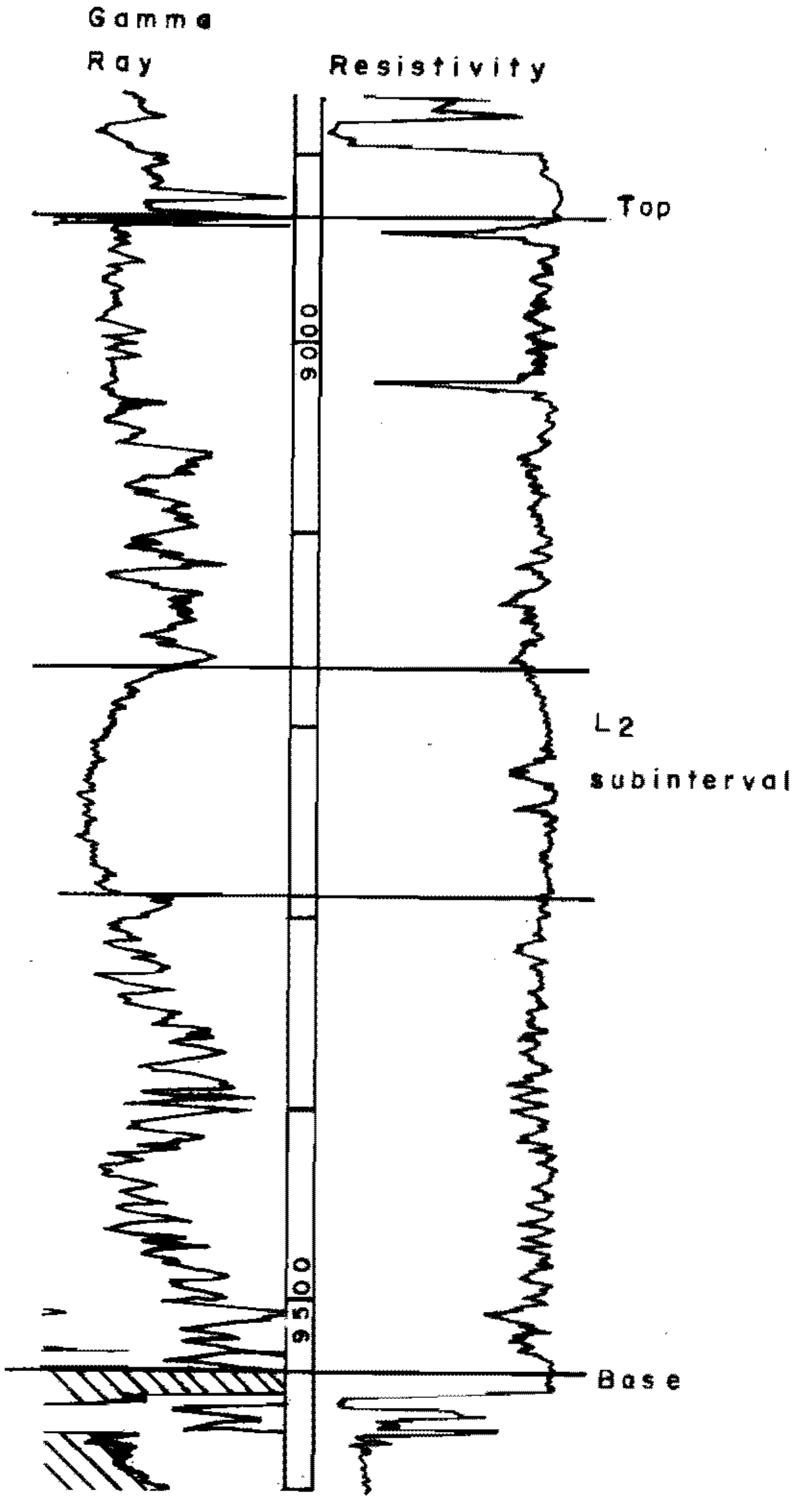
Fig. 51. Typical mechanical log of the L_2 subinterval in northwestern North Dakota. The porosity zone (L_2 subinterval) is reflected in the reduced gamma ray log count.

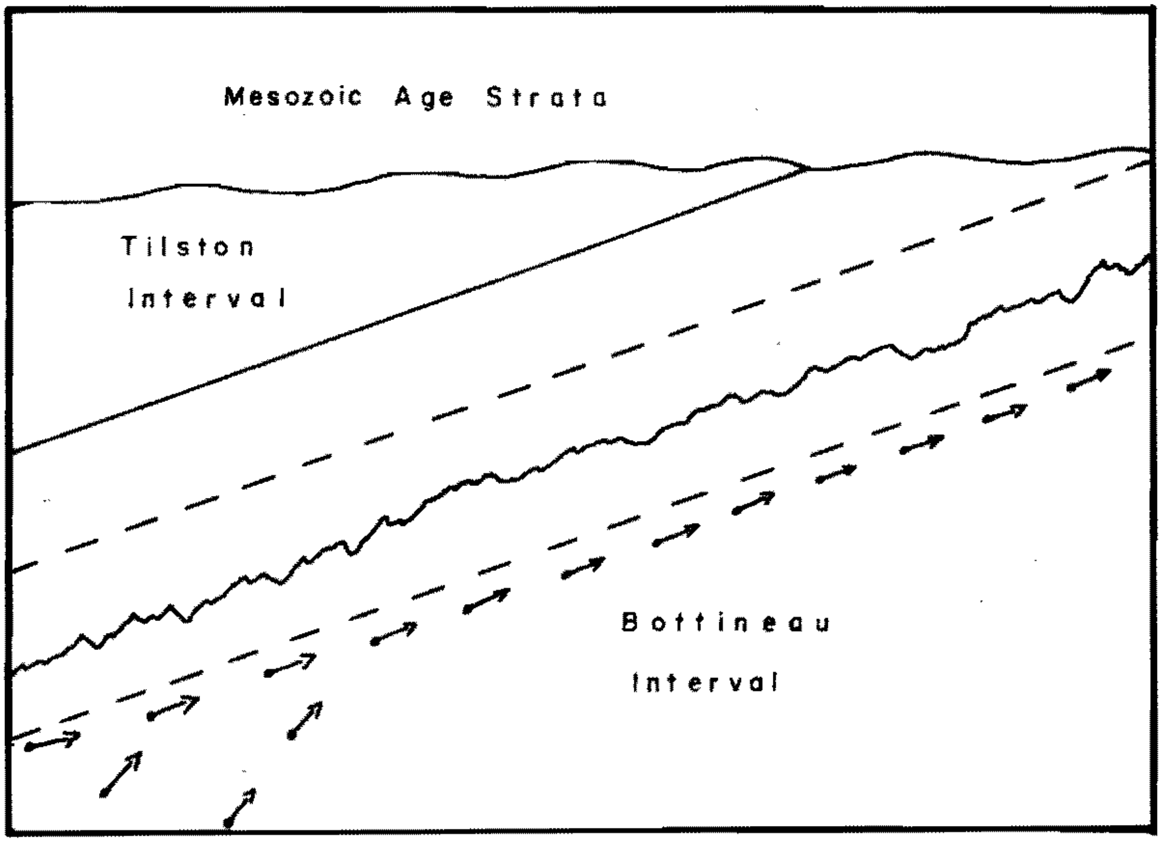
CALVERT, ASHLAND - CATER No. 1

NW NW 28-158-95

K.B. 2409

N.D.G.S. Well No. 3899





- migration path of oil and gas

- plane of stylolite

- zone of reduced porosity from cementation and insoluble residue

Fig. 52. Schematic diagram showing lateral migration of petroleum from porosity reduction by stylolites.

to deposition, coupled with the presence of the shale which may act as a reservoir cap, may form traps in this area (Figure 53).

Another area with potential for exploration is along the erosional unconformity in eastern North Dakota (Plate 1). This area has not been extensively drilled. For example, in north-central North Dakota, where extensive drilling has been done, most wells penetrate only younger Madison Formation strata with few wells penetrating Bottineau interval strata. Drilling along the Bottineau interval subcrop, especially those subcrops which are productive in Manitoba, may find some reserves. Traps which may be expected along the unconformity are discussed in greater detail by Himebaugh (1979) and include wedge-outs along the unconformity, and paleogeomorphic traps.

Bjorlie (1978) discussed possible traps in Scallion subinterval rocks in central North Dakota where the Carrington Shale (gray shale facies of this study) may act as a caprock. Mompers (1978, figure 5) shows possible migration paths of petroleum from Mississippian source rocks to the north and northeast from central North Dakota. No migration towards eastern and southeastern North Dakota was shown. However, Himebaugh (1979) reports that a number of Tilston interval shows have been discovered in southeastern North Dakota indicating that some petroleum migration has occurred into this area.

Future drilling may outline other areas of interest in the Bottineau interval. The present drilling activity in the western half of North Dakota may encounter shows in Bottineau interval rocks that could stimulate interest in this unit.

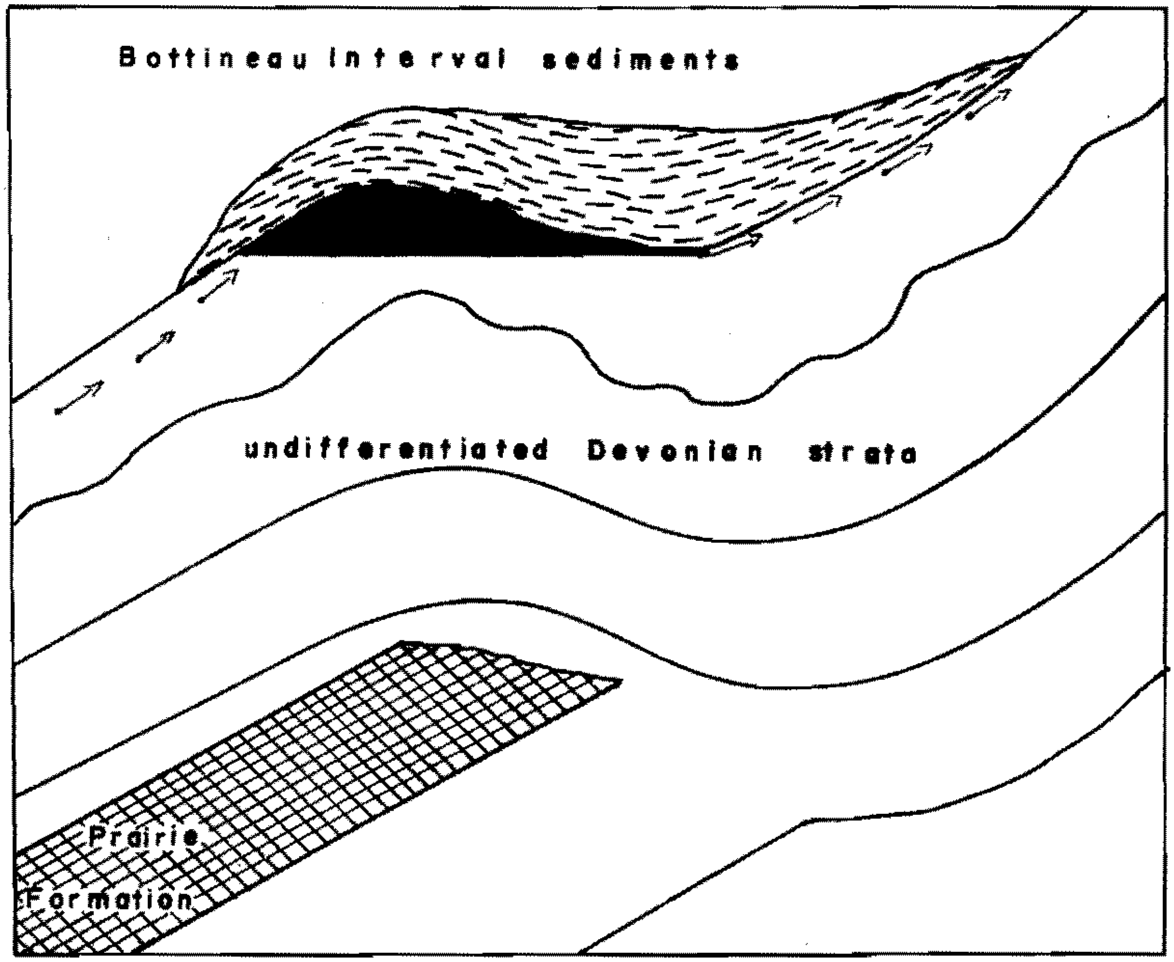


Fig. 53. Schematic diagram of a structural trap resulting from salt solution of the Prairie Formation. Shale bed forms caprock.

CONCLUSIONS

1. Bottineau interval rocks represent a transgression-regression sequence. Six major facies were developed during initial Bottineau interval sedimentation which represent a deep to shallow water depositional pattern. Maximum transgression was reached during upper Scallion subinterval sedimentation at which time deep water facies reached their maximum extent. Gradual marine regression followed and was continuous until the end of Bottineau interval sedimentation. Three younger facies were developed during the regression; these facies migrated into the formerly deeper water areas of the basin as regression continued.

2. Diagenesis of Bottineau interval rocks can be separated into two diagenetic provinces with slightly different histories. These provinces, in general, are divided on the basis of water depth at the time of deposition.

3. Diagenetic processes can be divided into pre- and post-lithification events. Pre-lithification diagenetic processes overlapped and interacted to some extent. Post-lithification diagenetic processes occurred as separate events and cannot be shown to have affected other diagenetic processes.

4. Areas of possible petroleum production are the L_2 subinterval in northwestern North Dakota, where the shale bed may have acted as a caprock in areas of salt solution in north-central North Dakota, and along the angular unconformity in eastern North Dakota. To date, drilling of Bottineau interval rocks has not been extensive and large areas exist which may have potential.

APPENDICES

APPENDIX A

NAME AND LOCATION OF WELLS STUDIED

NAME AND LOCATION OF WELLS STUDIED

Wells used in this study for correlation and sample examination are listed alphabetically by county and numerically by North Dakota Geological Survey well number within each county.

Well No.	Legal Description and Location
	ADAMS COUNTY
6050	Amerada-Hess Corp--Holmquist #1, SW SW S30 T129N R98W
	BENSON COUNTY
616	Sun Oil Company--Betsy Jorgenson #1, NE NE S5 T162N R68W
632	Calvert Exploration Co.--Arthur J. & Ida John and Gina Stadum #1, NW SE S31 T151N R70W
645	Shell Oil Co.--Murphy Christensen #1, NE NW S27 T153N R67W
651	Shell Oil Co.--Christian Hvinden #1, NE SE S21 T151N R69W
654	Shell Oil Co.--Eilert Spidahl #1, SE NE S21 T152N R69W
660	Shell Oil Co.--John K. Myre #1, SE NE S16 T152N R68W
663	Shell Oil Co.--Rudolph Gigstad #1, NE NW S10 T151N R68W
678	Shell Oil Co.--Lars A. Torgstad #1, NW NE S22 T153N R69W
683	Shell Oil Co.--H. R. Hofstrand #1, NE NE S2 T154N R69W
692	Shell Oil Co.--Oscar Sinnes #1, NE SW S2 T156N R67W
	BILLINGS COUNTY
291	Amerada Petroleum Corp.--Herman May Unit #1, NW NE S9 T139N R100W
555	Stanolind Oil & Gas Co.--Northwestern Improvement (N.P.) #1, SE SE S17 T143N R100W

Well No.	Legal Description and Location
	BILLINGS COUNTY
859	The Texas Co.--Government-M.S. Pace #1, SW NE S31 T144N R100W
1678	Amerada Petroleum Corp.--Scoria Unit #2, SW SW S2 T139N R101W
2853	Shell-Northern Pacific Railway Co.--Government 41X-5-1, NE NE S5 T143N R101W
3268	Amerada Petroleum Corp.--Scoria Unit #3, NE SW S10 T139N R101W
3746	Davis Oil Co.--Kevin-Federal #1, SW SW S10 T138N R100W
3927	Amerada Petroleum Corp.--U.S.A. Hodge #1, NW NE S21 T139N R101W
4254	Pan Am Petroleum Corp.--USA Adah G. Macauley "B" #1 SE NW S28 T137N R100W
4833	R. M. Watkins Engineering, Inc. & Mesa Petroleum Co.--Federal #1-34, NE NW S34 T141N R100W
5195	Lone Star Production Co.--Alfred Schwartz "B" #1, SE NE S2 T137N R100W
5423	Farmers Union, Inc.--Federal #14-32, SE SW S32 T144N R101W
5769	Southern Union Production Co.--Burlington Northern #1-27, SW SE S27 T141N R100W
6095	Gulf Oil Corp.--E. E. Miller #1-10, NW SE S10 T144N R98W
6140	Gulf Oil Corp.--State School Land #2-36, NW SE S26 T142N R98W
6169	Tenneco Oil Co.--Burlington Northern #1-25 NW NW S25 T143N R101W
6303	Tenneco Oil Co.--Burlington Northern #1-29, NE SW S29 T143N R100W
6310	Supron Energy Corp.--Federal 6-144-101 #1, SE NW S6 T144N R101W

Well No.	Legal Description and Location
	BOTTINEAU COUNTY
38	California Oil Co.--Blanche Thompson #1, SW SE S31 T160N R81W
64	Hunt Oil Co.--Oliver Olson #1, SW NW S18 T163N R77W
110	Lion Oil Co.--Huss #1, NW NW S23 T163N R75W
170	Lion Oil Co.--Magnuson #1, SE SW S2 T163N R77W
286	Lion Oil Co.--Erickson #1, SW NE S32 T164N R78W
328	Calvert Exploration Co.--E. Charbonneau #1, NW NW S28 T162N R74W
348	Cardinal Drilling Co.--Bennison et al #1, SW SW S12 T161N R75W
359	Ward-Williston Drilling Co.--North Dakota State #1, SW SE S36 T164N R74W
395	Ward-Williston Drilling Co.--State "A" #2, NE SE NW S36 T164N R80W
457	Calvert Exploration Co.--George Anderson #1, NW SW S34 T164N R78W
524	Dakota Drilling Co.--Ole Anderson #1, SE NW S19 T161N R81W
895	Lion Oil Co.--Wallace Hall et al #1, NW NW S14 T162N R76W
955	Lion Oil Co.--Roy Larson #1, SW NW S7 T163N R74W
1069	Cardinal Drilling Co.--Beatrice M. Keeler #1, NW NW S1 T159N R82W
1102	Cardinal Drilling Co. et al--J. Andrieux #1, SW NE S2 T161N R74W
1184	Monsanto-Tomahawk-Pilloud #1, NE NE S7 T163N R74W
1673	General Crude Oil Co.--Martin Rude #1, NE SW S23 T163N R74W
1968	Calvert Drilling, Inc. et al.--L. T. Hanson #1, SW NW S30 T163N R78W
2219	The California Co.--Bert Henry #4, SE SW S6 T161N R79W
2596	Phillips Petroleum Co.--Glenn Brandt #1, SE NW S19 T160N R80W

Well No.	Legal Description and Location
2638	Phillips Petroleum Co.--Branvold #1, SW SE S12 T162N R78W
3827	Amerada Petroleum Corp.--Lila Stark #1, SE SE S20 T162N R78W
4192	Continental Oil Co.--Thompson et al #1, NE SW S5 T160N R81W
4347	Cardinal Petroleum Co. et al--Ekrehagen Estate #1--A, NE SW S9 T163N R78W
4362	Chevron Oil Co.--Jack R. Rogers #1, SE NW S11 T160N R80W
4655	Amerada Petroleum Corp.--H. D. Lillestrand #1, SE SW S31 T162N R78W
4790	Union Oil Company of California--Abra Steen #1, SE SE S20 T159N R81W
4844	General American Oil Co. of Texas--Walter R. Sausker #1-15, NE SW S15 T161N R81W
4846	Lamar Hunt--W. Cranston #1, NE NW S8 T163N R81W
4918	Marathon Oil Co.--George C. Adams #1, NW SW S33 T161N R82W
4924	Union Oil Company of California--C. M. Huber #1-A-2, NE NE S2 T161N R81W
5071	Estate of William G. Helis--E. Van Horn et al #1, NW SW S34 T160N R81W
5141	Gemini Corp. et al--Carl #1-X, SW NE S33 T164N R77W
5147	Hickerson Oil Co.--Streich #1, SE SW S2 T160N R82W
5184	Champlin Petroleum Co.--Dunbar #1-42-14, SE NE S14 T162N R77W
5277	McMoRan Exploration Co.--Tonneson #1, SW SW S11 T162N R77W
5280	McMoRan Exploration Co.--Deraas #1, SW SW S24 T161N R74W
6021	Cities Service Oil Co.--Rice A #1, SW NW S27 T161N R82W
6126	Placid Oil Co.--Rosendahl #36-5, C SW NW S36 T163N R80W

Well No.	Legal Description and Location
	BOWMAN COUNTY
485	W. H. Hunt-Zach Brooks-State #1, NW NW S16 T129N R104W
516	Western Natural Gas Co.--Truax-Traer Coal #1, NW SW S13 T132N R102W
1446	James H. Snowden, et al--M. A. Morrison #1, SE SW S34 T130N R103W
1575	The Carter Oil Co.--Lewis L. & Ellen Johnson #1, NW SW S9 T129N R106W
2509	Shell Oil Co.--Government Unit #41-23A, NE NE S23 T130N R107W
2677	Shell Oil Co.-Government Unit #34X-3A-2, SW SE S3 T130N R107W
3150	H. W. Clarkson & E. W. Clarkson-Clarkson-White et al #1, NE SE S27 T130N R107W
3312	Shell Oil Co.--R. Young #35-4, NW SE S4 T129N R106W
3514	Shell Oil Co.--U. S. Government Unit #43-30C-43, NE SE S30 T130N R106W
3720	Shell Oil Co.--Government Unit #31X-34B-45, NW NE S34 T131N R107W
3798	Shell Oil Co.--Government #13-32, NW SW S32 T131N R106W
4143	A. J. Hodges, Ind., Inc.--Clarence Hestekin #1, NE NE S15 T130N R104W
4545	Pel-Tex Petroleum Co., Inc.--Joseph C. Kennedy #1, NW NE S17 T130N R100W
4577	Golden Eagle Exploration, Ltd.--Charles Holecek #1, NE NE S17 T129N R104W
4641	Ashland Oil and Refining Co.--U. S. A.-Melvin T-1#1, SW NW S30 T140N R102W
4654	International Nuclear Corp.--John M. Susa et al #1-61, SW NE S30 T130N R102W
4662	The Superior Oil Co.--Holecek #1, SE SE S8 T129N R104W
4669	Amerada-Hess Corp.--Melvin Miller #1, SW NE S21 T131N R104W

Well No.	Legal Description and Location
4832	Amarillo Oil Company--Albert Fossum #1-24, S/2 NW/4 S24 T130N R104W
4922	Pel-Tex, Inc.--Ingolf & Nora Landa #1, SE SW S5 T130N R100W
4952	Pel-Tex, Inc.--G. R. Boor, et al #1, SW SW S32 T130N R100W
4954	Amarillo Oil Co.--Albert Fossum #2-13, NW NW S13 T130N R104W
5000	Pel-Tex, Inc.--Erwin Coates et us #1, SW SW S28 T131N R105W
5070	Pennzoil United, Inc.--Swanke #1, NW NW S15 T131N R105W
5163	Farmers Union--North Dakota #15X-16, C S/2 S/2 S16 T131N R104W
5200	Eason Oil Co.--Carl Olson #1-13, SE NW NW S13 T129N R105W
5256	Farmers Union Central Exchange--Getz #13X-22, SE SW S22 T131N R104W
5270	Depco, Inc.--Hughes #13-27, NW SW S27 T129N R103W
5347	Depco, Inc.--Homquist #31-8, NW NW S8 T131N R104W
5402	Kenneth Luff & Hanover Planning--Jett #1-28, NE NW S28 T129N R101W
5421	Rainbow Resources--Clarence Hestekin #2A, SW NE S15 T130N R104W
5459	Depco, Inc.--Peters #14-29, SW SW S29 T130N R102W
5495	Patrick Petroleum Corp.--Mann-Greni #1, SE NE S4 T129N R103W
5567	Amax Petroleum Corp.--State of North Dakota #1, SW SE S36 T129N R106W
5584	Kenneth Luff & Hanover--Faris et al #1-22, SE SW S22 T130N R102W
5618	Kenneth Luff--G. Hughes #1-15, Approximately C S/2 N/2 S15 T129N R103W
5619	Kenneth Luff--E. Hanson #1-6, SW NW S6 T129N R101W
5772	True Oil Co.--Fisher #11-5, C NW NW S5 T131N R100W
5888	Kenneth D. Luff--O. Gunvaldsen #1-15, C NW SW S15 T132N R104W

Well No.	Legal Description and Location
5904	Petroleum, Inc.--Hilton #1, C NW NE S34 T131N R103W
5920	Kenneth D. Luff--M. L. Peters #1-20, NW NE S20 T130N R102W
5951	Kenneth Luff, Inc.--Wesley Anderson #1-3, SW NE S3 T103N R102W
6038	Kenneth D. Luff-Beck-White #1-34, SE NW S34 T129N R102W
6074	Farmland International et al--Richards & Southland Royalty #1-2, C SE SE S2 T129N R102W
6119	Pennzoil Co.--Milton G. Anderson #1, C S/2 SE S6 T130N R102W

BURKE COUNTY

2033	Hunt Oil Co.--North Tioga-Madison Unit G-25, SW SW S30 T160N R94W
2800	Sunray DX Oil Co.--Gagnum #1, SW NW S13 T163N R89W
3154	Mar-Win Development Co.--R. M. Hansen #3-D, NE NE S12 T163N R92W
4599	The Anschutz Corp., Inc.--Ormiston #1, SW SE S25 T162N R90W
4958	John B. Hawley Jr. Trust #1--Florence M. Ingerson #2, SW NE S2 T161N R91W
5161	North American Royalties, Inc.--Holte-Bank of North Dakota #1, NE NW S31 T161N R94W
5908	Chandler & Associates, Inc.--Wilson #2-33, C NW NE S33 T164N R90W
5919	Home Petroleum Corp.--Sunflot Heirs Unit #1, SE SW S30 T161N R94W
5956	Chandler & Associates, Inc.--Ewing #3-3, C NE NW S3 T161N R90W

BURLEIGH COUNTY

19	Continental-Pure--Davidson #1-Stratigraphic, SW SW SW S6 T140N R77W

Well No.	Legal Description and Location
145	Continental Oil Co.--Paul H. McCay #1, NW NW NW S32 T137N R76W
151	Hunt Oil Co.--Emma Kleven #1, SW SW S18 T140N R80W
174	Continental Oil Co.--Duemeland #1, NW NW S3 T140N R77W
701	Caroline Hunt Trust Estate-Board of University & School Lands #1, NE NE S36 T144N R75W
723	Caroline Hunt Trust Estate--R. P. Schlabach #1 NE NE S36 T139N R76W
756	Caroline Hunt Trust Estate--R. A. Nicholson #1, SW SE S32 T137N R77W
763	Caroline Hunt Trust Estate--Anton Novy #1, SE SE S14 T144N R77W
765	Caroline Hunt Trust Estate--Soder Investment Co. #1, SW SW S31 T142N R76W
772	Caroline Hunt Trust Estate--Paul Ryberg #1, NW NW S23 T140N R79W
1409	Leach Oil Co.--Calvert Drilling, Inc.--Patterson Land Co. #1, NW SE S11 T140N R77W
4389	Tom Vessels--Helen Bourgois #1, SW NE S33 T141N R80W
4685	E. C. Johnston Jr.--L. Edwards #1, SW SW S19 T140N R80W

CAVALIER COUNTY

Well No.	Legal Description and Location
27	Union Oil of California --Chris Skjervheim #1, NW NE S28 T159N R63W
36	Union Oil of California--Los Nejtos Union Central Life Insurance Co.--Ellis #1, NW NE S12 T161N R60W

DIVIDE COUNTY

Well No.	Legal Description and Location
548	Pure Oil Co.--Ole Gunderson #1, SW NW S11, T160N R98W
1443	Dakamont Exploration Corp.--Harold E. Jacobson #1, SW NE S6 T162N R96W
1546	Kerr-McGee Oil Industries, Inc.--Arlet Johnson #1, NE NW S34 T162N R101W

Well No.	Legal Description and Location
2010	The Carter Oil Co.--Dallas D. Moore #1, NW NE S7 T163N R102W
3260	Amerada Petroleum Corp.--George Anderson #1, NW SW S30 T161N R102W
3491	Hunt Petroleum Corp.--Joseph Thredt #1, NW SE S13 T160N R98W
4074	Calvert-Kelsch & Donlin--A. Legein #1, NE NE S20 T162N R95W
4394	Texaco Inc.--R. W. Redlin (NCT-1) #1, SW SW S20 T161N R97W
4423	Pan American Petroleum Corp.--Orville C. Raaum #1, NW SW S26 T162N R101W
4507	Petroleum, Inc.--Ole Hellen #1, NE NE S21 T163N R101W
4837	Miami Oil Producers, Inc., et al--Roy Hagen #1, SW NE S12 T160N R100W
5009	Consolidated Oil & Gas, Inc.--Charley Myhre, et al #1 NE SE S35 T160N R96W
5135	Ashland Oil, Inc.--F. Fenster #1-29, C NW S29 T161N R95W
5192	H. L. Hunt--A. B. Ericson #1, SW NE NE S3 T160N R95W
5246	Shell Oil Co.--Vernon Tanberg #1, NE NE S5 T161N R95W
5248	Oil Development Company of Texas--Rogers #1, NE NE S10 T160N R98W
5404	Tiger Oil Co.--Mathews #1-23, NW SE S23 T163N R99W
5535	Trend Corp.--Vatne et al #1, C NW SW S24 T160N R96W
5989	W. A. Moncrief & Westhoma--Keba Oil & Gas #31-1, NE SE S31 T164N R95W

DUNN COUNTY

Well No.	Legal Description and Location
413	Carter Oil Co.--Edward Lockwood, Jr. #1, SE SW S5 T147N R93W
505	Socony Vacuum Oil Co., Inc.--C. Dvorak #1, SE NE S6 T141N R94W
607	Socony-Vacuum Oil Co., Inc.--Angus Kennedy #F32-24-P, SW NE S24 T149N R93W

Well No.	Legal Description and Location
793	Socony-Vacuum Oil Co., Inc.--Pegasus Division-Solomon Bird Bear et al #F22-22-1, SE NW S22 T149N R91W
2352	California Oil Co., Inc.--I. J. Wilhite-U.S.A.-Reed #1, SE NW S18 T148N R95W
2400	Amerada Petroleum Corp.--Signalness Unit #1, SW SE S10 T148N R96W
2615	Stewart Petroleum Co.--Jack Dvirnak #1, NE NE S20 T146N R96W
2618	Pan American Petroleum Corp.--Jacob Huber #1, SW SE S15 T145N R91W
2724	Amerada Petroleum Corp.--Signalness Unit "A" #1, NW SE S15 T148N R96W
3044	Amerada Petroleum Corp.--Marie Selle T-1 #1, NE NE S27 T143N R92W
4220	Sinclair Oil & Gas Co.--N. A. Knudsvig #1, SW NE S13 T143N R94W
4611	Helmerich & Payne, Inc.--State of North Dakota #1, SW SW S36 T146N R96W
4725	Kathol Petroleum Inc.--Tiddens Petroleum Corp.--Little Missouri #1-24, SW SE S24 T148N R97W
4957	Miami Oil Producers, Inc.--Estate of Hairy Robe #1, NW NW S8 T147N R93W
5512	Adobe Investment Corp.--Signalness #1, NE NW S11 T148N R96W
5621	Mesa Petroleum Co.--Roshau #1, NE NW S23 T142N R97W
5887	Alpar Resources, Inc.--McNamara #1, SW SW S8 T144N R92W
6035	Gulf Oil Corp.--State #1, C SW SE S18 T145N R97W
6086	Amoco Production Co.--Berent Selle #1, C NE NE S7 T145N R94W
6091	Gulf Oil Corp.--Glovatsky #1, NW SW S17 T145N R97W
6103	Gulf Oil Corp.--Klatt #1-19, NW NE S19 T145N R97W
6105	Amoco Production Co.--William C. Lubke #1, SW NE S11 T146N R96W

Well No.	Legal Description and Location
6128	Gulf Oil Corp.--Elsie Marinenko #1-31, SE NE S31 T145N R97W
6148	Amoco Production Co.--Andrew N. Heiser #1, SW SW S2 T141N 96W

EDDY COUNTY

437	Calvert Exploration Co.--North Dakota State #1, NW NW S16 T150N R67W
768	Calvert Exploration Co.--#1 State #1, NE NE S8 T150N R65W
1274	Wetch, Zachmeier, & Disney Drilling Co.--C. E. Blasky #1, SE SE S9 T148N R62W

EMMONS COUNTY

16	Northern Ordinance--Franklin Investment Co. #1, C NW NW S35 T133N R75W
23	Roeser-Pendleton, J. J. Weber #1, SE S35 T133N R76W
43	Peak Drilling Co.--Olhauser #1, NE SE S8 T132N R78W
742	Socony-Vacuum Oil Co., Inc.--Kruse #F22-30-P, SE NW S30 T134N R75W

FOSTER COUNTY

287	Frazier-Conroy Drilling Co.--Sarah Dunbar #1, NW NW S13 T146N R63W
295	T. M. Evans--Bailey #1, SW NE S26 T145N R62W
334	T. M. Evans--Christian Erickson #1, SE NW S24 T145N R64W
403	Pure Oil Co.--J. M. Carr #1, NE NE S15 T146N R66W
652	S. D. Johnson--Joe Taylor #1, SW SW S20 T145N R67W
661	S. D. Johnson--C. W. Burnham #1, SE SE S17 T145N R66W
1105	Cardinal Drilling Co. et al--J. S. Smith #1, SE SW S8 T146N R65W
1112	Cardinal Drilling Co. et al--N. A. Graves & Federal Land Bank #1, NE NE S23 T146N R66W

Well No.	Legal Description and Location
1126	Cardinal Drilling Co. et al--J. M. Anderson #1, NW NW S10 T146N R67W
1208	Calvert Drilling, Inc.--Woodrow Topp #1, SW NE S2 T147N R64W
1227	Mike Wetch--H. F. Spickler #1-A, NE NE S25 T147N R64W
	GOLDEN VALLEY COUNTY
410	Gulf Oil Corp.--Dorough Federal #1, NE SW S24 T143N R103W
470	Blackwood & Nichols Co.--Gilman & Lang #1, NE SE S15 T140N R105W
4130	Amerada Petroleum Corp.--Ramona Waldron #1, SW NW S9 T138N R105W
4791	Woods Petroleum Corp.--Slocomb #1, C NW S29 T141N R104W
5438	Texas Gas Exploration Corp.--Guy M. Brown et al #1, NE NW S27 T141N R105W
	GRANT COUNTY
232	Youngblood & Youngblood--Kelstrom #1, SW SW S26 T133N R83W
3636	Cardinal-Lone Star-National Bulk Carriers, Inc.--Marie Bierwagen #1, SW NE S1 T133N R90W
5097	Helmerich & Payne, Inc.--Burlington Northern "J" #27-1, NE NW S27 T131N R88W
5118	Helmerich & Payne, Inc.--Burlington Northern "L" #23-1, NE SW S23 T130N R88W
5496	Wainco, Inc.--Krause #22-5, SE NW S5 T134N R90W
	HETTINGER COUNTY
511	Socony-Vacuum Oil Co., Inc.--Clarence & M. Jacobs #F14-24-P, SW SW S24 T134N R96W
4984	Pubco Petroleum Corp.--J. Haberstroh #12-2, NW NE S12 T135N R92W
5783	Farmers Union--Grosz #2-35, NW NE S35 T136N R93W

Well No.	Legal Description and Location
	KIDDER COUNTY
24	Magnolia Petroleum Corp.-Dakota "A" Stratigraphic Test, NE S36 T141N R73W
230	Carter Oil Co.--North Dakota State #1, NE SE S16 T143N R71W
748	Caroline Hunt Trust Estate--E. B. Sauter #1, NW NE S32 T142N R74W
	LOGAN COUNTY
590	Caroline Hunt Trust Estate--F. M. Fuller #1, SW SE S6 T136N R73W
1346	Calvert Drilling, Inc.--C. A. Zimmerman #1, NW SW S8 T136N R71W
1347	Calvert Drilling, Inc.--Ray Craig #1, NW NW S25 T136N R71W
1903	Herman Hanson Oil Syndicate--Jacob Piatz #1, SE SE S26 T134N R72W
5523	Wise Oil Co. No. 2 etal--Baltzer A. Weigel #1, NW NW S29 T135N R73W
	MCHENRY COUNTY
39	Hunt Oil Co.--W. B. Shoemaker #1, NE SW S3 T157N R78W
61	Hunt Oil Co.--Peter Lennertz #1, NW SE S17 T153N R77W
358	Calvert Exploration Co.--Albert Payne #1, SW NE S34 T156N R76W
769	Calvert Exploration Co.--Fred & Signa Wright #1, NW NW S14 T154N R78W
1354	Monsanto Chemical Co.--Ed #1, NW NW S26 T156N R77W
2675	Amerada Petroleum Corp.--T. Pfau #1, NW NW S34 T159N R79W
5279	McMoRan Exploration Co.--State #1, NE SW S34 T157N R76W
5281	McMoRan Exploration Co.--State #2, SW SW S16 T158N R75W
5283	McMoRan Exploration Co.--Fairbrother #1, NE NE S34 T158N R77W

Well No.	Legal Description and Location
	MCINTOSH COUNTY
89	General Atlas Carbon Co.--A. Ketterling #1, NE NE S15 T131N R73W
619	Calvert Exploration Co.--Max A. Wishek #1, SW NW S33 T130N R69W
620	Calvert Exploration Co.--C. C. Nitschke #1, NE SE S13 T130N R69W
621	Calvert Exploration Co.--John Bender #1, NW NW S19 T130N R69W
622	Calvert Exploration Co.--Karl Schock #1, SW NW S17 T131N R69W
	MCKENZIE COUNTY
33	C. W. Jones-Mallard Petroleum--Benhomer Risser #1, SW SE S12 T149N R96W
72	Amerada Petroleum Corp.--North Dakota "B" Tract 1 #1, SW NE S36 T150N R96W
147	Amerada Petroleum Corp.--George Wellan #1, NW NW S15 T152N R96W
341	Pan American Petroleum--Woodrow Starr #1, SW SE S21 T152N R94W
527	California Oil Company--Rough Creek Unit #1, NW NE S13 T148N R98W
545	Phillips Petroleum Co.--F. G. Hoehn "A" #1, NE SE S13 T152N R102W
956	Gulf Oil Corp.--Federal Unit #1, NW SW S28 T148N R104W
1202	Amerada Petroleum Corp.--Antelope-Madison Unit I 519, S/2 NW/4 S6 T152N R94W
1254	Amerada Petroleum Corp.--Antelope-Madison Unit N 509, SW SE S17 T152N R102W
1405	Gofor Oil Inc.--Catherine E. Peck #2, NW NE S27 T150N R96W
1495	Amerada Petroleum Corp.--Antelope Unit "D" #1, NW SE S32 T153N R94W

Well No.	Legal Description and Location
1606	Amerada Petroleum Corp.--Jore Unit #1, NE SW S35 T150N R97W
1744	Amerada Petroleum Corp.--Wherely-Risser-Olson Unit #1, NE SW S7 T149N R95W
1751	Texaco Inc.--L. Wiseness #1, NW SW S3 T152N R96W
1765	Texaco Inc.--R. Koeser (NCT-1) #1, NW NW S35 T151N R97W
2169	Texaco Inc.--L. Wiseness #2, Lot 11 S3 T152N R96W
2172	Amerada Petroleum Corp.--D. A. Nelson T-1 #1, SW SW S5 T152N R94W
2326	Amerada Petroleum Corp.--Harry Mendehall #1, SW SE S34 T154N R96W
2494	The Carter Oil Co.--Thomas Yellowface #1, SW SE S19 T151N R94W
2584	Shell-Northern Pacific--State of North Dakota #32-16-1, SW NE S16 T145N R101W
2602	Texaco Inc.--Seth A. Garland #5, NE S6 T153N R95W
2746	William Herbert Hunt--Anna M. Holt #1, NE SE S8 T153N R97W
2750	Amerada Petroleum Corp.--Bear Den Unit #3, NE NE S36 T149N R96W
2786	H. L. Hunt--U.S.A. "A" #1, NW SW S15 T148N R102W
2820	Texaco Inc.--Blue Buttes-Madison Unit G-105, NW SW S5 T151N R95W
2950	Amerada Petroleum Corp.--Angus Kennedy #2, SE NW S29 T151N R96W
3387	Amerada Petroleum Corp.--Antelope Unit "F" #1, NW NW S7 T152N R94W
3533	Hunt Oil Company--Haugen Unit #1, C SW S8 T153N R95W
3645	Quintana Petroleum Corp.--U.S.A. #1, SE SE S24 T145N R105W
3680	Calvert Drilling & Production Co.--G. C. Tank #1, NE SE S27 T151N R96W
3731	Occidental Petroleum Corp.--Audrey Rabbit Head Hall #1, NW SW S33 T150N R94W

Well No.	Legal Description and Location
3804	Calvert Drilling & Production Co.--Ralph Slaaten #1, NW SW S23 T153N R95W
4061	Socony Mobil Oil Co., Inc.--Grady Heirs #F11-161, NW NW S16 T152N R93W
4062	Shell Oil Co.--Government #22X-28-1, SE NW S28 T148N R101W
4085	Amerada Petroleum Corp.--USA Doris Unit #1, SE SE S2 T149N R97W
4095	Amerada Petroleum Corp.--Signalness-Tank Unit #1, SE SE S34 N151N R96W
4264	Texaco Inc.--Devonian Unit #5 Well #1, NE NW S3 T153N R95W
4304	Helmerich & Payne, Inc.--Federal McKenzie #1, NE NW S33 T146N R104W
4439	J. H. Moore & R. E. Massengill et al--Milton W. Olson #1, NE SE S18 T151N R103W
4594	Gulfland, Inc.--Drags Wolf #1, NW NW S10 T151N R94W
4723	Consolidated Oil & Gas et al--Federal Land Bank et al #23-1, SE NE S23 T151N R101W
4807	Consolidated Oil & Gas, Inc. et al—Federal Land Bank #24-1, SE NW S24 T151N R101W
4945	Universal Resources Corp.--Thompson #1, NW NW S32 T153N R95W
5002	General American Oil Co. of Texas--Burlington Northern #1-9, SE NW S9 T146N R103W
5182	True Oil Co.--Burlington Northern #22-27, SE NW S27 T148N R101W
5345	Chandler & Associates, Inc.--U. S. Government #1-27, NE NE S27 T150N R103W
5410	Texaco, Inc.--Devonian Unit #7, approximately C SW S34 T154N R95W
5655	Pennzoil Company--Federal #25-1, C SW S25 T150N R104W
5727	Amerada-Hess Corp.--Federal 33 #1, S/2 SE S33 T154N R95W
5775	H. A. Chapman--Kerr #1, NW SW S5 T150N R96W

Well No.	Legal Description and Location
5821	Shell Oil Co.--U. S. Government #34X-31-1, SW SE S31 T149N R104W
5824	Kerr-McGee Corp.--Federal 22 #1, NE NW S22 T148N R102W
5836	Kerr-McGee Corp.--North Dakota State #1-X, SW NE S16 T148N R102W
5840	Tiger Oil Co.--Federal #26-1, NE SE S26 T150N R104W
5846	Kerr-McGee Corp.--North Dakota State #2, C W/2 NW S16 T148N R102W
5866	Kerr-McGee Corp.--Robert Peterson #1, NW SW S11 T149N R99W
5909	Farmland International et al--Federal #1-18, C S/2 S18 T145N R103W
6014	Farmland International et al--Federal #1-19, NE NE S19 T145N R103W
6076	Apache Corp.--Knight #1-30, SE NW S30 T153N R95W
6121	Gulf Oil Corp.--USA #1-25, NE SE S25 T145N R98W
6122	Gulf Oil Corp.--Pete Glovatsky #1-24, NW NE S24 T145N R98W
6147	Gulf Oil Corp.--Lind #1-13, SE SE S13 T145N R98W

MCLEAN COUNTY

22	Samedan Oil Corp.--Vaughn Hanson #1, NE S10 T146N R81W
49	Stanolind Oil & Gas Co.--McLean County #1, SW SW S28 T150N R80W
432	Herman Hanson Oil Syndicate--N. E. Hanson #1, SW SE S2 T146N R81W

MORTON COUNTY

26	Phillips-Carter--Dakota #1, NW S29 T136N R81W
1620	Pan American Petroleum Corp.--Raymond Yetter #1, NE SW S27 T139N R90W

Well No.	Legal Description and Location
3859	Amerada Petroleum Corp.--James Meyer #1, SE NE S34 T135N R83W
3978	Austral Oil Co., Inc.--John J. Leingang #1, SE NW S34 T137N R83W
5379	Campbell Partners, Ltd.--Picha #1, NW NE S5 T138N R83W
5979	Houston Oil & Mineral--John J. Haider #1, NW NW S18 T136N R81W

MOUNTRAIL COUNTY

Well No.	Legal Description and Location
355	Amerada Petroleum Corp.--Tioga-Madison Unit K 143, SW NW S18 T158N R94W
474	William Herbert Hunt--W. & U. Dunham #1, NW NW S24 T155N R90W
528	William Herbert Hunt--L. C. Anderson #1, NW NE S25 T157N R89W
1002	Lon H. Cron-Martin C. Jorstad #1, NE NW S10 T157N R94W
2695	Hunt Petroleum Corp.--Josephine Dancing Bull et al #1, S9 T150N R92W
3686	Occidental Petroleum Corp.--Johnson #1, NE NE S10 T151N R93W
4113	Texaco, Inc.--Fort Berthold Allottee 437 #A-1, SW NW S4 T150N R93W
4386	Empire State Oil Company et al--Vorwerk #1, SE SE S28 T151N R90W
5072	Amerada-Hess Corp.--Albert Erickson #1X, NE NE S22 T158N R94W
5088	Shell Oil Co.--L. Texel #21-35, NE NW S35 T156N R93W
5257	McCulloch Oil Corp.--Wahner #1-34, NW SW S34 T151N R90W
5333	Shell Oil Co.--Morrow #44X-26, SE SE S26 T156N R93W
5831	Smokey Oil Co.--Will #14-33, SW SW S23 T157N R94W
6289	Thomson Petroleum Inc.--Harstad et al #1, NE SW S10 T155N R91W

Well No.	Legal Description and Location
	OLIVER COUNTY
15	Carter Oil Co.--E. L. Semling #1, C SE S18 T141N R81W
95	Youngblood & Youngblood--Eugene Wachter #1, SE SW S3 T141N R83W
3277	Sunray DX Oil Co.--Ervin V. Henke #1, NE SE S14 T142N R85W
4940	General American Oil Company of Texas--Raymond Henke #1-24, SW SW S24 T142N R85W
	PIERCE COUNTY
435	Midwest Exploration Co.--Heckman #1, SW NE S12 T158N R69W
538	Calvert Exploration Co.--Cyrus & Joseph Ramberg #1, NE SE S17 T154N R72W
706	Shell Oil Co.--Gifford Marchus #1, SE SE S23 T157N R70W
716	Shell Oil Co.--Joseph D. Bacher #1, NW NE S3 T158N R70W
780	Earl F. Wakefield--Christensen #1, NW SW S3 T157N R73W
3920	A. J. Hodges Industries, Inc.--Alex Martin #1, SE SE S23 T152N R74W
5576	Getty Oil Co.--Ludwig Vetter #1, SW SW S34 T152N T73W
	RENVILLE COUNTY
369	Sohio Petroleum Corp.--J. Nelson #1, SE SE S34 T158N R81W
815	Calvert Exploration Co.--Oscar W. Johnson #1, SW NW S13 T161N R85W
1689	Anschutz Drilling Co.--Finar Christianson #1, NE NW S7 T158N R81W
	ROLETTE COUNTY
83	Lion Oil Co.--Peder & Lillie Sebelius #1, SE NW S23 T161N R73W
316	T. M. Evans Production Co.--A. L. Johnson #1, NE SW S23 T160N R73W

Well No.	Legal Description and Location
553	S. D. Johnson--Willis A. Lawston #1, NW SW S16 T163N R69W
568	Ward-Williston Drilling Co.--State "B" #1, SE SW S11 T161N R72W
569	S. D. Johnson--C. M. Bryant Estate #1, SW NW S31 T164N R70W
579	S. D. Johnson--Melvin Tinglestad #1, SW SE S3 T163N R70W
615	Sun Oil Co.--William Wayne #1, SE NE S20 T162N R69W
659	Sun Oil Co.--Arthur Espe #1, NW SW S5 T163N R72W
685	British-American Oil Producing Co.--P. Wenstad #1, SW SW S32 T163N R73W
702	Shell Oil Co.--Ella M. Amble #1, SE SW S10 T159N R71W
754	British-American Oil Producing Co.--S. Grenier #1, SW SW S18 T161N R70W
806	British-American Oil Producing Co.--Henry Dietrich #1, NE SE S14 T163N R73W
917	Lion Oil Co.--Peter P. Nelson et ux #1, NE SE S22 T160N R72W
927	Lion Oil Co.--State of North Dakota #1, NE SW S36 T163N R73W
981	Lion Oil Co.--Peter Danielson #1, SE NE S26 T163N R72W
1517	Cities Service Oil Co.--Chippewa #1, NW NW S16 T162N R71W
1630	General Crude Oil Co.--Aida Higgins #1, NW SE S19 T161N R72W
1666	General Crude Oil Co.--Kenneth Tooke #1, SW NE S2 T161N R73W

SHERIDAN COUNTY

Well No.	Legal Description and Location
665	Caroline Hunt Trust Estate--John Waltz, Jr. #1, NE NE S15 T148N R76W
684	Caroline Hunt Trust Estate--J. R. Matz #1, NE NE S1 T147N R75W
693	Caroline Hunt Trust Estate--Walter E. Bauer #1, SW SW S19 T146N R76W

Well No.	Legal Description and Location
735	Caroline Hunt Trust Estate--C. A. Pfeiffer #1, SW SW S16 T146N R74W
	SIOUX COUNTY
631	Ohio Oil Co.--Standing Rock Sioux Tribal #1, NE SW S29 T131N R80W
	SLOPE COUNTY
91	Deep Rock-Stanolind--J. Brusich #1, SE SE S8 T135N R98W
3383	Pan American Petroleum Corp.--Lydia Foreman #1, SW SE S23 T133N R106W
3588	Sun Oil Co.--Greer-Federal #1, SE SE S21 T134N R105W
4075	H. L. Hunt--Northern Pacific Railroad "A" #1, NE SW S9 T136N R101W
4124	H. L. Hunt--Eva Hayden #1, NE NW S4 T136N R101W
4241	H. L. Hunt--Northern Pacific Railroad "A" #3, NE NW S23 T136N R101W
4280	Amerada Petroleum Corp.--Ivan Mitchell #1, NE SW S18 T135N R103W
4749	States Oil Co.--Sedevie, J. J. #1, NW NW S33 T133N R101W
5210	Belco Petroleum Corp.--Cannonball #3-3, NE NW S3 T133N R100W
5499	Jerry Chambers-Holmevig #1-21, C SW SW S21 T135N R101W
5506	Jerry Chambers--North Dakota State #1-16, SW NE S16 T135N R101W
5929	Jerry Chambers--William O. Rabe #1, SW SW S10 T135N R101W
5933	Jerry Chambers--H. J. Burke #1, SE SW S9 T133N R102W
	STARK COUNTY
344	Plymouth Oil Co.--Frank A. Fischer #1, SW NE S11 T137N R98W
539	William Herbert Hunt Co.--V. H. Kudrna #1, SW NW S20 T139N R97W

Well No.	Legal Description and Location
850	William Herbert Hunt Co.--Albert Privratsky #1, NW NW S15 T138N R98W
3160	Amerada Petroleum Corp.--Louis Koppinger #1, SE NW S20 T137N R95W
4134	Texaco, Inc.--Adam Schank (NCT-1) #1, NW SE S15 T137N R92W
4182	Texaco, Inc.--Adam Schank (NCT-1) #2, C SW S23 T137N R92W
4311	Union Oil Company of California--Victor H. Kudrna #1, NE SW S20 T139N R97W
5142	Bridger Petroleum Corp.--B. Kilzer #1, SE NE S9 T137N R92W
5143	Lone Star Producing Co.--K. Wanner #1, NE NW S9 T137N R97W
5255	Continental Oil Co.--Feimer-Anger #1, NE SW S22 T137N R95W
6243	Energetics, Inc.--Martin-Kilzer #1, SE NW S26 T137N R92W
	STUTSMAN COUNTY
40	Barnett Drilling Inc.--John Gaier #1, NW NW S11 T141N R67W
120	General Atlas Carbon Co.--A. Peplinski #1, SE NW S21 T142N R63W
134	General Atlas Carbon Co.--F. Berthel #1, SW NE S15 T142N R65W
370	Herman Hanson Oil Syndicate--R. Ogilvie #1, NW NW S21 T140N R65W
406	Herman Hanson Oil Syndicate--M. M. Mueller #1, NE NE S20 T140N R65W
602	S. D. Johnson Drilling Co.--J. J. Johnson #1, NW NW S4 T143N R69W
644	Gordon B. Butterfield--Rudolph Trautman #1, SE SE S5 T139N R68W
668	Calvert Exploration Co.--Margaret Meyers #1, SE SW S25 T137N R67W
669	Calvert Exploration Co.--C. Rau #1, SE SW S35 T139N R68W

Well No.	Legal Description and Location
670	Calvert Exploration Co.--D. C. Wood #1, SE SW S24 T139N R67W
671	Calvert Exploration Co.--George Ganser #1, NW SW S12 T140N R67W
672	Calvert Exploration Co.--Vincent Wanzek #1, NW NW S12 T139N R67W
673	Calvert Exploration Co.--F. L. Robertson #1, NE NE S26 T138N R67W
2444	Herman Hanson Oil Syndicate--O. M. Knutson #1, NE NW S4 T142N R65W

TOWNER COUNTY

227	National Bulk Carriers, Inc.--E. L. Hild #1, SE SW S31 T158N R66W
434	Midwest Exploration Co.--H. P. Juntensen #1, NW NW S27 T163N R68W
3980	LaHabana Corp. & National Assoc. Petroleum Co.--Keith R. Dunlop #1, SW SE S7 T162N R68W

WARD COUNTY

47	William Herbert Hunt Estate--Jee H. & Anna Wald #1, SE SW S23 T155N R81W
52	Wanete Oil Co.--M. O. Lee et al #1, C NE NE S24 T156N R85W
105	Stanolind Oil & Gas Co.--Walter & Ingeberg Waswick #1, SW NE S2 T153N R85W
126	Quintana Production Co.--C. W. Linnertz #1, SW SE S33 T156N R83W
392	Sam G. Harrison--J. H. Anderson et al #1, SW SW S21 T157N R85W
588	William Herbert Hunt--F. C. Neumann #1, SW SE S33 T152N R82W
656	William Herbert Hunt--Guy Almy #1, NW NE S13 T155N R82W
2946	Tenneco Oil Co.--W. J. Bertzfield #1, NW NE S12 T156N R81W

Well No.	Legal Description and Location
4923	Union Oil Company of California--Vernon Olson #1-B-5, NW NE S5 T156N R81W
4990	The Anschutz Corp., Inc-et al--Richard Musch #1, NW SW S22 T156N R84W
4992	Union Oil Company of California--Harold Anderson #1-I-2, NE SE S2 T156N R82W
5105	General Crude Oil Co.-Jerome Jensen #1, NW NW S28 T152N R86W
5158	Union Oil Company of California--Myrtle Hanson #1-C-13, NE NW S13 T153N R85W

WELLS COUNTY

Well No.	Legal Description and Location
207	Continental Oil Co.--Lueth #1, SE SE S27 T146N R73W
609	Caroline Hunt Trust Estate--George Leitner #1, SW SE S14 T148N R71W
635	S. D. Johnson--C. Hage #1, NE NE S30 T145 N R68W
642	Caroline Hunt Trust Estate--Obed Larson #1, NW NE S32 T150N R70W
689	Caroline Hunt Trust Estate--N. Thormodsgard #1, NE NE S31 T147N R71W
1211	Calvert Drilling, Inc.--Francis Zwinger #1, NE NE S8 T146N R68W

WILLIAMS COUNTY

Well No.	Legal Description and Location
32	Amerada Petroleum Corp.--Tioga-Madison Unit G 123, SW NW S12 T157N R95W
254	Amerada Petroleum Corp.--Beaver Lodge-Devonian Unit H 314, SW NE S19 T156N R95W
707	Amerada Petroleum Corp.--Gentz-Hagen #1, SE NW S15 T154N R95W
999	Texaco, Inc.--J. M. Donahue #1, SW NE S23 T154N R100W
1231	Amerada Petroleum Corp.--Beaver Lodge-Ordovician Unit #1, NE S2 T155N R96W

Well No.	Legal Description and Location
1385	Amerada Petroleum Corp.--North Dakota "A" Unit #9, SE SW S16 T156N R95W
1403	Amerada Petroleum Corp.--Beaver Lodge-Devonian Unit B 304, NE S15 T155N R96W
1514	Amerada Petroleum Corp.--Beaver Lodge-Devonian Unit B 310, C NE S34 T156N R96W
1636	Amerada Petroleum Corp.--Beaver Lodge-Ordovician Unit #2, SW S17 T156N R95W
1998	Amerada Petroleum Corp.--Beaver Lodge-Devonian Unit E 311, SW S25 T156N R96W
2009	Amerada Petroleum Corp.--North Dakota "C" A #2, NE NE S16 T158N R95W
2439	Investors Oil, Inc.--Hanson-Imperial-State #1, NE NE S36 T159N R96W
2828	Texaco, Inc.--L. J. Hovde #1, NW NW S15 T154N R98W
2887	Skelly Oil Co.--Isabele Legge #1, SW SE S20 T159N R103W
3007	Dallea Petroleum Corp., et al--Hamlet Unit #2, NE S30 T159N R95W
3126	Calvert Exploration Co.--McCoy Koshman Unit #1, C NW S30 T159N R95W
3363	Texaco, Inc.--Clarence Pederson (NCT-1) #1, NW SE S19 T157N R96W
3392	Great Plains Royalty Corp.--Jack Rouse, et al--E. Goetz #1-A, SE SE S12 T159N R95W
3442	Calvert Drilling and Production Co.--F. E. McCoy #1, SW S19 T159N R95W
3844	Amerada Petroleum Corp.--Beaver Lodge-Ordovician Unit #3, SE SE S1 T155N R96W
3899	Calvert Drilling & Production Co.--C. W. Cater #1, NW NW S28 T158N R95W
4321	Amerada Petroleum Corp.--North Dakota "C" "B" #9, NW SW S36 T158N R95W
4323	Amerada Petroleum Corp.--Lalim-Ives Unit #1, NE SW S26 T158N R95W

Well No.	Legal Description and Location
4340	Pan American Petroleum Corp.--Clifford Marmon #1, SW SW S2 T154N R95W
4510	Lamar Hunt--Bank of North Dakota-Oyloe #1, SW NE S7 T154N R103W
4572	Miami Oil Producers, Inc.--Nellie Miller #1, SW NE S18 T157N R103W
4597	Lamar Hunt--Donald Voll #1, SW NE S5 T154N R103W
4618	Amerada Petroleum Corp.--Nils Trogstad #1, NE NW S17 T156N R103W
4754	Sam Boren--A. I. Ossing #1, NE SE S21 T154N R103W
4916	Lamar Hunt--Paul Harstad #1, NE SW S29 T156N R102W
4936	International Energy Co.--Hove-McCarroll #1, SE NE S3 T154N R95W
5015	Home-Stake Production Company--Woodrow N. Sveen et ux #1, SE SE S31 T155N R96W
5069	Amerada-Hess Corp.--Beaver Lodge-Ord. Unit #5, C NW S36 T156N R96W
5114	Universal Resources Corp.--Agnes Burns #1, SE NW S21 T158N R103W
5197	Ashland Oil, Inc.--Hemsing #1-9, NE NW S9 T157N R95W
5310	Amerada-Hess Corp.--Beaver Lodge-Devonian Unit E-304, C NW S13 T155N R96W
5311	Amerada-Hess Corp.--Beaver Lodge-Devonian Unit C-306, SW NW S11 T155N R96W
5315	Amerada-Hess Corp.--Beaver Lodge-Devonian Unit D-311, C SE S26 T156N R96W
5366	Amerada-Hess Corp.--Beaver Lodge-Devonian Unit B-302X, SW NE NE S22 T155N R96W
5535	Trend Corp.--Vatne et al #1, C NW SW S24 T160N R96W
5656	Texakota, Inc.--H. Borstad #1, SW SW S3 T157N R95W
5762	True Oil Co.--Aafedt #22-32, C SE NW S32 T156N R103W

Well No.	Legal Description and Location
5871	Smokey Oil Co. Inc.--Flaten #23-2, NE SW S2 T157N R97W
6065	Tiger Oil Co.--Mattson #1-20, C SE S20 T155N R96W
6114	Smokey Oil Company, Inc.--Wheeler #21-6, NE NW S6 T156N R97W

APPENDIX B

WELL LOG DATA

WELL LOG DATA

Tops, bottom, and stratigraphic thickness of the Bottineau interval, as measured from the Kelly bushing (KB), are listed alphabetically by county and numerically by North Dakota Geological Survey well number within counties for each well studied.

Well No.	KB	TOP	BASE	THICKNESS
		ADAMS COUNTY		
6050	2695	7470	8042	572
		BENSON COUNTY		
616	1584	2380	2627	247
632	1637	2663	3193	530
636	1642	2400	2831	431
645	1492	2117	2438	321
651	1510	2389	2900	511
654	1589	2415	2922	507
660	1609	2267	2755	488
663	1560	2604	3120	516
678	1673	2500	3010	510
683	1767	2605	2980	375
692	1490	2090	2250	160
		BILLINGS COUNTY		
291	2774	9753	10,474	721
555	2815	10,155	10,915	760
859	2463	9860	10,610	780
1678	2634	9550	10,310	760
2853	2572	9913	10,684	771
3268	2540	9473	10,143	670
3746	2814	9620	10,343	723
3927	2548	9500	10,207	707
4254	2864	9430	10,193	693
4833	2593	9709	10,469	760
5195	2800	9420	10,144	724
5423	2486	9918	10,604	744
5769	2641	9783	10,498	715
6095	2583	10,120	10,979	859
6140	2676	10,000	10,750	750
6169	2555	9890	10,640	756
6310	2198	9645	10,420	775

Well No.	KB	TOP	BASE	THICKNESS
		BOTTINEAU COUNTY		
38	1526	4658	5327	669
64	1520	3304	3871	570
110	2205	3443	4005	562
170	1669	3230	3810	580
286	1539	3240	3850	610
328	1895	3100	3694	594
348	1603	2995	3588	593
359	2256	3337	3720	383
395	1488	3580	4161	581
457	1539	3296	3886	592
524	1522	4410	5014	604
895	1683	3163	3798	635
955	2236	3355	3900	545
1069	1536	4630	5242	612
1102	1664	2821	3420	599
1184	2209	3355	3860	505
1673	2160	3246	3748	502
1968	1513	3440	4119	679
2219	1494	3983	4580	597
2596	1511	4390	5005	615
2638	1495	3265	3930	665
3827	1502	3554	4169	615
4192	1516	4438	5046	608
4347	1532	3297	3950	653
4362	1508	4345	4954	609
4655	1486	3516	4142	626
4790	1476	4700	5355	655
4844	1511	4316	4920	604
4846	1518	3615	4202	587
4918	1561	4422	5058	636
4924	1514	4243	4834	591
5071	1503	4670	5218	608
5141	1598	3063	3664	601
5147	1534	4608	5220	612
5184	1552	3273	3870	597
5277	1543	3250	3855	605
5280	1527	3177	3774	597
6021	1553	4556	5159	603
6126	1499	3853	4420	567
		BOWMAN COUNTY		
485	3212	7956	8486	530
516	3074	8652	9302	650
1446	3028	7885	8450	565
1575	2953	7135	7657	522
2509	2979	7154	7638	484
2677	3034	7143	7612	469

Well No.	KB	TOP	BASE	THICKNESS
3150	3001	7246	7755	509
3312	2865	7138	7596	458
3514	2950	7216	7677	461
3720	3018	7253	7719	466
3798	3037	7515	7988	473
4143	3179	8138	8710	572
4545	2865	8030	8620	590
4577	3211	7923	8504	581
4641	3197	8114	8650	536
4654	2935	7948	8511	563
4662	3252	7956	8486	530
4669	3158	8224	8829	605
4832	3137	8056	8630	574
4922	2944	8142	8738	596
4952	2958	7980	8672	592
4954	3160	8104	8696	592
5000	2977	7712	8203	491
5070	2960	7926	8456	530
5163	3240	8320	8920	600
5200	3135	7708	8306	491
5256	3207	8276	8876	600
5270	2992	7684	8270	586
5347	3042	8225	8818	593
5402	2889	7675	8250	575
5421	3145	8050	8648	598
5459	2916	7986	8542	555
5495	3015	7897	8420	523
5567	3008	7812	8330	518
5584	2888	7810	8407	597
5618	2854	7735	8275	540
5619	2925	7789	8373	584
5772	2892	8323	8945	622
5888	3167	8523	9110	587
5904	3043	8190	8786	596
5920	2960	7957	8547	590
5951	3030	8131	8720	589
6038	2870	7585	8104	519
6074	2857	7717	8292	577
6119	3109	8145	8714	569

BURKE COUNTY

2033	2389	8506	9090	584
2800	1887	5902	6460	558
3154	1952	6547	7018	471
4599	1957	6646	7183	537
4958	1973	7044	7570	525
5161	2439	8364	8848	484
5908	1901	6135	6646	511
5919	2458	8339	8853	514
5956	1969	6817	7370	553

Well No.	KB	TOP	BASE	THICKNESS
		BURLEIGH COUNTY		
19	1909	4438	5010	572
145	1869	3920	4437	517
151	1922	5185	5810	625
174	1981	4395	4960	565
701	2023	4056	4588	532
723	1878	3877	4360	483
756	1891	4130	4674	544
763	1947	4486	5094	608
765	2027	4450	5045	595
772	2007	4830	5399	569
1409	2019	4353	4923	570
4389	2126	5407	6037	630
4685	1865	5118	5737	619
		CAVALIER COUNTY		
27	1554	1476	1511	35
36	1646	1062	1090	28
		DIVIDE COUNTY		
548	2241	8552	9010	458
1443	1943	7240	7820	480
1546	2261	8017	8443	426
2010	2195	7426	7730	304
3260	2104	7994	8456	462
3491	2345	8759	9221	462
4074	2136	7594	8079	485
4394	2157	8294	8744	450
4423	2249	8103	8452	449
4507	2214	7614	7978	364
4837	2112	8439	8855	416
5009	2290	8565	9103	538
5135	2291	8173	8663	490
5192	2373	8341	8835	494
5246	2364	7995	8467	472
5248	2243	8504	8984	480
5404	2209	7693	8046	353
5535	2299	8460	8988	528
5989	1903	6887	7345	458
		DUNN COUNTY		
413	2144DF	9529	10,388	859
505	2296	9250	10,010	760
607	2149	9658	10,508	850
793	2102	9158	9990	832
2352	2441	10,165	11,047	882

Well No.	KB	TOP	BASE	THICKNESS
2400	2394	10,028	10,886	858
2615	3039	10,802	11,669	867
2618	2212	8935	9776	841
2724	2383	10,014	10,870	856
3044	2200	8815	9620	805
4220	2210	9489	10,363	874
4611	2435	10,148	11,009	861
4725	2373	10,248	11,117	869
4957	2212	9603	10,460	797
5512	2110	9777	10,647	870
5621	2583	9847	10,645	799
5887	2203	9075	9918	843
6035	2614	10,200	11,060	860
6086	2327	9790	10,640	850
6091	2585	10,180	11,039	859
6103	2600	10,182	11,042	860
6105	2673	10,387	11,194	807
6128	2544	10,086	10,932	846
6148	2615	9700	10,488	788
		EDDY COUNTY		
437	1478	2053	2558	505
768	1561	1999	2290	293
1274	1584	1730	1852	122
		EMMONS COUNTY		
16	2027	3530	3982	452
23	2012	3656	4063	403
43	1820	3787	4200	413
742	2042	3700	4160	460
		FOSTER COUNTY		
287	1518	1723	1933	210
295	1496	1722	1790	68
334	1547	1940	2118	178
403	1547	2060	2425	365
652	1660	2371	2853	482
661	1599 DF	2095	2577	492
1105	1533	2032	2353	321
1112	1535	2078	2455	377
1126	1589	2220	2715	495
1208	1503	1875	2110	235
1227	1463	1716	2003	287

Well No.	KB	TOP	BASE	THICKNESS
		GOLDEN VALLEY COUNTY		
410	2515	9765	10,495	730
470	2867	9646	10,254	608
4130	2867	9687	10,218	531
4791	2895	9293	9830	607
5438	2710 GL	9590	10,193	603
		GRANT COUNTY		
232	1997	4996	5580	584
3636	2350	6794	7405	611
5097	2531	6108	6695	587
5118	2206	5672	6218	546
5496	2420	7138	7768	630
		HETTINGER COUNTY		
511	2614	8150	8785	635
4984	2524	7663	8340	677
5783	2548	8016	8692	676
		KIDDER COUNTY		
24	1968	3388	3965	577
230	1848	3163	3685	522
748	1889	3782	4298	516
		LOGAN COUNTY		
590	2011	3415	3906	491
1346	2022	3050	3530	480
1347	1917	2833	3315	482
1903	1974	3120	3430	310
5523	2117	3404	3886	482
		MCHENRY COUNTY		
39	1480	4010	4640	630
61	1570	4172	4820	648
358	1502	3560	4186	626
769	1481	4143	4807	664
1354	1489	3723	4360	637
2675	1478	4037	4691	654
5279	1476	3575	4200	625
5281	1470	3254	3860	606
5283	1477	3703	4341	638

Well No.	KB	TOP	BASE	THICKNESS
		MCINTOSH COUNTY		
89	2176	3170	3614	444
619	2024	2396	2502	106
620	2042	2400	2544	144
621	2056	2510	2640	130
622	2143	2563	2690	127
		MCKENZIE COUNTY		
33	2434	10,032	10,898	866
72	2388	9978	10,836	858
147	2480	9679	10,480	801
341	2145	9620	10,443	823
527	2478	10,345	11,194	849
545	2277	10,100	10,839	739
956	2339 DF	9790	10,595	805
1202	2129	9480	10,267	787
1254	2162	9575	10,372	797
1405	2342	9896	10,738	842
1495	2245	9588	10,273	785
1606	2334	10,036	10,888	852
1744	2429	10,050	10,910	860
1751	2353	9490	10,282	792
1765	2430	10,000	10,922	922
2169	2320	9440	10,223	783
2172	2098	9724	10,572	798
2326	2144	9304	10,057	753
2494	2200	9693	10,632	939
2584	2463	9904	10,759	855
2602	1983	8976	9707	731
2746	2110	10,258	10,993	735
2750	2137	9769	10,628	859
2786	2386	10,025	10,880	855
2820	2416	9658	10,568	910
2950	2298	9676	10,589	913
3387	2190	9420	10,204	784
3533	2396	9406	10,154	748
3645	2379	9612	10,371	759
3680	2371	9748	10,650	902
3804	2344	9535	10,287	752
4061	2020	9593	10,406	813
4062	2214	10,110	10,948	838
4085	2212	9918	10,770	852
4095	2432	9813	10,720	907
4264	2193	9214	9934	720
4304	2515	9854	10,628	774
4439	2200	9895	10,653	758
4594	1956	9413	10,336	923
4723	2948	9894	10,682	788

Well No.	KB	TOP	BASE	THICKNESS
4807	2130	10,000	10,793	793
4945	2273	9374	10,138	764
5002	2372	9872	10,658	786
5182	2165	10,470	11,280	810
5345	2248	9972	10,777	805
5410	1947	8950	9665	715
5655	2170	9790	10,580	790
5727	1923	8944	9654	710
5775	2403	9903	10,744	841
5821	2128	9537	10,314	777
5824	2422	10,080	10,930	850
5836	2411	10,089	10,890	801
5840	2103	9750	10,514	764
5846	2439	10,150	10,950	800
5866	2194	10,170	10,995	825
5909	2675	10,067	10,848	781
6014	2590	9980	10,760	780
6076	2267	9374	10,138	764
6121	2660	10,289	11,097	808
6122	2570	10,147	11,005	858
6147	2590	10,191	11,000	809
		MCLEAN COUNTY		
22	1995	5780	6452	672
49	2100	5658	6322	671
432	1947 GL	5707	6374	667
		MORTON COUNTY		
26.	2005	5014	5586	572
1620	2426	7893	8591	698
3859	2124	5383	5947	564
3978	2281	5833	6457	624
5379	1980	5804	6558	644
5979	1907	5005	5602	597
		MOUNTRAIL COUNTY		
355	2339	8693	9328	645
474	2161	8246	8973	727
528	2271	7720	8404	684
1002	2316	8994	9650	656
2695	2115	9432	10,337	905
3686	2159	9772	10,601	829
4113	2198	9705	10,648	943
4386	2216	8907	9696	789
5072	2367	8935	9630	695
5088	2409	9487	10,143	656
5257	2223	8914	9706	792

Well No.	KB	TOP	BASE	THICKNESS
5333	2376	9411	10,087	676
5831	2300	9139	9804	665
6289	2271	8890	9508	718
		OLIVER COUNTY		
15	2037	5708	6319	611
95	1924	5506	6135	629
3277	2193	6872	7555	683
4940	2253	6909	7595	686
		RENVILLE COUNTY		
369	1541	4873	5548	675
815	1707	5295	5892	597
1689	1532	4819	5429	610
		ROLETTE COUNTY		
83	1627	2688	3258	480
316	1680 GL	2582	2756	174
553	1869 DF	2432	2572	140
568	1677	2680	3178	498
569	1919 DF	2732	2904	172
579	1901 DF	2570	2755	185
615	1809	2463	2636	173
659	2287	3280	3560	280
685	2042	3115	3585	470
702	1599	2656	2960	314
754	1734	2680	2919	239
806	2180	3218	3540	322
917	1602	2605	3060	455
927	2198	3255	3602	347
981	2287 DF	3180	3434	254
1517	2159	3108	3348	470
1630	1632	2719	3199	480
1666	1675	2799	3256	457
		SHERIDAN COUNTY		
665	1792	4172	4787	615
684	1849	3948	4517	569
693	1982	4565	5182	617
735	1994	4020	4595	575
		SIOUX COUNTY		
631	1730 DF	3972	4438	466

Well No.	KB	TOP	BASE	THICKNESS
		SLOPE COUNTY		
91	2803	8009	9580	611
3383	2798	7854	8368	514
3588	2895	8429	9020	591
4075	2777	9162	9853	691
4124	2729	9153	9851	698
4241	2868	9231	9910	679
4280	2971	9042	9676	634
4749	2976	8664	9296	632
5210	2975	8816	9437	621
5499	2863	9014	9668	654
5506	2856	9045	9710	665
5929	2788	9010	9680	670
5933	1897	8616	9250	634
		STARK COUNTY		
344	2798	9330	10,020	690
539	2590	9390	10,140	750
850	2650	9398	10,055	657
3160	2695	8830	9542	712
4134	2310	7828	8525	697
4182	2344	7827	8522	695
4311	2560	9350	10,010	720
5142	2326	7890	8600	710
5143	2688	9176	9880	704
5255	2717	8843	9546	703
6243	2345 GL	7834	8530	696
		STUTSMAN COUNTY		
40	1869 DF	2450	2910	460
120	1493	1774	1932	158
134	1552	2016	2280	264
370	1673	2018	2272	252
406	1576	2024	2282	258
602	1946 DF	2940	3450	510
644	1945	2633	3100	467
668	1907	2340	2708	368
669	1880	2503	2948	445
670	1874	2385	2763	378
671	1900	2389	2840	451
672	1867	2343	2782	439
673	1919	2405	2747	342
2444	1545	2023	2328	305
		TOWNER COUNTY		
227	1465	2040	2151	111
434	1713	2124	2276	152
3980	1761	2323	2425	102

Well No.	KB	TOP	BASE	THICKNESS
		WARD COUNTY		
47	1595 DF	5072	5682	610
52	1839	6076	6738	662
105	2175	6875	7540	665
126	1772	5720	6368	648
392	1875	6325	6960	635
588	2086 DF	6123	6788	665
656	1632	5383	6029	646
2946	1556	4822	5467	645
4923	1573	4989	5660	671
4990	1788	5932	6576	684
4992	1618	5100	5735	635
5105	2120	7397	8100	703
5158	2117	6857	7519	662
		WELLS COUNTY		
207	1933	3678	4206	528
609	1610	2868	3316	448
635	1783	2648	3140	492
642	1599	2766	3225	459
689	1702	3100	3620	520
1211	1608	2422	2916	494
		WILLIAMS COUNTY		
32	2458	8942	9616	674
254	2397	9013	9735	723
707	2178	9240	9947	707
999	2253	10,214	10,925	711
1231	2316	8920	9630	710
1385	2360	9008	9730	722
1403	2165	8850	9580	730
1514	2286	9076	9780	704
1636	2401	9010	9729	719
1745	2341 GL	8953	9608	655
1998	2396	9067	9778	711
2009	2446	8875	9486	611
2439	2325	8803	9377	574
2828	2233	10,325	11,048	723
2887	2001	8447	8932	485
3007	2372	8839	9401	562
3126	2370	8820	9384	564
3363	2332	9500	10,130	630
3392	2317	8687	9238	551
3442	2367	8843	9375	532
3844	2370	9068	9795	727
3899	2409	8935	9536	601
4321	2457	8895	9549	654

Well No.	KB	TOP	BASE	THICKNESS
4323	2460	8900	9518	618
4340	1972	9178	9895	717
4510	2252	9817	10,467	650
4572	2293	9250	9796	546
4597	2338	9897	10,517	620
4618	2413	9653	10,252	599
4754	2223	9858	10,537	679
4916	2409	9880	10,537	657
4936	2051	9170	9883	713
5015	1945	9030	9786	756
5069	2345	9012	9714	702
5114	2912	8980	9499	519
5197	2434	9000	9641	641
5310	2333	9051	9783	732
5311	2287	8910	9638	728
5315	2357	9018	9723	705
5366	2102	8833	9568	735
5535	2299	8449	8988	539
5656	2468	8976	9627	651
5762	2433	9817	10,420	603
5871	2301	9560	10,120	560
6065	1976	9060	9763	703
6114	2390	9967	10,590	623

APPENDIX C

CORE DESCRIPTION

CORE DESCRIPTION

Cores are listed alphabetically by county and numerically by North Dakota Geological Survey well numbers within counties.

Well No.	Depth	Description
		BENSON COUNTY
#2537	2060-2064	Gray-green mudstone (dolomitic).
	2064-2070	Buff mudstone (dolomitic, pyritic) with thin buff wackestone beds (iron stained, dolomitic).
	2070-2073	Pink oolitic packstone (stylolitic, dolomitic).
	2073-2087	Buff mudstone (dolomitic, iron stained, stylolitic).
	2087-2104	Cream oolite grainstone interbedded with buff mudstone (dolomitic).
	2104-2120	Buff mudstone (dolomitic, stylolitic, iron stained).
		BOTTINEAU COUNTY
#38	5006-5048	Light to dark gray wackestones and packstones (dolomitic, cherty, pyritic) interbedded with medium to dark gray argillaceous wackestones to mudstone (pyritic, dolomitic, horizontal burrows are common).
	5048-5056	Medium gray shale (calcareous, nonfossiliferous) with a few thin wackestone and packstone beds.
#110	3447-3450	Red to purple mudstone (dolomitic, iron stained) interbedded with gray and red packstone (dolomitic, iron stained, cherty, burrowed).
#955	3354	Bottineau interval top.
	3354-3368	Buff argillaceous mudstone (dolomitic, iron stained, cherty) with a few fossiliferous interbeds.
	3368-3381	Red argillaceous mudstone (dolomitic, iron stained) interbedded with cream to light gray wackestones and packstones (dolomitic, cherty, iron stained).

Well No.	Depth	Description
	3381-3393	Buff to light gray argillaceous mudstone (anhydritic, dolomitic).
	3393-3428	Pink to gray packstones and wackestones (dolomitic, anhydritic, iron stained) interbedded with dark red to purple argillaceous mudstone (dolomitic, iron stained).
#1184	3349-3356	Red to pink mudstones and wackestones (dolomitic, iron stained)interbedded with gray-green mudstones (dolomitic).
	3356-3377	Light to medium gray wackestones and packstones with scattered shaly laminae (oil stained, stylolitic, dolomitic, fractured).
		DUNN COUNTY
#607	10,483-10,509	Dark gray to black mudstone (dolomitic, pyritic, fractured, burrowed) interbedded with dark gray to black packstones (pyritic, dolomitic, fractured).
#793	9702-9994	Dark gray to black mudstones and wackestones (dolomitic, pyritic, fractured, burrowed) interbedded with dark gray to black packstone (dolomitic, pyritic, fractured).
		FOSTER COUNTY
#403	2057-2063	Light gray mudstones and wackestones (dolomitic, stylolitic, anhydritic, iron stained) interbedded with dark red argillaceous mudstone (dolomitic, iron stained).
		HETTINGER COUNTY
#511	8402-8414	Dark gray mudstones to packestones (dolomitic, fractured, pyritic) interbedded with dark gray calcareous shale (fractured).
	8414-8493	Core missing.
	8493-8507	Dark gray mudstone to packstone (dolomitic, pyritic, fractured) with thin calcareous shale interbeds.
	8507-8598	Core missing.
	8598-8654	Dark gray mudstone to packstone (dolomitic, pyritic) with thin calcareous shale interbeds.

Well No.	Depth	Description
		KIDDER COUNTY
#230	3446-3455	Light to dark gray packstone with shaly laminae (dolomitic) interbedded with purple mudstones and wackestones (dolomitic, iron stained).
		MCKENZIE COUNTY
#2172	10,087-10,145	Dark gray to black mudstones and wackestones (dolomitic, pyritic, fractured, burrowed) interbedded with dark gray packstones (dolomitic, pyritic, fractured).
#1516	6240-6246	Medium gray mudstone and packstone (anhydritic, pyritic) interbedded with black calcareous shale (pyritic).
	6246-6372	Core missing.
	6372-6390	Light to dark gray wackestones and packstone (pyritic, fractured, intraclastic, burrowed) interbedded with whispy to massive black calcareous shale (pyritic, fractured).
	6390-6427	Core missing.
	6427-6433	Carbonate as above.
	6433-6436	Core Missing.
	6436-6482	Carbonate as above.
		PIERCE COUNTY
#274	3072	Bottineau interval top
	3072-3080	Cream packstone with whispy shale laminae (dolomitic, intraclastic) interbedded with buff mudstone to wackestone.
	3080-3098	Cream packstone (cherty, dolomitic, iron stained) interbedded with red to purple argillaceous mudstone (iron stained).
	3098-3175	Gray packstone and grainstone (cherty, dolomitic) interbedded with cream to light gray wackestone (dolomitic, burrowed).

Well No.	Depth	Description
	3175-3192	Pink wackestones and packstones (cherty, dolomitic).
	3192-3199	Pink wackestones and packstones (cherty, dolomitic, fractured) interbedded with dark gray wackestone (dolomitic, fractured).
	3199-3227	Gray and red wackestones and packstones (cherty, dolomitic, intraclastic) interbedded with dark gray argillaceous wackestones (dolomitic, cherty).
	3227-3238	Light to dark gray wackestones and packstones (cherty, dolomitic).
	3238-3303	Carbonate as above interbedded with dark gray argillaceous mudstones (dolomitic, burrowed).
	3303-3339	Cream oolitic grainstone (intraclastic, stylolitic).
	3339-3343	Gray wackestones and packstones (oolitic, cherty, intraclastic, dolomitic, burrowed) interbedded with dark gray argillaceous mudstone (dolomitic).
		ROLETTE COUNTY
#83	2662-2674	Gray-green argillaceous mudstone (dolomitic, anhydritic) interbedded with red mudstone (iron stained, dolomitic, cherty).
	2674-2677	Cream packstone (dolomitic, cherty, iron stained).
	2677-2679	Red argillaceous mudstone (iron stained, dolomitic) interbedded with gray-green mudstone (dolomitic).
	2679-2682	Cream packstone (dolomitic, cherty, iron stained, intraclastic).
	2682-2694	Gray-green mudstone (dolomitic) interbedded with red argillaceous mudstone (iron stained, cherty, dolomitic).
	2694-2698	Red argillaceous mudstone (dolomitic, iron stained) interbedded with purple argillaceous mudstone (iron stained, dolomitic).

Well No.	Depth	Description
	2698–2737	Red Argillaceous mudstone (iron stained, dolomitic) interbedded with gray-green mudstone (dolomitic) and yellow calcareous mudstone.
	2737–2740	Buff packstone (dolomitic, iron stained, cherty, intraclastic).
	2740–2749	Gray-green mudstone (dolomitic, fractured, anhydritic) interbedded with buff packstone (dolomitic, anhydritic, iron stained).
	2749–2761	Buff packstone (dolomitic, intraclastic) interbedded with yellow argillaceous mudstone (iron stained).
#615	2469–2475	Cream to light brown mudstone (dolomitic, iron stained).
	2475–2619	Cream to purple wackestones and packstones (dolomitic, cherty, anhydritic, fractured, iron stained) interbedded with red-yellow mudstone (dolomitic, cherty).
#659	3282–3288	Buff wackestones and packstones (anhydritic, iron stained, dolomitic).
	3288–3289	Buff mudstone (dolomitic, iron stained, burrowed).
	3289–3363	Buff wackestones (dolomitic, cherty, burrowed) interbedded with buff packstones (dolomitic, cherty, iron stained).
	3363–3443	White packstone (Stylolitic, fractured).
#754	2680	Bottineau interval top.
	2680–2709	Gray to pink wackestones and packstones (dolomitic, anhydritic, fractured, iron stained, cherty) with whispy dark gray shale laminae.
#917	2610–2619	Light gray wackestones and packstones (dolomitic, stylolitic, anhydritic, iron stained) interbedded with medium gray to red mudstone (dolomitic, iron stained).
	2619–2653	Pink argillaceous mudstone (dolomitic, anhydritic, iron stained) with scattered packstone beds (dolomitic, iron stained).

Well No.	Depth	Description
	2653-2674	Buff wackestones and packstones (dolomitic, anhydritic, iron stained, intraclastic) interbedded with red-yellow mudstone (dolomitic, iron stained).
	2674-2694	Pink wackestone (dolomitic, anhydritic) interbedded with dark gray mudstone (dolomitic).
	2694-2698	Cream oolite grainstone.
	2698-2700	Red argillaceous mudstone (dolomitic, iron stained.
	2700-2770	Core missing.
	2770-2818	Light to dark gray wackestone (dolomitic) interbedded with dark gray to black calcareous shale.
#927	3255	Bottineau interval top.
	3255-3256	Light gray wackestone (dolomitic, burrowed, intraclastic).
	3256-3268	Cream oolite grainstone (stylolitic).
	3268-3285	Cream oolite grainstone (stylolitic) interbedded with red mudstones and wackestones (dolomitic, iron stained).
#1517	3112	Bottineau interval top.
	3112-3113	Green and red calcareous shale interbedded with purple wackestone (dolomitic).
	3113-3116	Red packstone (dolomitic, iron stained) interbedded with red-yellow mudstone (dolomitic, iron stained).
	3116-3119	Cream wackestone (dolomitic, cherty) interbedded with buff mudstone (dolomitic, iron stained).
	3119-3121	Red and green packstone (dolomitic, iron stained, cherty) interbedded with dull red mudstone (dolomitic, iron stained).
	3121-3130	Cream packstone (dolomitic, cherty) interbedded with buff mudstone (dolomitic, cherty).

Well No.	Depth	Description
#1630	2723-2724	Red-yellow mudstone (dolomitic, argillaceous, iron stained).
	2724-2736	Pink to light gray packstone (stylolitic, dolomitic, iron stained, anhydritic) interbedded with eyllow argillaceous mudstone.
	2736-2751	Pink wackestone (dolomitic, cherty, iron stained) interbedded with yellow argillaceous mudstone.
#2862	2761-2791	Cream to pink wackestones and packstones (dolomitic, cherty, stylolitic, iron stained) interbedded with red mudstone (dolomitic, iron stained).
#3083	2719	Bottineau interval top.
	2719-2763	Buff packstone (dolomitic, fractured, cherty, stylolitic, iron stained, burrowed) interbedded with red-yellow mudstones and calcareous shales (dolomitic iron stained).
		WELLS COUNTY
#207	4185-4196	Cream to pink wackestone (dolomitic, iron stained) interbedded with thin red mudstones (dolomitic, iron stained).

APPENDIX D

WELL CUTTINGS DESCRIPTION

WELL CUTTINGS DESCRIPTION

Well cuttings are listed alphabetically by county and numerically within counties by North Dakota Geological Survey well numbers. Bottineau interval contacts in the descriptions are taken from well logs (Appendix B). Some wells refer first to a facies and are followed by a general description for the facies. These wells were examined during reconnaissance and, if they were not near the facies boundary, were not studied in detail.

Well No.	Depth	Description
		BENSON COUNTY
#654	2415	Bottineau interval top.
	2415-2425	Cream oolites interbedded with minor light brown mudstones (dolomitic).
	2425-2430	Gray shale.
	2430-2475	Cream grainstones and packstones (iron stained).
	2475-2755	Cream oolites interbedded with carbonate as above.
	2755-2835	Cream to light purple wackestones and mudstones.
	2835-2845	Cream oolites.
	2845-2865	Cream to light purple wackestones.
	2865-2875	Cream oolites.
	2875-2890	Cream packstones and grainstones.
	2890-2922	Gray shale.
#660	2267	Bottineau interval top.
	2267-2310	Pink to red packstones and grainstones.
	2310-2335	Cream oolites with scattered beds of pink to red packstones.
	2335-2360	No samples.
	2360-2580	White wackestones and packstones (iron stained).

Well No.	Depth	Description
	2580-2590	Light red-brown wackestones and packstones.
	2590-2675	White wackestones and packstones interbedded with brown packstones (iron stained).
	2675-2755	Gray shale (Calcareous).
#663	2604	Bottineau interval top.
	2604-2765	Light red packstones interbedded with cream grainstones.
	2765-2870	Light gray packstones and grainstones.
	2870-2880	Dark gray shale (Calcareous).
	2880-2965	Light brown to pink grainstones and packstones.
	2965-2970	Gray shale.
	2970-3120	Buff wackestones interbedded with scattered gray shales.
#683	2605	Bottineau interval top.
	2605-2705	White wackestones (dolomitic).
	2705-2810	White wackestones interbedded with red grainstones (dolomitic and cherty).
	2810-2945	White wackestones interbedded with dull red mudstones.
	2945-2970	Carbonate as above with quartz sand.
	2970-2980	Carbonate as above.
		BOTTINEAU COUNTY
#286	3240	Bottineau interval top.
	3240-3285	Red-brown wackestones and packstones.
	3285-3455	Cream wackestones and packstones.
	3455-3475	Medium gray wackestones.
	3475-3525	Red-brown wackestones.
	3525-3595	Medium gray wackestones.

Well No.	Depth	Description
	3595-3850	Light brown to gray wackestones.
#5280	3177	Bottineau interval top.
	3177-3340	Light brown oolites and packstones.
	3340-3360	Carbonate as above with quartz sand.
	3360-3375	Light gray packstones.
	3375-3400	White packstones.
	3400-3430	Cream oolites and white packstones.
	3430-3570	Light gray packstones.
	3570-3590	Dark gray wackestones.
	3590-3610	Medium gray packstones.
	3610-3680	Dark gray wackestones.
	3680-3710	White packstones (dolomitic).
	3710-3774	Dark gray to brown mudstones (dolomitic).
		BOWMAN COUNTY
#1575	7135	Bottineau interval top.
	7135-7512	Cream wackestones and packstones interbedded with cream grainstones (iron stained).
	7512-7575	Cream oolites interbedded with buff mudstones (dolomitic).
	7575-7657	Medium gray mudstones (dolomitic, argillaceous).
#3798	7515	Bottineau interval top.
	7515-7575	Cream oolites interbedded with cream grainstones.
	7575-7920	Light brown to light gray wackestones (dolomitic, iron stained).
	7920-7970	Cream oolites.
	7970-7988	Cream oolites interbedded with buff to light brown packstones (dolomitic).

Well No.	Depth	Description
#4832	8056	Bottineau interval top.
	8056-8165	Medium brown packstones and grainstones (dolomitic).
	8165-8500	Dark gray wackestones (dolomitic).
	8500-8630	Light brown wackestones (slightly dolomitic).
#4952	7980	Bottineau interval top.
	7980-8010	Medium brown oolites interbedded with brown mudstones (dolomitic).
	8010-8340	Brown wackestones to grainstones.
	8340-8370	Medium gray wackestones (dolomitic).
	8370-8572	Dark gray wackestones and mudstones (dolomitic).
		BURKE COUNTY
#2800	5902	Bottineau interval top.
	5902-6460	Light to dark gray wackestones and packstones (dolomitic, pyritic).
		DIVIDE COUNTY
#2010	7426	Bottineau interval top.
	7426-7730	Central Basin Facies-Medium to dark gray wackestones and mudstones (dolomitic, pyritic, argillaceous).
		DUNN COUNTY
#413	9529	Bottineau interval top.
	9529-9685	Medium to dark gray wackestones and mudstones with packstones pods (dolomitic, pyritic, argillaceous).
	9685-10,388	Medium to dark gray wackestones and mudstones (dolomitic, pyritic).
		EDDY COUNTY
#437	2053	Bottineau interval top.
	2053-2070	Light cream to red grainstones.

Well No.	Depth	Description
	2070-2130	Carbonate as above with quartz sand.
	2130-2180	Carbonate as above interbedded with red wackestone.
	2180-2210	Pink and white wackestones.
	2210-2220	Gray shale.
	2220-2550	Pink and white wackestones and grainstones.
	2550-2558	Orange wackestone (dolomitic).
		FOSTER COUNTY
#287	1723	Bottineau interval top.
	1723-1900	White to buff dolomitic mudstone.
	1900-1933	Red shale with sand.
#403	2060	Bottineau interval top.
	2060-2062	Light gray mudstone.
	2062-2063	Pink grainstone.
	2063-2065	Light gray dolomitic mudstone interbedded with red mudstones.
	2065-2095	Cream packstones and grainstones (iron stained, cherty, dolomitic)
	2095-2110	Cream wackestones (dolomitic, cherty, iron stained).
	2110-2130	Cream packstones interbedded with white wackestones.
	2130-2165	Cream wackestones interbedded with light red mudstones (cherty, dolomitic).
	2165-2330	White packstones interbedded with pink mudstones.
	2330-2365	White wackestones (dolomitic, cherty).
	2365-2425	Red-brown shale interbedded with orange-red wackestones.

Well No.	Depth	Description
		GOLDEN VALLEY COUNTY
#470	9646	Bottineau interval top.
	9650-10,254	Dark gray to black wackestones with packstone pods (dolomitic, pyritic).
		GRANT COUNTY
#232	4996	Bottineau interval top.
	4996-5060	Light gray wackestones interbedded with light gray packstones and grainstones (pyritic, dolomitic, cherty).
	5060-5105	Cream oolites interbedded with light gray packstones.
#3636	6794	Bottineau interval top.
	6794-6840	Cream oolites interbedded with buff packstones.
	6840-6890	Light gray to buff grainstones and packstones.
	6890-6900	Buff oolites interbedded with buff wacke-stones.
	6900-7100	Buff to light grain grainstones interbedded with light gray wackestones.
	7100-7405	Carbonate as above interbedded with light gray mudstones.
#5118	5672	Bottineau interval top.
	5672-5710	Light gray oolitic packstones.
	5710-5725	Buff oolites.
	5725-6000	Light gray to buff packstones and grainstones.
	6000-6218	Light gray wackestones and packstones with white wackestone beds.
		MCHENRY COUNTY
#61	4172-4450	Light to medium gray wackestones and packstones (pyritic, dolomitic).
	4450-4550	Cream oolites interbedded with light gray oolitic packstones and grainstones.

Well No.	Depth	Description
	4550-4800	Light to medium gray wackestones and mudstones.
	4800-4820	Dark gray shale.
#2675	4037	Bottineau interval top.
	4037-4350	Light gray to light brown packstones and wackestones (dolomitic, argillaceous).
	4350-4640	Light gray to brown mudstones and wackestones (pyritic, dolomitic).
	4640-4655	Black shale.
	4655-4691	Light to medium gray wackestones and mudstones.
		MCKENZIE COUNTY
#956	9790	Bottineau interval top.
	9790-10,595	Central Basin facies-Light to medium gray wackestones and packstones with packstone pods (dolomitic, pyritic).
		MCLEAN COUNTY
#49	5658	Bottineau interval top.
	5658-6045	Light to medium gray packstones and grainstones (peloidal, argillaceous, pyritic).
	6045-6322	Medium gray wackestones and mudstones (pyritic, dolomitic).
		MORTON COUNTY
#3978	5833	Bottineau interval top.
	5833-5910	White to buff packstones interbedded with light gray grainstones (cherty, dolomitic).
	5910-6180	Light gray packstones and grainstones (cherty, dolomitic).
	6180-6200	Carbonate as above with scattered interbeds of white packstones.
	6200-6390	Light gray to brown wackestones and mudstones (dolomitic, pyritic).

Well No.	Depth	Description
	6390-6457	Light gray to white mudstones.
		MOUNTRAIL COUNTY
#474	8246	Bottineau interval top.
	8246-8973	Central Basin Facies-Medium to dark gray wackestones and mudstones with packstone pods (dolomitic, pyritic).
#528	7720	Bottineau interval top.
	7720-8404	Basin Flank facies-Dark to medium gray wackestones and packstones interbedded with medium gray mudstones (argillaceous, dolomitic, pyritic).
		OLIVER COUNTY
#95	5506	Bottineau interval top.
	5506-5535	White packstones.
	5535--5845	Medium gray packstones and grainstones (dolomitic).
	5845-6135	Dark brown mudstones and wackestones (dolomitic, pyritic).
#4940	6909	Bottineau interval top.
	6909-6920	Light gray wackestones and packstones.
	6920-6980	Carbonate as above with minor oolitic interbeds.
	6980-7490	Dark brown wackestones and mudstones (dolomitic, pyritic).
	7490-7595	Dark to medium gray mudstones and wackestones (pyritic, dolomitic, argillaceous).
		PIERCE COUNTY
#435	2378-2420	Cream to white mudstones and wackestones (dolomitic).
	2420-2440	Light purple wackestones and packstones (dolomitic).

Well No.	Depth	Description
	2440-2470	Carbonate as above with white mudstone interbeds.
	2470-2547	White wackestones and mudstones interbedded purple mudstone.
#3920	3366	Bottineau interval top.
	3366-3740	Light to medium gray packstones and grainstones (oolitic in places).
	3740-3937	Light to dark gray mudstones and packstones (slightly pyritic, dolomitic).
		RENVILLE COUNTY
#815	5295	Bottineau interval top.
	5295-5892	Central Basin facies-Medium to dark gray wackestones and mudstones with packstone pods (dolomitic, pyritic).
		ROLETTE COUNTY
#316	2582	Bottineau interval top.
	2582-2756	Light pink to cream mudstones (cherty, dolomitic, iron stained, anhydritic)
		SHERIDAN COUNTY
#693	4565	Bottineau interval top.
	4565-4930	Light gray to light brown grainstones and packstones with quartz.
	4930-5040	Light gray to brown wackestones and mudstones with quartz.
	5040-5090	Quartz sand with minor carbonate as above.
	5090-5100	Gray shale interbedded with light gray mudstone.
	5100-5182	Light gray mudstones and wackestones with abundant quartz sand.
#735	4020	Bottineau interval top.
	4020-4270	Light gray to brown packstones and grainstones (pyritic, dolomitic).

Well No.	Depth	Description
	4270-4290	Light gray mudstones and wackestones.
	4290-4330	Light brown packstones and grainstones.
	4330-4400	Light gray packstones interbedded with white packstones (dolomitic, pyritic).
	4400-4430	Light gray mudstones (dolomitic, pyritic).
	4430-4567	Light gray to light brown wackestones and mudstones (dolomitic, cherty).
		SLOPE COUNTY
#3383	7854	Bottineau interval top.
	7854-7930	Light gray to brown wackestones and packstones (pyritic, dolomitic).
	7930-7950	Buff oolites interbedded with light gray packstones.
	7950-8270	Dark to medium gray wackestones and mudstones (dolomitic, pyritic).
	8270-8368	Medium gray wackestones and packstones (dolomitic, pyritic)
#3588	8429	Bottineau interval top.
	8429-9020	Central Basin facies-Light to dark gray wackestones and packstones with packstone pods (dolomitic, pyritic).
#4280	9042	Bottineau interval top.
	9042-9470	Light to medium gray wackestones with packstones (dolomitic, pyritic, peloidal).
	9470-9676	Light to dark gray wackestones and packstones (pyritic, dolomitic).
		WELLS COUNTY
#207	3678	Bottineau interval top.
	3678-3730	Cream packstones (dolomitic).
	3730-3735	Cream oolites.

Well No.	Depth	Description
	3735-3740	No samples.
	3740-3825	Cream oolites interbedded with light brown wackestones and packstones (iron stained).
	3825-3830	No samples.
	3830-3930	Light to medium gray packstones and grainstones interbedded with minor gray shale.
	3930-4135	Light gray to brown wackestones and packstones.
	4135-4185	White wackestones and mudstones (dolomitic).
	4185-4206	Core samples.
#689	3100	Bottineau interval top.
	3100-3260	Light brown packstones and mudstones (dolomitic, cherty, iron stained)
	3260-3370	Medium gray grainstones and packstones interbedded with medium gray wackestones (iron stained).
	3370-3420	Light red grainstones (iron stained).
	3420-3540	Carbonate as above interbedded with white chalky packstones.
	3540-3580	Red-brown shale.
	3580-3620	Gray shale.
#1211	2422	Bottineau interval top.
	2422-2660	Cream packstones and grainstones with quartz sand (iron stained).
	2660-2800	Cream wackestones interbedded with white chalky packstones.
	2800-2840	Light gray packstones.
	2840-2880	Red-brown shale with green mottling.
	2880-2916	Gray shale.

Well No.	Depth	Description
		WILLIAMS COUNTY
#1231	8920	Bottineau interval top.
	8920-8940	Dark gray calcareous shale.
	8940-9000	Medium brown wackestones (dolomitic, pyritic).
	9000-9630	Medium brown mudstones interbedded with wackestones (dolomitic, pyritic).
#3363	9500	Bottineau interval top.
	9500-10,130	Central Basin Facies-Dark gray to black mudstones and wackestones with packstone pods (dolomitic, pyritic).

APPENDIX E

THIN SECTION DESCRIPTION

THIN SECTION DESCRIPTION

Wells from which thin section samples were taken are listed alphabetically by county and numerically, within counties, by North Dakota Geological Survey well numbers. Thin sections are listed by depth, from stratigraphically highest to lowest. If more than one thin section was taken from samples from the same foot of core they are listed as A, B, C, and D. Three wells, 1516, 793, and 511, did not have adequate depth markings or were representative samples of longer cored intervals. In these cases, thin sections are sequentially numbered.

Well No.	Depth	Description
		BENSON COUNTY
#2537	2063	Brachiopod crinoid sparry packstone (silicified, iron stained, equant and overgrowth cements).
	2064	Mudstone.
	2066	Crinoid mudstone.
	2067	Mudstone (iron stained, solution voids).
	2068	Crinoid wackestone.
	2069	Mudstone.
	2070	Brachiopod crinoid packstone (silicified, fringing, equant, and overgrowth cements).
	2071	Oolite grainstone (fringing and equant cements).
	2074	Brachiopod crinoid sparry packstone underlying mudstone (iron stained, silicified, pyritic).
	2075	Mudstone grading to brachiopod crinoid sparry packstone (pyritic, stylolitic, silicified).
	2083	Brachiopod crinoid wackestone.
	2091	Oolite grainstone.
	2095	Brachiopod crinoid wackestone.
	2096	Brachiopod crinoid packstone.
	2098	Brachiopod crinoid packstone.

Well No.	Depth	Description
	2101	Brachiopod crinoid packstone.
	2108	Mudstone (iron stained).
	2118	Mudstone grading to crinoid packstone (fractured).
	2119	Brachiopod crinoid grainstone.
		BOTTINEAU COUNTY
#38	5006A	Crinoid mudstone (fractured, dolomitic).
	5006B	Bracniopod crinoid bryozoan mudstone (pyritic, dolomitic, burrowed).
	5006C	Brachiopod crinoid mudstone (dolomitic, fractured).
	5007A	Brachiopod crinoid bryozoan wackestone (dolomitic, silicified, pyritic).
	5007B	Crinoid bryozoan brachiopod packstone (micro-stylolitic).
	5007C	Brachiopod crinoid bryozoan wackestone.
	5008A	Brachiopod bryozoan crinoid wackestone (burrowed, filled fractured).
	5008B	Brachiopod bryozoan crinoid packstone.
	5009A	Bryozoan crinoid mudstone (dolomitic, burrowed).
	5009B	Brachiopod crinoid wackestone.
	5012A	Brachiopod bryozoan crinoid packstone.
	5012B	Crinoid brachiopod mudstone.
	5016A	Bryozoan brachiopod crinoid packstone.
	5016B	Crinoid mudstone grading to bryozoan brachiopod crinoid wackestone.
	5017	Brachiopod peloid crinoid grainstone.
	5018A	Mudstone (dolomitic).
	5018B	Brachiopod bryozoan crinoid mudstone (burrowed).

Well No.	Depth	Description
	5019	Mudstone (burrowed) over bryozoan brachiopod crinoid wackestone (dolomitic, pyritic, silicified).
	5020	Bryozoan mudstone (calcite filled fracture).
	5022	Mollusk brachiopod bryozoan crinoid packstone.
	5024	Crinoid mudstone (dolomitic) grading to crinoid wackestone (equant cement void fill).
	5026	Bryozoan brachiopod crinoid wackestone.
	5027	Bryozoan brachiopod crinoid sparry packstone (microstylolitic, overgrowths).
	5028	Crinoid bryozoan mudstone (burrowed).
	5034	Brachiopod bryozoan crinoid packstone.
	5036	Brachiopod bryozoan crinoid packstone (lower half is heavily silicified).
	5038	Crinoid brachiopod packstone.
	5039	Crinoid packstone.
	5040	Brachiopod crinoid packstone.
	5042A	Coral brachiopod crinoid packstone.
	5042B	Crinoid brachiopod bryozoan coral packstone.
	5043	Bryozoan brachiopod crinoid packstone.
	5045	Peloid crinoid packstone.
	5046	Coral crinoid packstone.
	5048	Brachiopod crinoid wackestone.
#110	3448A	Bryozoan brachiopod crinoid packstone overlying brachiopod crinoid mudstone (burrowed).
	3448B	Crinoid mudstone overlying brachiopod crinoid packstone (silicified).
	3448C	Mudstone overlying bryozoan intraclast brachiopod peloid grainstone (burrowed, overgrowth and equant cement, iron stained, silicified).

Well No.	Depth	Description
	3448D	Crinoid mudstone.
	3449A	Ostracod crinoid pellet packstone.
	3449B	Crinoid mudstone interbedded with brachiopod ostracod crinoid wackestone.
	3449C	Brachiopod crinoid ostracod packstone interbedded with crinoid mudstone (silicified).
	3449D	Crinoid mudstone interbedded with ostracod brachiopod crinoid packstone (silicified, iron stained, filled fracture).
#955	3327	Crinoid grainstone.
	3355	Mudstone (anhydritic).
	3358	Brachiopod crinoid packstone overlying crinoid mudstone (anhydritic).
	3364	Brachiopod crinoid wackestone interbedded with mudstone.
	3366	Crinoid packstone (silicified).
	3368	Brachiopod crinoid grainstone grading to crinoid wackestone.
	3369	Brachiopod crinoid wackestone grading to brachiopod crinoid sparry packstone (equant cement, overgrowths, silicified).
	3378	Mudstone (fractured).
	3379	Brachiopod crinoid grainstone (silicified).
	3382	Brachiopod crinoid wackestone.
	3386	Crinoid brachiopod mudstone.
	3391	Brachiopod crinoid sparry packstone interbedded with brachiopod crinoid wackestone.
	3392	Crinoid wackestone.
	3394	Brachiopod crinoid packstone.
	3405	Bryozoan brachiopod crinoid grainstone (equant cement and overgrowths).

Well No.	Depth	Description
	3413	Brachiopod crinoid packstone (interbedded with brachiopod crinoid packstone (stylolitic).
	3418	Brachiopod crinoid packstone (soft sediment deformation).
	3420	Brachiopod crinoid mudstone interbedded with brachiopod crinoid wackestone.
	3422	Bryozoan brachiopod crinoid packstone pods in mudstone.
	3423	Brachiopod crinoid wackestone.
#1184	3350	Laminated mudstone interbedded with crinoid wackestone (anhydritic, equant cement).
	3352	Brachiopod crinoid wackestone.
	3354	Brachiopod crinoid packstone (replacement anhydrite, silicified).
	3355	Crinoid mudstone (anhydritic).
	3356	Crinoid packstone (iron stained, silicified, anhydritic).
	3358	Bryozoan brachiopod crinoid packstone.
	3359	Bryozoan brachiopod crinoid packstone.
	3362	Mudstone.
	3363	Brachiopod crinoid packstone grading to mudstone (silicified).
	3365	Crinoid wackestone (burrowed) interbedded with crinoid packstone.
	3369	Brachiopod crinoid packstone (stylolitic, silicified, overgrowths).
	3372	Mudstone interbedded with crinoid packstone beds.
	3373	Bryozoan brachiopod crinoid grainstone.
	3374	Crinoid packstone.
	3375	Brachiopod crinoid packstone.

Well No.	Depth	Description
		DUNN COUNTY
#607	10,483	Crinoid mudstone (pyritic).
	10,484	Crinoid ostracod mudstone.
	10,487	Brachiopod mudstone.
	10,488	Crinoid brachiopod mudstone interbedded with crinoid brachiopod ostracod wackestone.
	10,490	Glauconitic crinoid brachiopod wackestone underlying glauconitic crinoid brachiopod grainstone.
	10,493	Crinoid brachiopod ostracod wackestone.
	10,496	Ostracod crinoid brachiopod packstone.
	10,497	Ostracod crinoid brachiopod wackestone.
	10,499	Glauconitic trilobite ostracod brachiopod crinoid wackestone.
	10,502	Bryozoan ostracod brachiopod crinoid packstone with ostracod mudstone pods.
	10,504	Mollusk trilobite bryozoan ostracod brachiopod crinoid packstone (dolomitic).
	10,507	Mollusk trilobite bryozoan brachiopod crinoid ostracod packstone.
	10,508	Gastropod brachiopod crinoid ostracod wackestone.
#793	1	Brachiopod ostracod bryozoan crinoid wackestone (pyritic, burrowed).
	2	Brachiopod crinoid ostracod wackestone.
	3	Laminated mudstone (burrowed).
	4	Crinoid bryozoan ostracod wackestone.
	5	Trilobite mollusk brachiopod crinoid bryozoan packstone.
	6	Ostracod bryozoan wackestone.
	7	Ostracod brachiopod crinoid bryozoan packstone.

Well No.	Depth	Description
	8	Brachiopod crinoid bryozoan packstone overlying mollusk crinoid bryozoan wackestone.
	9	Laminated mudstone.
	10	Laminated crinoid ostracod wackestone.
	11	Laminated bryozoan ostracod mudstone.
	12	Mudstone (burrowed, cut and fill structure).
	13	Mudstone.
	14	Mudstone (vertical escape burrow).
	15	Mudstone.
	16	Brachiopod ostracod crinoid bryozoan wackestone.
	17	Crinoid mudstone.
	18	Mudstone.
	19	Laminated mudstone.
	20	Crinoid mudstone.
	21	Laminated mudstone.
	22	Bryozoan mudstone.
	23	Crinoid mudstone.
	24	Brachiopod ostracod crinoid wackestone.
	25	Brachiopod mollusk ostracod crinoid wackestone.
	26	Ostracod brachiopod trilobite crinoid wackestone.
	27	Brachiopod mollusk bryozoan ostracod crinoid wackestone.
	28	Crinoid mudstone.
	29	Brachiopod ostracod crinoid wackestone (pyritic).
	30	Glauconitic ostracod bryozoan crinoid packstone (silicified).
	31	Crinoid brachiopod mudstone.

Well No.	Depth	Description
	32	Brachiopod mudstone.
	33	Mollusk crinoid ostracod wackestone.
	34	Bryozoan crinoid ostracod wackestone.
	35	Glauconitic bryozoan ostracod crinoid wackestone.
	36	Brachiopod bryozoan crinoid ostracod wackestone.
	37	Brachiopod bryozoan ostracod crinoid wackestone.
	38	Brachiopod ostracod crinoid wackestone.
	39	Bryozoan crinoid ostracod mudstone.
	40	Black shale.
	41	Coral brachiopod ostracod crinoid bryozoan wackestone.
	42	Glauconitic ostracod bryozoan brachiopod crinoid wackestone.
	43	Ostracod brachiopod crinoid mudstone.
	44	Brachiopod ostracod crinoid mudstone.
	45	Crinoid brachiopod ostracod mudstone.
	46	Ostracod crinoid brachiopod mudstone.
	47	Glauconitic brachiopod bryozoan crinoid ostracod wackestone.
	48	Ostracod brachiopod crinoid wackestone.
	49	Laminated glauconitic crinoid brachiopod wackestone.
	50	Glauconitic crinoid brachiopod packstone.
		FOSTER COUNTY
#403	2057	Crinoid mudstone (dolomitic).
	2058A	Mudstone.
	2058B	Mudstone.
	2061	Brachiopod crinoid packstone (silicified, equant cement).

Well No.	Depth	Description
		HETTINGER COUNTY
#511	1	Mudstone (dolomitic).
	2	Crinoid brachiopod wackestone (pyritic).
	3	Crinoid brachiopod grainstone (fringing, equant, and overgrowth cements).
	4	Mollusk crinoid brachiopod packstone (calcite filled fracture).
	5	Crinoid pelecepod gastropod brachiopod packstone (silicified).
	6	Mudstone (pyritic).
	7	Crinoid brachiopod packstone interbedded with mudstone (burrowed).
	8	Mudstone (calcite filled fracture).
	9	Crinoid brachiopod mudstone (burrowed).
	10	Brachiopod crinoid packstone pod in mudstone (pyritic, microstylolitic).
	11	Crinoid mudstone.
	12	Brachiopod mudstone.
	13	Brachiopod mudstone.
	14	Brachiopod crinoid mudstone.
	15	Mudstone.
	16	Mudstone.
	17	Brachiopod crinoid wackestone.
	18	Brachiopod crinoid wackestone.
		KIDDER COUNTY
#230	3445	Brachiopod crinoid packstone (overgrowths, iron stained, microstylolitic).
	3446	Brachiopod crinoid wackestone.

Well No.	Depth	Description
	3447	Brachiopod crinoid packstone.
	3448	Coral brachiopod crinoid packstone underlying laminated mudstone.
	3451	Brachiopod crinoid packstone.
	3453	Mollusk brachiopod crinoid packstone (silicified, iron stained).
	3454	Brachiopod crinoid wackestone (calcite filled fracture, silicified).
		MCKENZIE COUNTY
#2172	10,900	Ostracod brachiopod crinoid mudstone (fractured, dolomitic, silicified).
	10,092	Brachiopod ostracod crinoid wackestone overlying brachiopod crinoid grainstone (overgrowths, silicified, pyritic).
	10,096	Brachiopod ostracod crinoid bryozoan wackestone (dolomitic).
	10,097	Mudstone underlying brachiopod ostracod crinoid bryozoan wackestone.
	10,098	Brachiopod crinoid ostracod bryozoan wackestone (pyritic, dolomitic).
	10,104	Brachiopod crinoid bryozoan wackestone.
	10108A	Crinoid bryozoan ostracod mudstone.
	10108B	Brachiopod bryozoan crinoid packstone.
	10,110	Crinoid mudstone (dolomitic).
	10,114	Brachiopod crinoid bryozoan mudstone.
	10,118	Brachiopod bryozoan crinoid wackestone.
	10,120	Ostracod bryozoan crinoid mudstone.
	10,124	Brachiopod ostracod crinoid bryozoan mudstone interbedded with brachiopod crinoid bryozoan packstone.
	10,128	Ostracod bryozoan crinoid wackestone.

Well No.	Depth	Description
	10,130	Ostracod brachiopod crinoid bryozoan wackestone.
	10,133	Ostracod mudstone.
	10,135	Ostracod brachiopod crinoid bryozoan mudstone (pyritic, silicified, dolomitic).
	10,140	Laminated crinoid brachiopod mudstone.
	10,141	Crinoid bryozoan brachiopod ostracod mudstone.
	10,142	Ostracod brachiopod crinoid bryozoan wackestone.
		MCLEAN COUNTY
#1516	6243A	Crinoid brachiopod wackestone (pyritic, dolomitic).
	6243B	Brachiopod crinoid pellet packstone (overgrowths, silicified, equant cement).
	6244	Bryozoan pellet brachiopod crinoid grainstone.
	6372	Brachiopod crinoid pellet packstone.
	6373	Brachiopod crinoid pellet packstone underlying brachiopod crinoid wackestone (dolomitic, pyritic).
	6374	Crinoid brachiopod pellet wackestone.
	6375	Crinoid brachiopod pellet packstone.
	6377	Crinoid brachiopod pellet packstone.
	6378	Brachiopod bryozoan crinoid pellet packstone (stylolitic).
	6381	Brachiopod crinoid pellet packstone.
	6384	Trilobite bryozoan gastropod brachiopod crinoid pellet packstone.
	6386	Ostracod brachiopod crinoid pellet packstone (overgrowths).
	6389	Intraclast coral bryozoan brachiopod crinoid pellet grainstone (silicified, micrite envelopes).
	6428	Intraclast bryozoan brachiopod crinoid pellet grainstone.
	6429	Brachiopod crinoid pellet packstone.

Well No.	Depth	Description
	6430	Brachiopod crinoid pellet packstone.
	6431	Brachiopod crinoid wackestone.
	6436	Bryozoan brachiopod crinoid pellet grainstone.
	6438	Bryozoan brachiopod crinoid pellet sparry packstone (fringing cement, overgrowths).
	6439	Mudstone interbedded with bryozoan brachiopod crinoid packstone.
	6441	Intraclast mollusk bryozoan brachiopod crinoid pellet grainstone.
	6442	Brachiopod crinoid pellet packstone (coalesced pellets).
	6444	Brachiopod crinoid pellet grainstone (calcite filled fracture).
	6445	Brachiopod crinoid pellet packstone.
	6447	Brachiopod crinoid pellet grainstone (stylolitic).
	6449	Ostracod crinoid wackestone.
	6450	Brachiopod crinoid pellet grainstone.
	6451	Brachiopod crinoid pellet grainstone.
	6452	Mollusk brachiopod crinoid pellet grainstone (anhydritic, silicified, equant and overgrowth cements).
	6454	Mollusk brachiopod crinoid pellet grainstone.
	6456	Bryozoan brachiopod crinoid packstone.
	6457	Crinoid pellet grainstone.
	6458	Ostracod brachiopod crinoid pellet grainstone.
	6461	Ostracod brachiopod crinoid pellet wackestone.
	6464	Brachiopod crinoid pellet grainstone.
	1	Brachiopod crinoid wackestone interbedded with mollusk bryozoan brachiopod crinoid pellet grainstone.

Well No.	Depth	Description
	2	Mollusk bryozoan brachiopod crinoid pellet grainstone.
	3	Brachiopod bryozoan crinoid pellet grainstone.
	4	Intraclast brachiopod crinoid pellet grainstone (calcite filled fracture, overgrowths).
	5	Brachiopod ostracod crinoid pellet grainstone.
	6	Bryozoan brachiopod crinoid pellet grainstone (anhydritic, fringing cement).
	7	Intraclast mollusk brachiopod crinoid pellet grainstone.
	8	Intraclast brachiopod crinoid pellet grainstone.
	9	Brachiopod crinoid pellet packstone.
	10	Intraclast mollusk brachiopod crinoid pellet grainstone.
	11	Brachiopod crinoid pellet packstone.
	12	Brachiopod crinoid pellet packstone.
	13	Brachiopod crinoid wackestone.
	14	Brachiopod crinoid pellet packstone.
	15	Brachiopod crinoid pellet grainstone.
	16	Laminated brachiopod crinoid wackestone interbedded with brachiopod crinoid packstone.
	17	Brachiopod crinoid pellet grainstone.
	18	Brachiopod crinoid pellet grainstone.
	19	Brachiopod crinoid pellet packstone.
		PIERCE COUNTY
#274	3073	Brachiopod crinoid packstone (silicified).
	3075	Brachiopod crinoid packstone (overgrowths).
	3077	Brachiopod crinoid wackestone (dolomitic).
	3078	Mudstone (dolomitic).

Well No.	Depth	Description
	3081	Brachiopod crinoid pellet packstone.
	3082	Intraclast bryozoan brachiopod crinoid grainstone (overgrowth, equant and fringing cement, silicified).
	3086	Crinoid brachiopod packstone interbedded with brachiopod mudstone (dolomitic, iron stained)
	3089	Coral brachiopod crinoid packstone.
	3093	Brachiopod crinoid wackestone interbedded with pellet brachiopod crinoid packstone.
	3094	Brachiopod crinoid wackestone (burrowed).
	3096	Brachiopod crinoid packstone.
	3097	Oolite grainstone.
	3098	Brachiopod crinoid pellet grainstone.
	3099	Brachiopod crinoid packstone (silicified, iron stained).
	3101	Brachiopod crinoid wackestone interbedded with brachiopod crinoid packstone.
	3103	Brachiopod crinoid packstone.
	3104	Brachiopod crinoid mudstone grading to packstone.
	3105	Brachiopod crinoid pellet packstone.
	3116	Brachiopod crinoid pellet grainstone.
	3118	Crinoid brachiopod packstone.
	3121	Brachiopod crinoid pellet grainstone.
	3123	Brachiopod crinoid pellet sparry packstone (equant and overgrowth cement, silicified).
	3130	Brachiopod crinoid packstone (dolomitic).
	3132	Brachiopod crinoid packstone.
	3135	Brachiopod crinoid wackestone underlying crinoid mudstone (dolomitic).
	3139	Crinoid mudstone.

Well No.	Depth	Description
	3142	Brachiopod crinoid packstone.
	3144	Bryozoan brachiopod crinoid wackestone.
	3148	Brachiopod crinoid wackestone.
	3150	Brachiopod crinoid pellet packstone.
	3155	Brachiopod crinoid pellet packstone underlying brachiopod crinoid wackestone.
	3156	Crinoid wackestone underlying brachiopod crinoid mudstone (dolomitic, iron stained).
	3157	Brachiopod crinoid sparry packstone grading to grainstone.
	3177	Brachiopod pellet crinoid packstone.
	3180	Brachiopod pellet crinoid packstone.
	3184	Intraclast mollusk brachiopod crinoid grainstone (silicified, equant and overgrowth cements).
	3185	Brachiopod pellet crinoid grainstone grading to sparry brachiopod crinoid sparry packstone.
	3187	Brachiopod crinoid wackestone.
	3191	Intraclast brachiopod crinoid packstone.
	3193	Crinoid ostracod mudstone (dolomitic, calcite filled fracture, iron stained).
	3196	Brachiopod crinoid sparry packstone.
	3198A	Brachiopod crinoid packstone.
	3198B	Brachiopod pellet crinoid grainstone overlying mudstone (dolomitic, iron stained, silicified).
	3202	Brachiopod pellet crinoid packstone.
	3204	Mudstone.
	3208	Brachiopod crinoid packstone.
	3209	Brachiopod crinoid pellet packstone grading to grainstone.

Well No.	Depth	Description
	3210	Brachiopod pellet crinoid packstone underlying brachiopod crinoid wackestone.
	3224	Brachiopod crinoid packstone.
	3227	Mudstone (dolomitic, anhydritic).
	3229	Brachiopod crinoid packstone.
	3230	Mudstone interbedded with intraclast brachiopod crinoid grainstone.
	3233	Brachiopod crinoid packstone.
	3236	Brachiopod crinoid packstone.
	3237	Bryozoan brachiopod crinoid grainstone (anhydritic).
	3243	Brachiopod pellet crinoid packstone (microstylo-litic, calcite filled fracture).
	3244	Brachiopod pellet crinoid packstone.
	3248	Brachiopod crinoid packstone.
	3249	Brachiopod crinoid packstone.
	3252	Brachiopod crinoid sparry packstone.
	3253	Brachiopod crinoid packstone.
	3254	Brachiopod crinoid packstone.
	3255	Brachiopod crinoid packstone (microstylolitic).
	3258	Brachiopod crinoid packstone.
	3261A	Crinoid mudstone (dolomitic).
	3261B	Crinoid brachiopod wackestone (dolomitic, silicified).
	3262	Brachiopod pellet crinoid grainstone.
	3265	Crinoid mudstone.
	3266	Brachiopod crinoid wackestone.
	3267	Brachiopod crinoid wackestone.
	3271A	Brachiopod crinoid pellet packstone.

Well No.	Depth	Description
	3271B	Brachiopod crinoid packstone (microstylolitic, silicified, dolomitic).
	3272	Brachiopod pellet crinoid packstone.
	3274	Brachiopod pellet crinoid packstone overlying brachiopod mudstone.
	3275	Bryozoan brachiopod crinoid packstone.
	3276	Bryozoan brachiopod crinoid sparry packstone.
	3278	Bryozoan brachiopod crinoid packstone.
	3279	Bryozoan brachiopod crinoid packstone (anhydritic).
	3281	Brachiopod crinoid mudstone.
	3284	Brachiopod crinoid pellet packstone with pods of mudstone (dolomitic).
	3286	Bryozoan brachiopod crinoid packstone overlying crinoid mudstone.
	3290	Brachiopod crinoid packstone interbedded with pellet crinoid wackestone and mudstone (dolomitic, silicified).
	3291	Brachiopod crinoid packstone.
	3294	Bryozoan brachiopod crinoid packstone.
	3296	Brachiopod crinoid packstone.
	3297	Brachiopod crinoid wackestone.
	3299	Brachiopod crinoid packstone.
	3300	Brachiopod crinoid sparry packstone (equant and overgrowth cement).
	3301	Brachiopod crinoid wackestone.
	3303	Brachiopod crinoid grainstone.
	3304	Coral brachiopod crinoid packstone.
	3305	Brachiopod crinoid grainstone.
	3306	Bryozoan brachiopod oolite crinoid packstone.

Well No.	Depth	Description
	3308	Brachiopod crinoid packstone.
	3309	Bryozoan brachiopod oolite grainstone.
	3310	Oolite brachiopod bryozoan crinoid packstone (silicified, equant and overgrowth cement).
	3311	Brachiopod crinoid packstone.
	3313	Brachiopod crinoid grainstone.
	3316	Bryozoan brachiopod crinoid packstone.
	3318	Foraminifera brachiopod bryozoan intraclast ostracod crinoid packstone.
	3319	Oolite grainstone.
	3321A	Brachiopod bryozoan foraminifera mollusk intraclast oolite crinoid grainstone.
	3321B	Foraminifera brachiopod bryozoan ostracod intraclast crinoid oolite grainstone.
	3325	Oolite grainstone.
	3327	Brachiopod ostracod crinoid grainstone.
	3330	Brachiopod bryozoan crinoid packstone interbedded with mollusk brachiopod crinoid grainstone.
	3334	Intraclast mollusk brachiopod bryozoan crinoid grainstone.
	3335	Brachiopod crinoid oolite packstone.
	3337	Brachiopod crinoid packstone underlying bryozoan brachiopod crinoid grainstone.
	3338	Mollusk brachiopod oolite crinoid packstone.
	3339	Brachiopod crinoid packstone interbedded with brachiopod crinoid wackestone.
	3341A	Mudstone interbedded with brachiopod bryozoan ostracod crinoid echinoid grainstone.
	3341B	Crinoid mudstone interbedded with crinoid wackestone.
	3343	Peloid brachiopod ostracod crinoid sparry packstone.

Well No.	Depth	Description
		ROLETTE COUNTY
#83	2663	Mudstone (dolomitic, anhydritic).
	2664	Mudstone overlying brachiopod crinoid wackestone (anhydritic, iron stained).
	2668	Mudstone.
	2669	Crinoid brachiopod wackestone.
	2670	Brachiopod crinoid wackestone overlying brachiopod crinoid packstone (dolomitic, anhydritic, iron stained, solution voids).
	2671	Mollusk crinoid brachiopod wackestone (stylolitic, silicified).
	2673	Brachiopod crinoid pellet grainstone underlying crinoid wackestone.
	2674	Brachiopod crinoid wackestone interbedded with brachiopod crinoid packstone.
	2675	Brachiopod crinoid packstone.
	2678	Brachiopod crinoid wackestone interbedded with brachiopod crinoid packstone.
	2679	Brachiopod pellet crinoid sparry packstone (anhydritic, equant and overgrowth cement).
	2681	Brachiopod crinoid pellet packstone.
	2682	Brachiopod crinoid pellet packstone underlying brachiopod pellet mudstone.
	2684	Laminated crinoid wackestone (dolomitic, iron stained).
	2686	Bryozoan brachiopod crinoid wackestone.
	2688	Brachiopod crinoid packstone underlying crinoid brachiopod wackestone.
	2689	Anhydrite underlying brachiopod crinoid packstone.
	2691	Mollusk brachiopod crinoid wackestone.
	2692	Crinoid mudstone (dolomitic).

Well No.	Depth	Description
	2693	Brachiopod crinoid pellet packstone.
	2695	Mudstone underlying brachiopod ostracod crinoid wackestone.
	2696	Brachiopod crinoid pellet grainstone.
	2697	Brachiopod crinoid pellet grainstone.
	2698	Brachiopod crinoid packstone.
	2699	Brachiopod crinoid wackestone.
	2702A	Bryozoan brachiopod crinoid sparry packstone grading to mudstone (silicified, anhydritic, equant and overgrowth cement).
	2702B	Brachiopod crinoid packstone grading to mudstone.
	2703	Crinoid mudstone (iron stained, dolomitic).
	2704	Brachiopod crinoid pellet packstone.
	2705	Mudstone underlying crinoid wackestone.
	2706	Mollusk brachiopod crinoid pellet packstone.
	2707	Mudstone interbedded with brachiopod crinoid wackestone (iron stained, silicified)
	2708	Brachiopod crinoid sparry packstone interbedded with mudstone.
	2710	Mudstone underlying brachiopod crinoid pellet packstone.
	2711	Brachiopod crinoid wackestone grading to packstone.
	2714	Crinoid brachiopod wackestone.
	2716	Brachiopod crinoid mudstone (anhydrite filled fracture, dolomitic).
	2717	Brachiopod crinoid mudstone.
	2721	Brachiopod crinoid wackestone.
	2723	Brachiopod crinoid wackestone.
	2725	Brachiopod crinoid packstone grading to grainstone.

Well No.	Depth	Description
	2727	Brachiopod crinoid packstone.
	2728	Crinoid wackestone underlying brachiopod crinoid packstone.
	2730	Brachiopod crinoid wackestone underlying Bryozoan brachiopod crinoid grainstone.
	2733	Mudstone underlying brachiopod crinoid packstone.
	2736	Crinoid wackestone (dolomitic, iron stained).
	2738	Brachiopod crinoid packstone.
	2740	Brachiopod crinoid grainstone.
	2741	Intraclast brachiopod crinoid packstone.
	2743	Brachiopod crinoid packstone.
	2745	Brachiopod crinoid packstone underlying brachiopod crinoid wackestone.
	2749	Intraclast brachiopod crinoid packstone.
	2753	Intraclast brachiopod crinoid packstone.
	2755	Brachiopod crinoid packstone.
	2760	Brachiopod crinoid packstone (solution void).
#615	2470	Mudstone (anhydritic, anhydrite filled fracture, dolomitic).
	2471	Mudstone.
	2473	Mudstone.
	2474	Brachiopod crinoid wackestone.
	2478A	Coral bryozoan brachiopod crinoid wackestone.
	2478B	Mudstone
	2480	Crinoid mudstone (chert nodules, dolomitic).
	2482	Chert nodule.
	2483	Crinoid brachiopod wackestone (chert nodule).
	2485	Mollusk foraminifera brachiopod crinoid wackestone.

Well No.	Depth	Description
	2486	Brachiopod crinoid wackestone.
	2490	Brachiopod crinoid mollusk mudstone.
	2494	Crinoid mudstone.
	2495	Crinoid wackestone (iron stained).
	2498	Brachiopod crinoid wackestone.
	2502	Brachiopod crinoid wackestone.
	2506	Brachiopod crinoid wackestone.
	2509	Brachiopod crinoid wackestone.
	2512	Brachiopod crinoid wackestone (chert nodules, dolomitic, anhydritic).
	2515A	Chert nodule.
	2515B	Chert nodule underlying crinoid wackestone.
	2517	Brachiopod crinoid mudstone.
	2519	Brachiopod crinoid mudstone.
	2523	Brachiopod crinoid mudstone.
	2524	Brachiopod crinoid wackestone (chert nodules, fractured, iron stained).
	2429	Bryozoan brachiopod crinoid mudstone.
	2531A	Bryozoan brachiopod crinoid wackestone.
	2531B	Chert nodule underlying mudstone.
	2533	Chert nodules interbedded with bryozoan brachiopod crinoid mudstone.
	2532A	Crinoid mudstone (cherty).
	2532B	Crinoid mudstone (fractured).
	2537	Brachiopod crinoid mudstone.
	2538	Brachiopod crinoid mudstone (cherty).
	2540	Brachiopod crinoid mudstone (ahydrite filled fracture)

Well No.	Depth	Description
	2544	Mollusk brachiopod crinoid wackestone.
	2545	Bryozoan brachiopod crinoid wackestone.
	2547	Coral brachiopod bryozoan crinoid wackestone.
	2548A	Mudstone (cherty, anhydritic).
	2548B	Bryozoan brachiopod crinoid wackestone (dolomitic).
	2553	Bryozoan brachiopod crinoid wackestone.
	2554A	Crinoid mudstone.
	2554B	Bryozoan brachiopod crinoid mudstone grading to mollusk crinoid brachiopod bryozoan wackestone.
	2558	Crinoid mudstone.
	2561	Brachiopod crinoid mudstone.
	2562	Crinoid mudstone.
	2567	Brachiopod crinoid mudstone (iron stained, cherty).
	2569	Brachiopod crinoid mudstone.
	2570	Brachiopod crinoid wackestone.
	2575A	Brachiopod crinoid wackestone.
	2575B	Mudstone (anhydrite filled solution voids, fractured).
	2576	Brachiopod crinoid wackestone.
	2578	Bryozoan brachiopod crinoid wackestone.
	2580	Crinoid mudstone.
	2581	Bryozoan brachiopod crinoid mudstone.
	2583	Crinoid bryozoan wackestone.
	2584	Coral crinoid wackestone.
	2585	Brachiopod crinoid mudstone (filled and unfilled fractures, cherty).
	2586	Brachiopod crinoid mudstone.

Well No.	Depth	Description
	2587	Brachiopod crinoid wackestone.
	2589	Bryozoan brachiopod crinoid wackestone.
	2591	Bryozoan brachiopod crinoid wackestone.
	2592	Brachiopod crinoid bryozoan wackestone.
	2595	Crinoid brachiopod crinoid wackestone.
	2599A	Crinoid brachiopod wackestone.
	2599B	Brachiopod crinoid wackestone.
	2603	Brachiopod crinoid bryozoan wackestone.
	2605A	Brachiopod crinoid wackestone.
	2605B	Mollusk brachiopod crinoid bryozoan wackestone.
	2608	Bryozoan brachiopod crinoid packstone underlying brachiopod crinoid wackestone.
	2609	Crinoid bryozoan wackestone (cherty).
	2611A	Bryozoan brachiopod crinoid wackestone.
	2611B	Bryozoan crinoid packstone.
	2612	Bryozoan brachiopod crinoid wackestone with pods of brachiopod crinoid bryozoan packstone.
	2613	Brachiopod crinoid wackestone.
	2614	Bryozoan crinoid packstone.
	2615	Bryozoan mollusk coral crinoid wackestone.
	2617	Crinoid mudstone.
	2618	Chert nodule.
	2619	Mudstone.
#659	3282	Oolite packstone (anhydritic).
	3283	Brachiopod crinoid packstone (iron stained, anhydritic).
	3287	Brachiopod crinoid packstone (silicified, equant cement, iron stained).

Well No.	Depth	Description
	3288	Brachiopod crinoid packstone.
	3289	Brachiopod crinoid mudstone (dolomitic).
	3290	Skeletal hash wackestone.
	3292	Mudstone.
	3294	Crinoid mudstone.
	3295	Brachiopod crinoid packstone.
	3297	Brachiopod crinoid mudstone.
	3301	Brachiopod crinoid wackestone.
	3303	Brachiopod crinoid sparry packstone (micro-stylolitic, overgrowth and equant cements, iron stained).
	3304	Brachiopod crinoid packstone.
	3305	Brachiopod crinoid wackestone interbedded with brachiopod crinoid packstone.
	3307	Mudstone interbedded with brachiopod crinoid wackestone.
	3309	Brachiopod crinoid wackestone.
	3310	Brachiopod crinoid pellet packstone (micro-stylolitic, silicified).
	3312	Brachiopod crinoid packstone.
	3313A	Crinoid wackestone.
	3313B	Brachiopod crinoid mudstone.
	3314	Brachiopod crinoid packstone (anhydritic, silicified, equant and overgrowth cements).
	3316	Brachiopod crinoid wackestone.
	3318	Brachiopod pellet crinoid packstone.
	3320	Bryozoan brachiopod crinoid packstone.
	3321	Brachiopod crinoid wackestone.

Well No.	Depth	Description
	3322	Brachiopod crinoid packstone.
	3324	Brachiopod crinoid wackestone.
	3325	Brachiopod crinoid wackestone.
	3327	Mudstone (dolomitic).
	3330A	Brachiopod crinoid wackestone.
	3330B	Skeletal hash wackestone.
	3331	Crinoid wackestone.
	3333	Brachiopod crinoid packstone.
	3335	Brachiopod crinoid wackestone.
	3336	Brachiopod crinoid packstone.
	3339	Brachiopod crinoid packstone.
	3349	Brachiopod crinoid wackestone.
	3354	Brachiopod crinoid mudstone.
	3356	Brachiopod crinoid mudstone.
	3363	Coral brachiopod crinoid wackestone.
	3364	Brachiopod crinoid wackestone.
	3371	Brachiopod crinoid packstone.
	3378	Brachiopod crinoid packstone.
	3380	Brachiopod crinoid wackestone.
	3388	Coral brachiopod crinoid wackestone.
	3406	Crinoid wackestone.
	3428	Mollusk brachiopod crinoid packstone.
#754	2680	Brachiopod crinoid packstone.
	2684	Coral crinoid wackestone.
	2685	Brachiopod crinoid wackestone (silicified, anhydrite filled solution voids).

Well No.	Depth	Description
	2692	Brachiopod crinoid wackestone.
	2694	Brachiopod crinoid wackestone.
	2699	Mollusk brachiopod crinoid packstone (silicified).
	2701	Crinoid brachiopod mudstone (iron stained).
	2705	Mollusk crinoid brachiopod packstone (interbedded with mudstone (dolomitic).
	2708	Mollusk brachiopod crinoid packstone underlying crinoid mudstone.
#917	2611	Crinoid pellet grainstone (iron stained, silicified, overgrowths).
	2615	Brachiopod crinoid pellet grainstone.
	2621	Mudstone (anhydrite filled fracture, dolomitic).
	2629	Brachiopod crinoid wackestone.
	2634	Brachiopod crinoid wackestone.
	2637	Brachiopod crinoid grainstone (anhydritic, silicified, overgrowths).
	2650	Brachiopod crinoid grainstone.
	2656	Brachiopod crinoid packstone.
	2659	Brachiopod crinoid pellet grainstone.
	2664	Brachiopod crinoid packstone grading to wackestone.
	2669	Crinoid grainstone (overgrowth and equant cement).
	2674	Brachiopod crinoid grainstone.
	2681	Crinoid wackestone.
	2686	Bryozoan brachiopod crinoid packstone (iron stained).
	2687	Brachiopod crinoid wackestone.
	2694	Oolite grainstone.
	2697	Brachiopod crinoid packstone.
	2699	Brachiopod crinoid mudstone.

Well No.	Depth	Description
	2771	Bryozoan brachiopod crinoid packstone.
	2773	Mudstone.
	2776	Brachiopod crinoid mudstone.
	2780	Brachiopod crinoid wackestone.
	2785	Brachiopod crinoid packstone.
	2790	Bryozoan brachiopod crinoid grainstone grading to bryozoan brachiopod crinoid packstone.
	2795	Brachiopod crinoid packstone (stylolitic, silicified, overgrowth and equant cement).
	2801	Brachiopod pellet crinoid grainstone.
	2804	Coral brachiopod crinoid packstone.
	2808	Brachiopod crinoid pellet grainstone.
	2811	Brachiopod crinoid packstone (calcite filled fracture, silicified, soft sediment deformation).
	2817	Brachiopod crinoid grainstone.
#927	3252	Mudstone (dolomitic, iron stained).
	3255	Brachiopod crinoid wackestone (anhydrite filled voids, anhydrite replaced fossils, iron stained).
	3256	Brachiopod crinoid wackestone.
	3258	Oolite grainstone underlying oolite crinoid brachiopod packstone.
	3261	Oolite grainstone (fringing and equant cement, iron stained, anhydritic, recrystallized oolites).
	3264	Oolite grainstone.
	3270	Oolite grainstone underlying mudstone.
	3273	Mollusk bryozoan brachiopod crinoid grainstone (stylolitic, iron stained, microstylolitic, equant and overgrowth cement).
	3275	Crinoid oolite grainstone.
	3282	Brachiopod crinoid packstone.

Well No.	Depth	Description
	3284	Bryozoan brachiopod crinoid grainstone.
#1630	2722	Brachiopod crinoid pellet grainstone (anhydritic, stylolitic, silicified, overgrowth and equant cement).
	2725	Brachiopod crinoid grainstone.
	2726	Brachiopod crinoid pellet grainstone.
	2727	Bryozoan brachiopod crinoid pellet grainstone.
	2732	Brachiopod crinoid packstone.
	2737	Brachiopod crinoid packstone (silicified).
	2738	Crinoid wackestone.
	2739	Bryozoan brachiopod crinoid grainstone (anhydritic, silicified, overgrowth and equant cement).
	2740	Bryozoan brachiopod crinoid grainstone interbedded with crinoid mudstone.
	2744	Crinoid wackestone.
	2745	Brachiopod crinoid packstone.
	2748	Bryozoan brachiopod crinoid pellet packstone.
	2749	Bryozoan brachiopod crinoid packstone.
#2862	2761	Brachiopod crinoid wackestone grading to packstone (silicified).
	2764	Bryozoan brachiopod crinoid packstone overlying crinoid packstone.
	2765	Brachiopod crinoid wackestone interbedded with brachiopod crinoid packstone (iron stained, microstylolitic).
	2767	Bryozoan brachiopod crinoid wackestone grading to brachiopod crinoid packstone.
	2768	Brachiopod crinoid packstone (silicified, overgrowth and equant cement).
	2775	Brachiopod crinoid packstone interbedded with brachiopod crinoid wackestone (soft sediment deformation, iron stained, silicified).

Well No.	Depth	Description
	2776	Intraclast brachiopod crinoid peloid packstone.
	2778	Crinoid packstone underlying crinoid mudstone (microstylolitic, iron stained).
	2780	Crinoid mudstone underlying crinoid packstone.
	2783	Bryozoan brachiopod crinoid packstone.
	2789	Intraclast brachiopod crinoid pellet packstone.
#3083	2720	Brachiopod crinoid wackestone.
	2721	Crinoid mudstone with crinoid packstone pods.
	2723	Brachiopod crinoid wackestone (iron stained, silicified).
	2724	Brachiopod bryozoan crinoid packstone interbedded with bryozoan brachiopod crinoid pellet wackestone (anhydritic, silicified, overgrowth and equant cement).
	2725	Intraclast brachiopod mollusk crinoid pellet packstone.
	2728	Brachiopod crinoid pellet grainstone.
	2732	Brachiopod crinoid wackestone.
	2734	Brachiopod crinoid grainstone.
	2736	Brachiopod crinoid grainstone interbedded with mudstone (anhydritic, silicified).
	2737	Brachiopod crinoid pellet grainstone.
	2739	Brachiopod crinoid mudstone.
	2741	Brachiopod crinoid wackestone interbedded with brachiopod crinoid packstone.
	2742	Coral brachiopod crinoid packstone.
	2745	Pellet packstone.
	2746	Bryozoan brachiopod crinoid mudstone.
	2758	Mudstone interbedded with bryozoan brachiopod crinoid grainstone.

Well No.	Depth	Description
		WELLS COUNTY
#207	4185	Brachiopod crinoid wackestone (iron stained).
	4187	Brachiopod crinoid wackestone.
	4188	Brachiopod crinoid wackestone.
	4189	Brachiopod crinoid wackestone.
	4190	Brachiopod crinoid wackestone.
	4191	Brachiopod crinoid wackestone.
	4193	Brachiopod crinoid wackestone.
	4194	Brachiopod crinoid wackestone.
	4199	Brachiopod crinoid wackestone interbedded with mudstone (fractured, microstylolitic).

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