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STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE THREE FORKS FORMATION (UPPER DEVONIAN), WILLISTON BASIN, NORTH DAKOTA

by
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Bachelor of Arts, St. Cloud State University, 1981

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

August
1984

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Title Stratigraphy and Depositional Environments
of the Three Forks Formation (Upper Devonian),
Williston Basin, North Dakota

Department Geology

Degree Master of Science

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Signature Gayle M. Dumonceaux

Date July 25, 1984

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Life can only be understood backward,

but must be lived forward.

Soren Kierkegaard

ABSTRACT

The Three Forks Formation (Upper Devonian) is present in the subsurface in the western two-thirds of North Dakota and is generally conformable with the underlying Birdbear Formation and the overlying Bakken Formation. The Three Forks attains a maximum thickness of 265 feet (81 meters) in the central basin, east and south of the Nesson Anticline, and thins to an erosional edge in eastern North Dakota.

The Three Forks is composed of micrite and dolomicrite, which may be fossiliferous and argillaceous. From the study of core samples and detailed petrographic analysis of thin sections, five lithofacies were recognized and their extent determined. These lithofacies are: micrite, argillaceous micrite, dolomicrite, argillaceous dolomicrite, and argillaceous biomicrite. Major criteria used in categorization of each lithofacies were fossil biota, sedimentary structures, and other lithologic features.

Sedimentation of the Three Forks Formation occurred in an epeiric sea setting. The five lithofacies represent deposition in supralittoral, littoral, and low-energy sublittoral environments. These environments were formed approximately parallel to the periphery of the basin. Of the three energy zones depicted for an epeiric sea depositional setting, the Three Forks is interpreted to have been deposited solely within the most landward, lowest energy zone.

Extreme sea level fluctuations and resultant progradations are responsible for the widespread distribution of argillaceous material. Allochthonous material was distributed by wind-generated waves and currents. Repeated transgressions and regressions caused the lateral

migration of environments and produced the complex mosaic of lithofacies.

Major diagenetic features within the Three Forks include dolomitization, anhydritization, and calcite recrystallization (neomorphism). Dolomitization is best accounted for by the evaporative pumping model, which may also have been responsible for anhydrite formation in the supralittoral environment. Eight structural types of anhydrite are present in those rocks interpreted as being deposited in an arid, supralittoral environment. These structural types are: nodular, distorted nodular, bedded nodular, distorted bedded nodular, distorted nodular mosaic, bedded nodular mosaic, distorted mosaic, and bedded massive. Calcite recrystallization involves microspar and pseudospar formation.

INTRODUCTION

General

The Upper Devonian Three Forks Formation is present in the Williston Basin in North Dakota, and in adjacent parts of Montana, Wyoming, South Dakota, and Canada. The interval between the depths of 10,076 feet to 10,310 feet in the Mobil Producing Company No. 1 Birdbear Well (SE1/4 NE1/4, sec. 22, T. 149 N., R. 91 W., Dunn County, North Dakota) has been designated the standard subsurface section of the Three Forks Formation in the Williston Basin (Figure 1; North Dakota Geological Society, 1961). At this locality, it includes the strata between the Birdbear Formation and the Bakken Formation.

The Three Forks Formation consists of interbedded greenish-gray and reddish-brown micrite and dolomicrite with anhydrite nodules scattered throughout and subordinate amounts of biomicrite. Attaining a maximum thickness of approximately 265 feet (81 meters) in western North Dakota, the Three Forks Formation thins to zero along its erosional edge on the eastern margin of the basin (NDGS, 1961). It is thickest in the central Williston Basin, east and south of the Nesson Anticline (Figure 2; Sandberg, 1961).

Although the "Sanish Sand", locally present at the top of the Three Forks along the Nesson Anticline in McKenzie County, is important as an oil producer, no comprehensive study has been done on this formation in the state.

Figure 1. Illustration of the Log from North Dakota Geological Survey (NDGS) well number 793. This is the standard subsurface section for the Three Forks Formation.

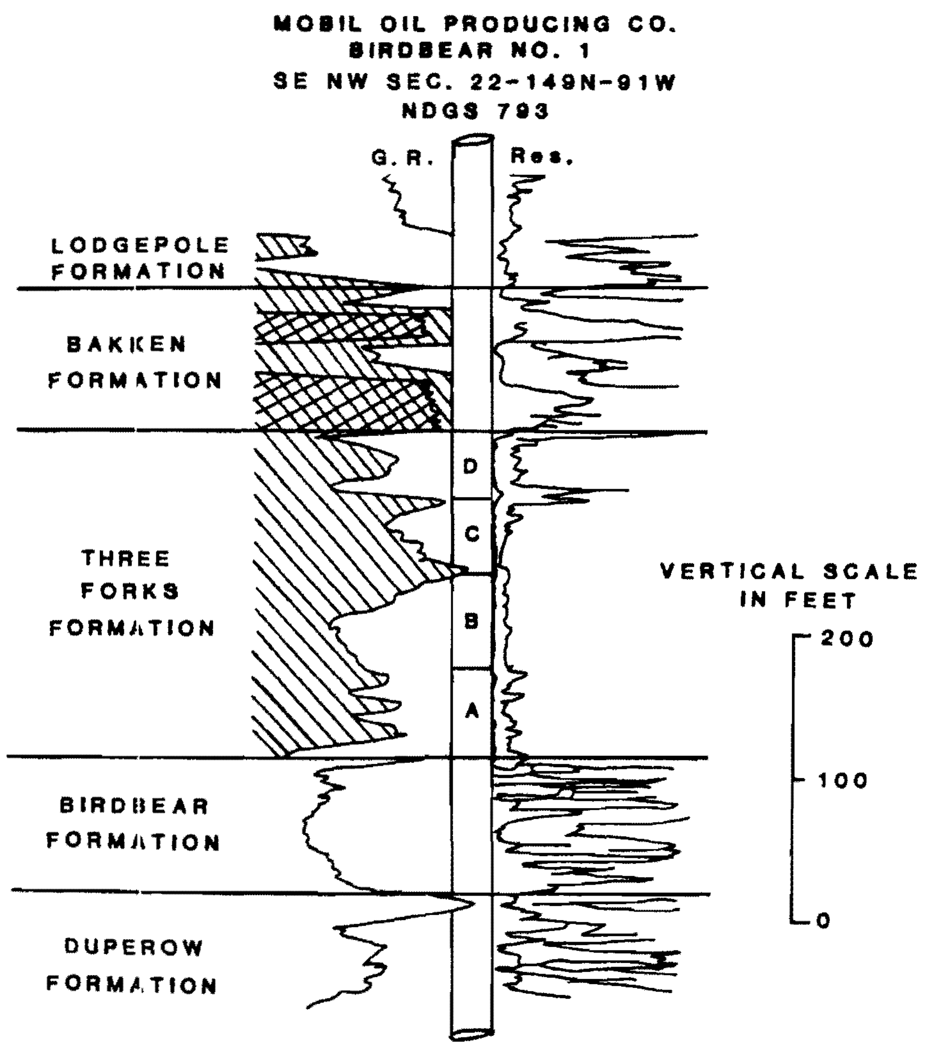
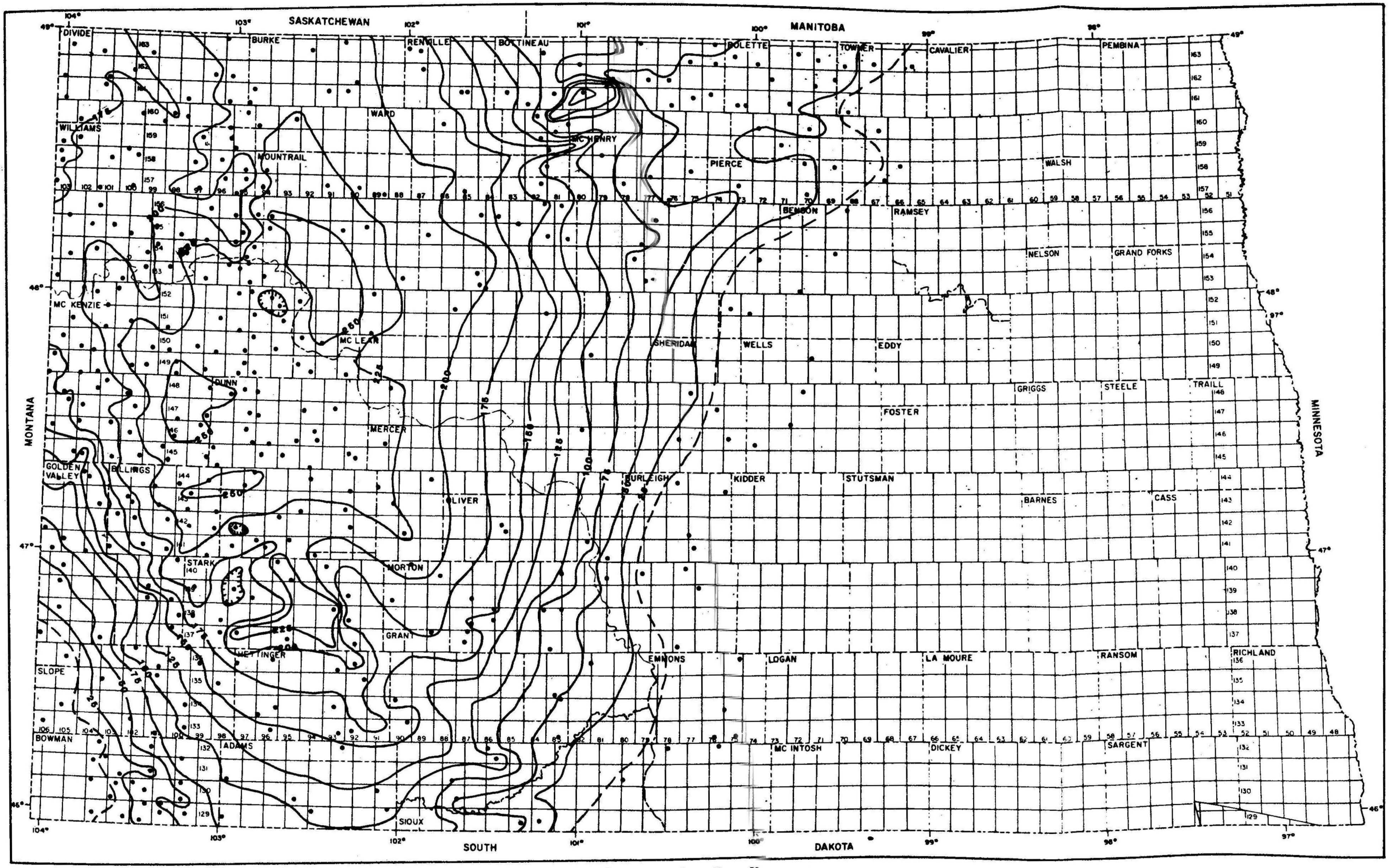

MOBIL OIL PRODUCING CO.
BIRDBEAR NO. 1
SE NW SEC. 22-149N-91W
NDGS 793
G.R.
Res.
LODGEPOLE FORMATION
BAKKEN FORMATION
THREE FORKS FORMATION
D
C
B
A
BIRDBEAR FORMATION
DUPEROW FORMATION
VERTICAL SCALE IN FEET
200
100
0

Figure 2. Isopach map of the Three Forks Formation in North Dakota.



• Control Point

– – – – Approximate Limit Of The Three Forks Formation

10 0 10 20 30 40 miles

SCALE

NORTH DAKOTA

Purpose of Study

The purpose of this study is: 1) to delineate the stratigraphic unit; 2) to interpret the depositional environments during Three Forks time; and 3) to construct a depositional model based on interpretations which are the results of a core and thin section study.

Tectonic History and Early Basin Development

The Williston Basin is a structural and sedimentary basin extending over 51,600 square miles (133,600 square kilometers) in North Dakota, South Dakota, Montana, Saskatchewan, and Manitoba (Carlson and Anderson, 1966). Sedimentary rock thickness is greater than 15,000 feet (4,600 meters) and represents every geologic period of Phanerozoic time. Since every sequence (i.e., the intracratonic sequences of Sloss, 1963) is represented in the Williston Basin, the history of the preserved sedimentary rock section can be conveniently subdivided based on major regional unconformities (Carlson and Anderson, 1966).

An intracratonic basin, the Williston Basin forms a large depression in the western edge of the Canadian Shield (Gerhard et al., 1982, p. 990). Basin development may have been influenced by the north-south-trending Precambrian Superior and Churchill Geologic Province boundary that extends through central North Dakota into Manitoba (Ballard, 1963). This boundary delineates the hinge line for the eastern part of the Williston Basin (Figure 2).

Structural features in the North Dakota portion of the Williston Basin consist of several anticlines including the Cedar Creek and Nesson, the Bismarck-Williston Lineament, and several minor structures such as the Burleigh and Cavalier Highs (Figure 3; Gerhard et al., 1982). Structures in the basin may be the result of movement of basement blocks which were structurally defined in Precambrian time and since then have influenced sedimentation rates (Gerhard et al., 1982, p. 993).

The Williston Basin was not present during Early Paleozoic time, but rather existed as an indentation in the north part of the western cratonic shelf (Gerhard et al., 1982, p. 999). During the Early Ordovician, the basin began to subside, causing a major transgressive event which was eventually broken during the Devonian by uplift. This uplift, which was due to movement along the Transcontinental Arch, caused the Williston Basin to tilt northward, connecting it to the Elk Point Basin (Gerhard et al., 1982, p. 1003). During this time, depositional environments were predominantly shallow marine. Subtidal and intertidal environments developed in the basin center, with sabkha deposits present along the basin margin (Gerhard et al., 1982, p. 989).

Previous Work

Originally described by Peale (1893) for exposures at its type section in Logan, Montana, the Three Forks derives its name from the junction of the three forks of the Missouri River near Three Forks, Montana. In Montana, the Three Forks Formation includes the strata between the underlying Jefferson Limestone and the overlying Madison Limestone (Figure 4; North Dakota Geological Society, 1961; Sandberg and Hammond, 1958). The type section is considered to be the north side of the Gallatin River at Logan, Montana (Sloss and Laird, 1947). Peale

Figure 3. Significant subsurface structures in the Williston Basin, North Dakota (Modified after Gerhard et al., 1982).

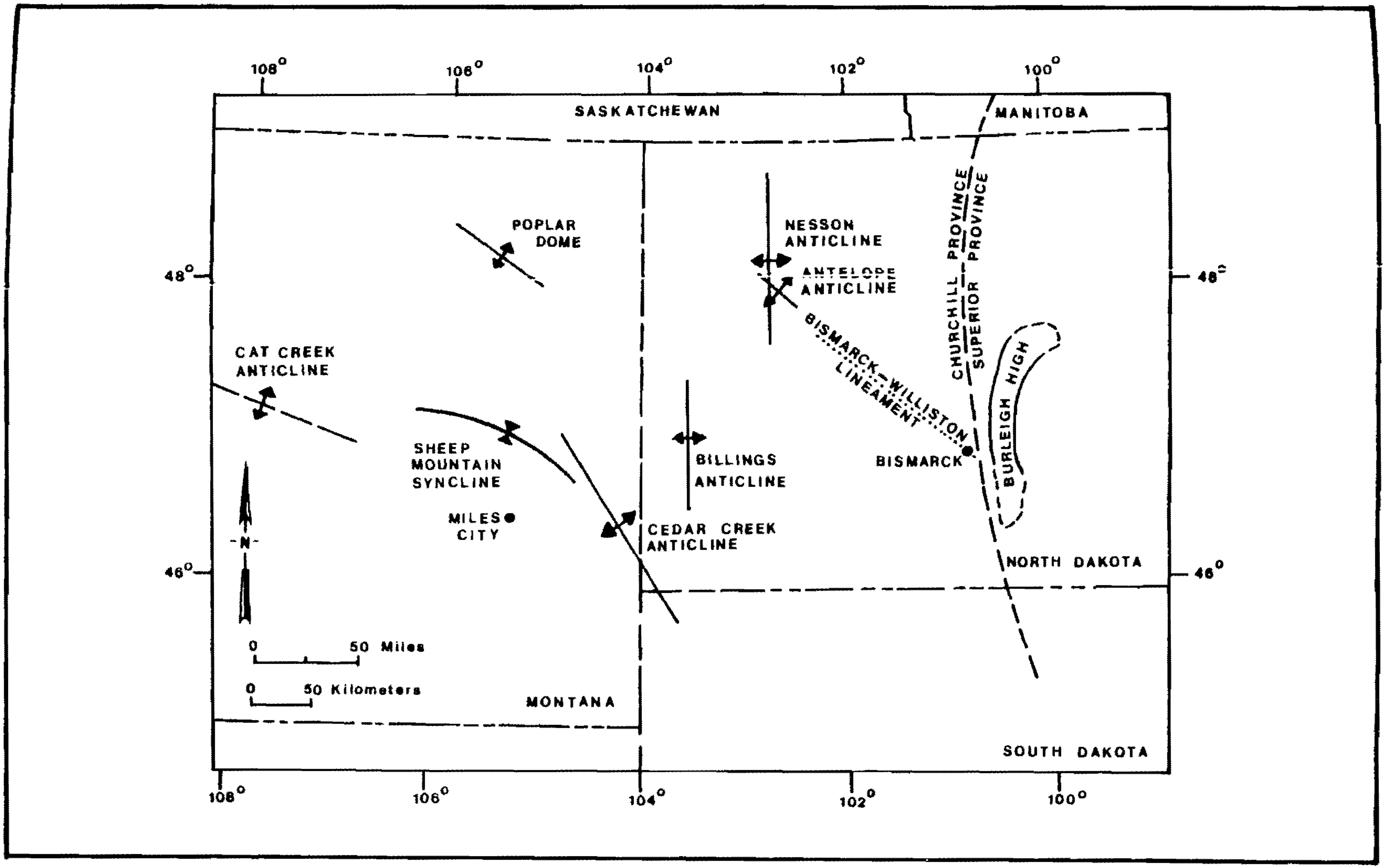
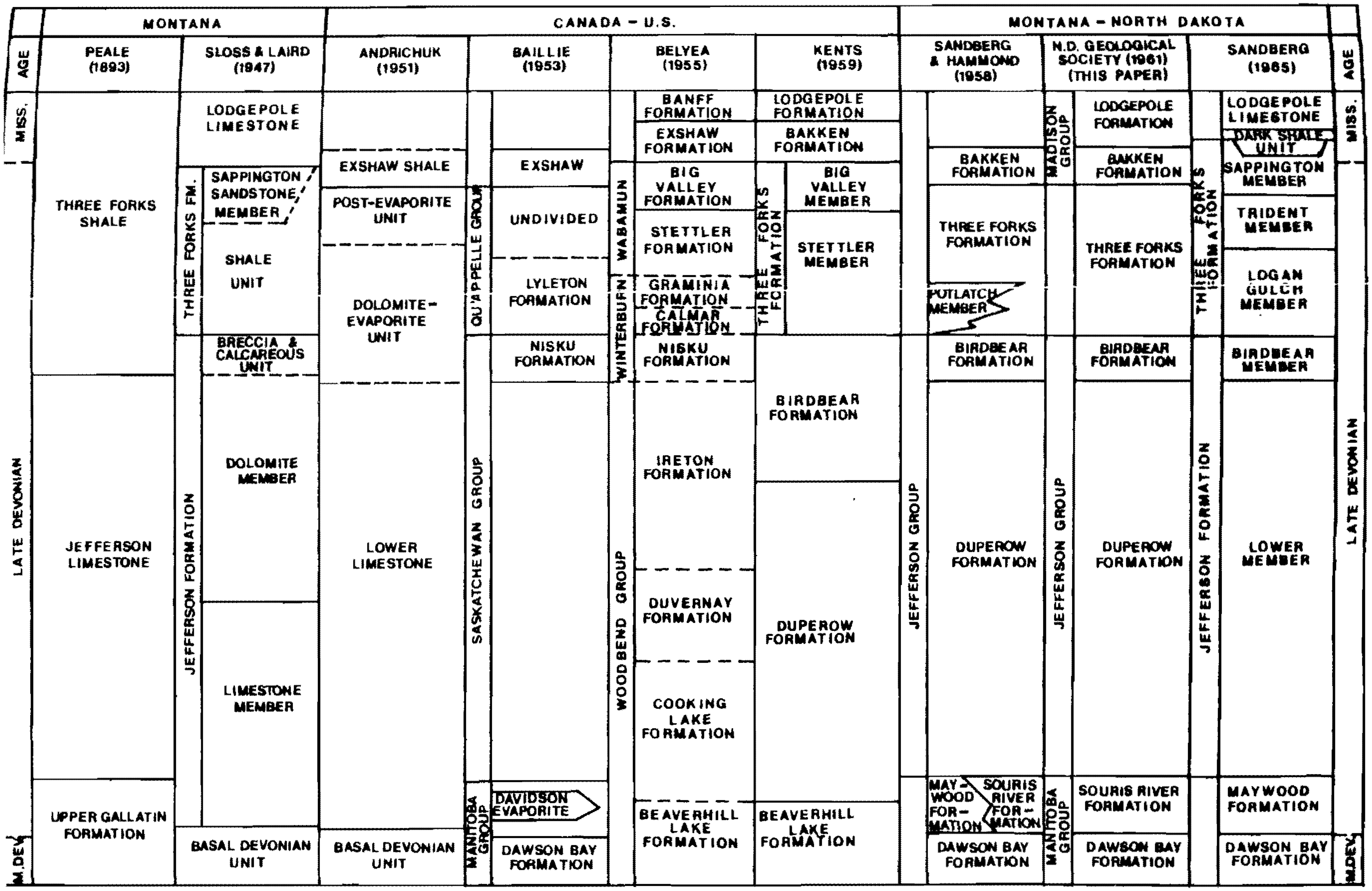

SASKATCHEWAN
MANITOBA
POPLAR DOME
NESSON ANTICLINE
ANTELOPE ANTICLINE
CHURCHILL PROVINCE
SUPERIOR PROVINCE
BISMARCK-WILLISTON LINEAMENT
BURLEIGH HIGH
CAT CREEK ANTICLINE
SHEEP MOUNTAIN SYNCLINE
MILES CITY
BILLINGS ANTICLINE
BISMARCK
CEDAR CREEK ANTICLINE
NORTH DAKOTA
MONTANA
SOUTH DAKOTA
N
0 50 Miles
0 50 Kilometers
108°
106°
104°
102°
100°
48°
46°

Figure 4. Chart of nomenclature and correlation of strata names as
d in text (Modified after Loeffler, 1982).


MONTANA
CANADA - U.S.
MONTANA - NORTH DAKOTA
AGE
PEALE (1893)
SLOSS & LAIRD (1947)
ANDRICHUK (1951)
BAILLIE (1953)
BELYEA (1955)
KENTS (1959)
SANDBERG & HAMMOND (1958)
N.D. GEOLOGICAL SOCIETY (1961) (THIS PAPER)
SANDBERG (1965)
AGE
MISS.
LATE DEVONIAN
M.DEV.
THREE FORKS SHALE
JEFFERSON LIMESTONE
UPPER GALLATIN FORMATION
LODGEPOLE LIMESTONE
THREE FORKS FM.
SAPPINGTON SANDSTONE MEMBER
SHALE UNIT
BRECCIA & CALCAREOUS UNIT
JEFFERSON FORMATION
DOLOMITE MEMBER
LIMESTONE MEMBER
BASAL DEVONIAN UNIT
EXSHAW SHALE
POST-EVAPORITE UNIT
DOLOMITE-EVAPORITE UNIT
LOWER LIMESTONE
BASAL DEVONIAN UNIT
QU'APPELLE GROUP
SASKATCHEWAN GROUP
MANITOBA GROUP
EXSHAW
UNDIVIDED
LYLETON FORMATION
NISKU FORMATION
DAVIDSON EVAPORITE
DAWSON BAY FORMATION
WABAMUN
WINTERBURN
WOODBEND GROUP
BANFF FORMATION
EXSHAW FORMATION
BIG VALLEY FORMATION
STETTLER FORMATION
GRAMINIA FORMATION
CALMAR FORMATION
NISKU FORMATION
IRETON FORMATION
DUVERNAY FORMATION
COOKING LAKE FORMATION
BEAVERHILL LAKE FORMATION
LODGEPOLE FORMATION
BAKKEN FORMATION
THREE FORKS FORMATION
BIG VALLEY MEMBER
STETTLER MEMBER
BIRDBEAR FORMATION
DUPEROW FORMATION
BEAVERHILL LAKE FORMATION
JEFFERSON GROUP
BAKKEN FORMATION
THREE FORKS FORMATION
POTLATCH MEMBER
BIRDBEAR FORMATION
DUPEROW FORMATION
MAY-WOOD FOR-MATION
SOURIS RIVER FOR-MATION
DAWSON BAY FORMATION
MADISON GROUP
JEFFERSON GROUP
MANITOBA GROUP
LODGEPOLE FORMATION
BAKKEN FORMATION
THREE FORKS FORMATION
BIRDBEAR FORMATION
DUPEROW FORMATION
SOURIS RIVER FORMATION
DAWSON BAY FORMATION
THREE FORKS FORMATION
JEFFERSON FORMATION
LODGEPOLE LIMESTONE
DARK SHALE UNIT
SAPPINGTON MEMBER
TRIDENT MEMBER
LOGAN GULCH MEMBER
BIRDBEAR MEMBER
LOWER MEMBER
MAYWOOD FORMATION
DAWSON BAY FORMATION

originally described the Three Forks Formation as consisting, from bottom to top, of gray and green argillaceous dolomite, gray-green shale, and yellow-gray calcareous sandstone (North Dakota Geological Society, 1961).

Berry (1943, pp. 14-16) separated the uppermost unit from the Three Forks and named it the Sappington Sandstone. Berry assigned a Mississippian age to the Sappington based on the presence of Syringothyris. Sandberg and Hammond (1958, p. 2322) considered the Sappington to be a member of the Three Forks Formation and assigned it a Late Devonian and Early Mississippian age. The specific locality and type section for the Sappington Member was given by Holland (1952).

The Three Forks Formation in Montana was divided into three lithic divisions by McMannis (1962) and Sandberg (1962). These are a lower evaporitic member, a middle shale member, and an upper sandstone member (Benson, 1966). Eventually, these units were formally named (in ascending order) as the Logan Gulch, Trident, and Sappington Members (Sandberg, 1965). In 1962, Rau proposed the member names of London Hills (replacing the Logan Gulch) and Horseshoe Hills (replacing the Trident), while retaining the Sappington Member name. Rau's member names are equivalent to those presently used, but it is not known whether Rau ever formally proposed his selection of names. Jointly these members attain a maximum thickness of about 800 feet (244 meters) in northwestern Montana (Sandberg and Mapel, 1967).

Each member was deposited under different environmental conditions (Sandberg, 1965). The restricted marine Logan Gulch Member represents an eastward facies change from evaporites to carbonates to nearshore detrital rocks. It is generally conformable with the underlying Jefferson Limestone. Commonly conformable with the lower member, the green shales of the open marine Trident Member change facies eastward to carbonates. The Sappington Member, separated from the Trident by a widespread disconformity, is largely a regressive marginal marine unit (Sandberg, 1965; Benson, 1966).

Since the Sappington lies between well-established Devonian rocks below and Mississippian rocks above, there are differences of opinion concerning the systematic boundary (Gutschick, McLane, and Rodriquez, 1976). Robinson (1963) supported a dual age for the Sappington based on fossil collections. More recent collections suggest that only the uppermost beds are of Mississippian age (Sandberg, 1965).

Additional workers, such as Christopher (1961) and Rau (1962) retained the Sappington as a member of the Three Forks. Gutschick, Suttner, and Switek (1962) and McMannis (1962) continued to consider the Sappington as a separate formation.

The exact placement of the Devonian-Mississippian boundary in southwestern Montana has been recognized and thoroughly discussed since Peale's original work in 1893 (Robinson, 1963). As Robinson (1963, p. 34) stated, concerning the "Sappington Problem", questions on the age of a formation usually arise from a shortage of paleontologic evidence, but in the case of the Three Forks, the age problem stems from an overabundance of fossils.

Using measured sections and wells, the Sappington Member has been found to be equivalent with the subsurface Exshaw Shale in Alberta. The Exshaw, in turn, is equivalent to the lower black shale and middle siltstone units of the Bakken Formation. Thus the basal part of the Sappington is a correlative of the Bakken Formation in the Williston Basin (Sandberg, 1965).

In a biostratigraphic study (Sandberg and Poole, 1977), twenty-seven conodont zones were recognized worldwide in the Late Devonian. The distribution of these conodont zones have been used to interpret depositional environments, and to indicate paleogeography, paleotectonism, and sedimentation rates. No evidence to date has been found to support a Mississippian age for the uppermost units of the Sappington Member, and the age of the Sappington Member is considered to be Late Devonian and Early Mississippian (?) (Sandberg and Poole, 1977).

The name Three Forks was extended into the Williston Basin by Sandberg and Hammond (1958) and includes all strata between the underlying Birdbear Formation and the overlying Bakken Formation. As stated previously, the interval in the Mobil Birdbear Well is considered to be the standard subsurface section of the Three Forks Formation in the Williston Basin with an approximate thickness of 265 feet (81 meters). At this locality, the Three Forks consists of interbedded and interlaminated grayish-green and reddish-brown micrite and dolomicrite. Many structural varieties of anhydrite are present throughout the section, as well as minor amounts of biomicrite.

In general, fossils are rare in the Three Forks in the subsurface. The upper ten feet (3 meters) in the standard subsurface section may contain Ambocoelia sp and Camarotoechia sp (Sandberg and Hammond, 1958). At its type section, brachiopods, pelecypods, ammonoids, bryozoans, and conulariids have been identified (Peale, 1893).

Locally present along the Nesson Anticline is a coarse-grained siltstone to fine-grained sandstone unit which has, in informal Williston Basin subsurface terminology, been referred to as the Sanish Sand (Kume, 1963). Oil production in the Three Forks is due to tension-fracture systems in the Sanish Sand (Murray, 1968).

In 1942, Kline first reported the occurrence of Devonian rocks in northeastern North Dakota. Since the relationships of these rocks were poorly known, no formation names were applied at that time. The Devonian age assignment was dependent upon comparison of rock samples from wells drilled in North Dakota to known Devonian rocks in Manitoba.

The anhydritic character of the lower part of the Three Forks may be due to an eastward-extending tongue of the Potlatch Anhydrite present in northwestern Montana (North Dakota Geological Society, 1961; Sandberg and Hammond, 1958). To the east, the distinctive lithology of the central basin grades into red dolomitic and anhydritic shale and siltstone, which was named the Lyleton Formation (Allan and Kerr, 1950).

Spanning the upper Birdbear into the lower Three Forks Formation, the anhydritic facies reflects deposition in a restricted evaporitic environment. The main evaporitic body is the Potlatch Anhydrite. The upper Three Forks represents deposition in a shallow sea under fluctuating normal marine and restricted marine conditions. The redbed facies, on the eastern margin, suggests deposition in a nearshore environment (North Dakota Geological Society, 1961). From west to east, evaporite deposition is replaced by clastic deposition. The redbed facies to the east suggests that the environment prohibited the accumulation and preservation of anhydrite (Andrichuk, 1951).

Baillie (1955, p. 608) proposed the name Qu'Appelle Group to identify the uppermost Devonian strata of the Williston Basin in Saskatchewan and Manitoba. In eastern Saskatchewan, Manitoba, and North Dakota, the Qu'Appelle Group consists of a single formation, the Lyleton (Baillie, 1953). The Lyleton Formation, as used in North Dakota, refers to the redbed facies present on the eastern margin of the Williston Basin. The Qu'Appelle Group, the Lyleton Formation, and the Three Forks Formation have all been applied to the same stratigraphic unit in the Williston Basin (North Dakota Geological Society, 1961). The Lyleton Formation has never been formally proposed nor adequately defined in terms of contacts and type locality. Due to its equivalence to the Three Forks Formation, Sandberg and Hammond (1958) recommended that the term Lyleton be disregarded.

Time equivalent to the Three Forks Formation in Montana and North Dakota is the Wabamun Group in Alberta (Andrichuk, 1951) and the Qu'Appelle Group in eastern Saskatchewan and Manitoba (Kents, 1959). Belyea (1955) has studied the stratigraphy and prepared cross-sections of the Devonian formations in Alberta.

The Wabamun Group is subdivided into the Stettler Formation and the Big Valley Formation. In western Saskatchewan, the Three Forks Formation consists of the Stettler and Big Valley Members which are approximately continuous with those formations which bear the same name in Alberta (Kents, 1959). The Stettler Formation is equivalent to the Potlatch Evaporite in Montana. Conformably overlying the Stettler is the Big Valley Formation.

In southern Saskatchewan, the Three Forks is given group status by
Christopher (1962). Christopher's subdivisions are, from bottom to top, the Torquay, Big Valley, and Bakken Formations. The Torquay Formation is equivalent to the Potlatch Evaporite and the Stettler Formation and Member. The inclusion of the Bakken Formation is based on its correlation to Peale's "upper shales" and the Sappington Sandstone of Berry (Christopher, 1962).

There is little indication of an unconformity between the lower shale member of the Bakken and the underlying Three Forks in the deeper parts of the Williston Basin (Fuller, 1956). In eastern Saskatchewan and western Manitoba, the middle arenaceous member of the Bakken rests on the eroded surface of the Qu'Appelle Group (Fuller, 1956). After deposition of the Big Valley Member, a period of uplift and erosion occurred. This is indicated by the presence of a pebble bed which intervenes between the base of the Bakken and the underlying unit (Fuller, 1956; Kents, 1959; Fuller and Porter, 1962). This pebble zone is not present, however, in southern Saskatchewan, where the Big Valley and Bakken interfinger (Christopher, 1962).

The term Three Forks is preferable for several reasons: 1) Since 1951 when oil was discovered in the Williston Basin, the name Three Forks has been in use; 2) The Three Forks Formation has been traced from outcrops at its type section in Montana into the subsurface of the Williston Basin by Sandberg and Hammond; and 3) The Three Forks Formation, having been described from core chips at its standard subsurface section, has been formally established in the basin (North Dakota Geological Society, 1961).

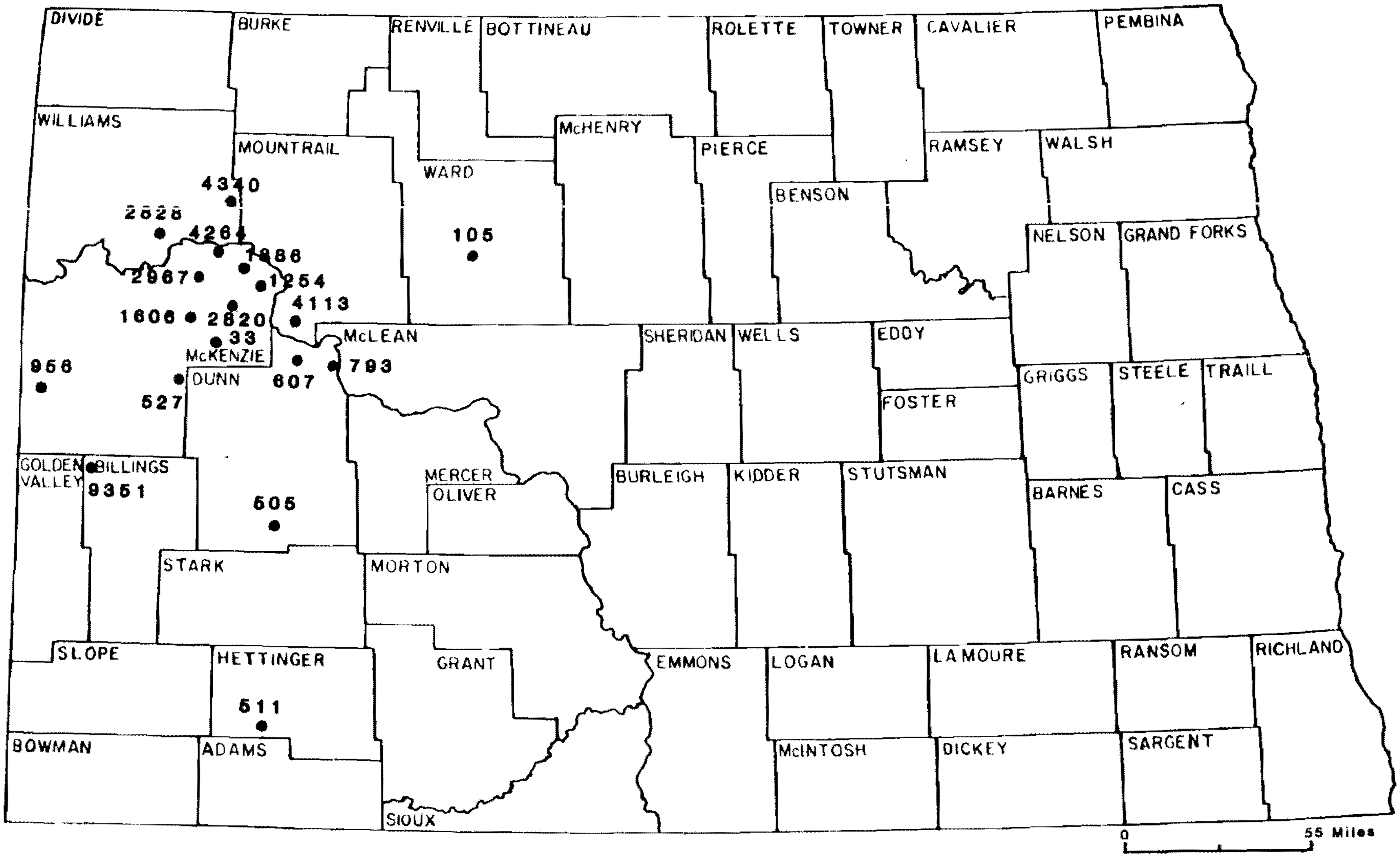
METHOD OF STUDY

The area of study was confined to the state of North Dakota. The major source of lithologic data came from cores housed at the Wilson M. Laird Core and Sample Library of the North Dakota Geological Survey, Grand Forks. Core distribution used in this study is shown in Figure 5.

Cores were slabbed, lithology described, and thin sections made wherever lithology or stratification changed. A 10% solution of HCl was used to denote the presence of dolomite in core slabs by its lack of effervescence. In thin section, dolomite was distinguished from calcite by staining in a solution of Alizarin red S as described by Friedman (1971). Folk's (1959) carbonate classification scheme was used for rock names, the system of Maiklem et al. (1969) was used for anhydrite forms, and the rock color chart developed by Goddard et al. (1948) was utilized for indicating the color of core slabs.

Formation contact picks were compiled from gamma-ray, well logs, which are on file with the North Dakota Geological Survey. From the data collected, isopach and structure maps were generated to indicate the extent, thickness, and structure of the Three Forks Formation. Well logs were also used in constructing cross-sections across various areas of the state.

Figure 5. Location of Three Forks cores.


DIVIDE
BURKE
RENVILLE
BOTTINEAU
ROLETTE
TOWNER
CAVALIER
PEMBINA
WILLIAMS
MOUNTRAIL
WARD
McHENRY
PIERCE
RAMSEY
WALSH
BENSON
NELSON
GRAND FORKS
4340
2528
4264
1886
2967
1254
4113
1606
2820
33
105
McKENZIE
McLEAN
SHERIDAN
WELLS
EDDY
956
607
793
DUNN
527
GRIGGS
STEELE
TRAILL
FOSTER
GOLDEN VALLEY
BILLINGS
9351
MERCER
OLIVER
BURLEIGH
KIDDER
STUTSMAN
BARNES
CASS
505
STARK
MORTON
SLOPE
HETTINGER
GRANT
EMMONS
LOGAN
LA MOURE
RANSOM
RICHLAND
511
BOWMAN
ADAMS
McINTOSH
DICKEY
SARGENT
SIOUX
0
55 Miles

STRATIGRAPHY

Type Section

In accordance with the work of Sandberg and Hammond (1958), the standard subsurface type section of the Three Forks Formation occurs in the Mobil Producing Company No. 1 Birdbear Well located in SE1/4 NW1/4, sec. 22, T. 149 N., R. 91 W., Dunn County, North Dakota, between the depths of 10,076 and 10,310 feet. At this locality, core descriptions were based on detailed microscopic examination of chips whenever a major lithologic change occurred. Sandberg and Hammond (1958) based their core descriptions on a clastic classification scheme. Since this original description, the Three Forks Formation has continued to be described as interbedded and interlaminated greenish-gray and grayish-red dolomitic siltstone and shale. In this study, however, a carbonate terminology was found to be more appropriate.

Mechanical Log Characteristics

Data on the extent, thickness, and structure of the Three Forks Formation were compiled from a study involving approximately 400 well logs. Wherever possible, gamma-ray, well logs were used in making formation contact picks, because the greater deflection of the gamma ray in shales is easily differentiated from the lesser deflection in limestones, as in the Birdbear Formation. In some instances, electric and sonic well logs were utilized when no gamma ray logs were available. Compilation of data was based on a density of one well log per township. In certain areas, such as along the Nesson Anticline and in the anomalous area in the northeastern part of the state (Figure 2), thickness and structure changes warranted tighter control and thus two or three logs were used in each township.

The unique log response in this part of the Paleozoic rock section in the Williston Basin is that shown by the shales of the Bakken Formation. These shales display such high gamma ray responses that this formation is widely used as a marker unit in the basin (Figure 1). Due to these "hot" shale kicks, the contact between the Bakken and Three Forks Formations can be readily recognized. The lower contact with the Birdbear Formation is chosen where the gamma ray response becomes "quiet" and the resistivity readings are high. The Three Forks Formation produces a very low resistivity reading and a variable gamma ray response. Higher gamma ray readings occur in those areas where there is an increase in argillaceous content.

Fuller (1956), while working on cross-sections of the Qu'Appelle Group in southeastern Saskatchewan, found that it was composed of three sedimentary cycles. Each cycle begins with iron-stained dolomitic siltstones and, with increasing argillaceous content, terminates in radioactive red shales. These cycles can be clearly seen on gamma-ray, well logs (Figure 1). This writer found that it was possible, in North Dakota, to delineate four cycles rather than three. It may be that the uppermost cycle (D) is absent in Fuller's study area due to erosion or non-deposition.

It was found in studying core, especially in the subsurface type section (NDGS Well 793), that the four cycles so readily visible on the well logs are not evident in the rock section. These cycles cannot be thought of as representing different rock types or alternating rock types, as the majority of the Three Forks consists of micrite and dolomicrite. Argillaceous content does vary throughout the section, but this is noticeable only in thin section. The advantage of subdividing the Three Forks into four members (A-D) is to indicate the truncation of the units along the flanks of the basin and the angular unconformity that occurs where the overlying Bakken is eroded.

Areal Extent and Thickness

In the North Dakota portion of the Williston Basin, the Three Forks Formation reaches a maximum thickness of approximately 265 feet (81 meters). It is thickest in the central basin, east and south of the Nesson Anticline, and thins to zero along the eastern and southwestern flanks of the basin (Figure 2). An abnormal thickening of the Three Forks occurs in Bottineau County. This large increase in thickness is probably due to solution and subsequent collapse of salts and evaporites in the Middle Devonian Prairie Formation. In structurally lower areas, such as this collapsed zone, the Three Forks should be thicker,and correspondingly, should be thinner over structurally high areas which were active during the time of deposition.

The Cedar Creek Anticline is the most significant feature affecting formation thickness. As the anticline is approached, a thinning of the formation occurs (Figure 2). In general, the Nesson Anticline had little effect on deposition, since only minor thinning of the Three Forks occurs in this area. The one effect of the Nesson Anticline on the formation is the area of thickness on its eastern flank. Other areas of thickening may be due to erosion of the Birdbear or the result of further salt collapse in the Prairie Formation. The thickening in

Stark County cannot be explained by salt collapse since the limit of salt deposition lies to the north. As indicated on the isopach map, the depocenter of the Three Forks is poorly developed and extends over much of west-central North Dakota. Dunn, McKenzie, and Mountrail Counties are the areas of greatest accumulation.

On the isopachous map (Figure 2), a long arcuate area of thinning extends along the eastern margin of the basin. Sandberg (1961, p. 122) suggested this represents a buried anticline or possibly a Late Devonian hinge line. The west side of this area delineates the zero edge of the Three Forks, while the east side is the limit of the Birdbear Formation. The preservation of the Birdbear may be due to a syncline paralleling the anticlinal feature (Sandberg, 1961). The isopach map also shows the effects of channelling in the northeastern part of the state. One major channel and one minor one have removed approximately 30-40 feet (9-12 meters) of the Three Forks.

Structural Configuration

The structure contour map (Figure 6) on the top of the Three Forks Formation clearly indicates the geometry of the basin and the Nesson and Cedar Creek Anticlines. The deepest section of the basin is located in northern McKenzie County, just west of the Nesson Anticline, while the shallowest is in Rolette and Towner Counties.

The absence of the Three Forks Formation over the Cedar Creek Anticline may be due to pre-Mississippian erosion or non-deposition (Figure 2). Along the Nesson Anticline, thinning and absence of beds at the top of the Three Forks indicates that thinning was both erosional and depositional (Sandberg, 1961; Figure 7).

igure 6. Structural map on the top of the Three Forks Formation in
Dakota.

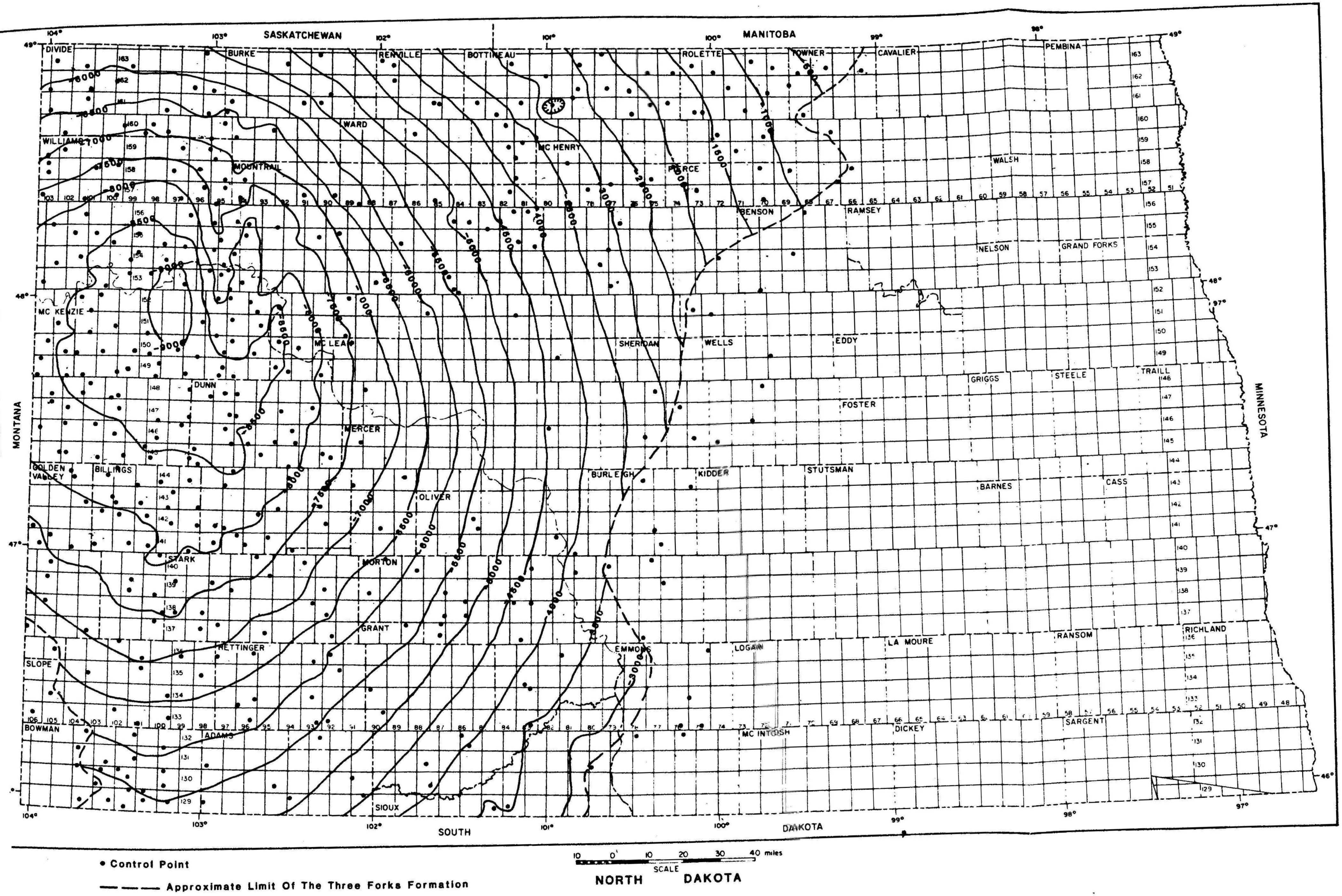
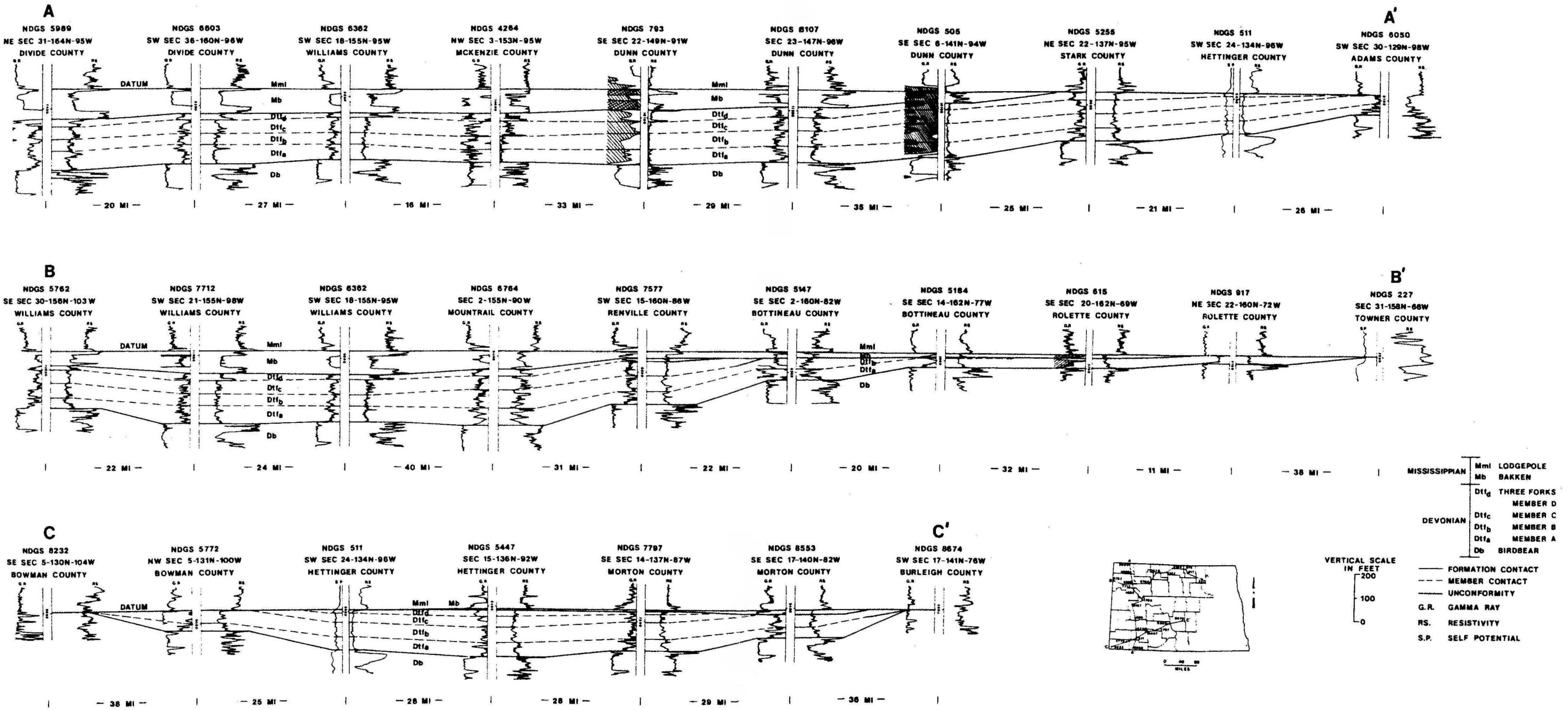

SASKATCHEWAN
MANITOBA
MONTANA
MINNESOTA
SOUTH DAKOTA
DIVIDE
BURKE
RENVILLE
BOTTINEAU
ROLETTE
TOWNER
CAVALIER
PEMBINA
WILLIAMS
WARD
MC HENRY
PIERCE
WALSH
MOUNTRAIL
BENSON
RAMSEY
NELSON
GRAND FORKS
MC KENZIE
MC LEAN
SHERIDAN
WELLS
EDDY
GRIGGS
STEELE
TRAILL
DUNN
FOSTER
MERCER
GOLDEN VALLEY
BILLINGS
BURLEIGH
KIDDER
STUTSMAN
BARNES
CASS
OLIVER
STARK
MORTON
GRANT
HETTINGER
EMMONS
LOGAN
LA MOURE
RANSOM
RICHLAND
SLOPE
BOWMAN
ADAMS
SIOUX
MC INTOSH
DICKEY
SARGENT
104°
103°
102°
101°
100°
99°
98°
97°
49°
48°
47°
46°
• Control Point
Approximate Limit Of The Three Forks Formation
10 0 10 20 30 40 miles
SCALE
NORTH DAKOTA

Figure 7. Cross-sections of the Three Forks Formation in North ota.


A
NDGS 5989
NE SEC 31-164N-95W
DIVIDE COUNTY
NDGS 6603
SW SEC 36-160N-96W
DIVIDE COUNTY
NDGS 6362
SW SEC 18-155N-95W
WILLIAMS COUNTY
NDGS 4264
NW SEC 3-153N-95W
MCKENZIE COUNTY
NDGS 793
SE SEC 22-149N-91W
DUNN COUNTY
NDGS 8107
SEC 23-147N-96W
DUNN COUNTY
NDGS 505
SE SEC 6-141N-94W
DUNN COUNTY
NDGS 5255
NE SEC 22-137N-95W
STARK COUNTY
NDGS 511
SW SEC 24-134N-96W
HETTINGER COUNTY
A'
NDGS 6050
SW SEC 30-129N-98W
ADAMS COUNTY
DATUM
Mml
Mb
Dtfd
Dtfc
Dtfb
Dtfa
Db
— 20 MI —
— 27 MI —
— 16 MI —
— 33 MI —
— 29 MI —
— 35 MI —
— 25 MI —
— 21 MI —
— 26 MI —
B
NDGS 5762
SE SEC 30-156N-103W
WILLIAMS COUNTY
NDGS 7712
SW SEC 21-155N-98W
WILLIAMS COUNTY
NDGS 6362
SW SEC 18-155N-95W
WILLIAMS COUNTY
NDGS 6764
SEC 2-155N-90W
MOUNTRAIL COUNTY
NDGS 7577
SW SEC 15-160N-86W
RENVILLE COUNTY
NDGS 5147
SE SEC 2-160N-82W
BOTTINEAU COUNTY
NDGS 5184
SE SEC 14-162N-77W
BOTTINEAU COUNTY
NDGS 615
SE SEC 20-162N-69W
ROLETTE COUNTY
NDGS 917
NE SEC 22-160N-72W
ROLETTE COUNTY
B'
NDGS 227
SEC 31-158N-66W
TOWNER COUNTY
DATUM
Mml
Mb
Dtfd
Dtfc
Dtfb
Dtfa
Db
— 22 MI —
— 24 MI —
— 40 MI —
— 31 MI —
— 22 MI —
— 20 MI —
— 32 MI —
— 11 MI —
— 38 MI —
C
NDGS 8232
SE SEC 5-130N-104W
BOWMAN COUNTY
NDGS 5772
NW SEC 5-131N-100W
BOWMAN COUNTY
NDGS 511
SW SEC 24-134N-96W
HETTINGER COUNTY
NDGS 5447
SEC 15-136N-92W
HETTINGER COUNTY
NDGS 7797
SE SEC 14-137N-87W
MORTON COUNTY
NDGS 8553
SE SEC 17-140N-82W
MORTON COUNTY
C'
NDGS 8674
SW SEC 17-141N-76W
BURLEIGH COUNTY
DATUM
Mml
Mb
Dtfd
Dtfc
Dtfb
Dtfa
Db
— 38 MI —
— 25 MI —
— 28 MI —
— 28 MI —
— 29 MI —
— 36 MI —
MISSISSIPPIAN
Mml LODGEPOLE
Mb BAKKEN
DEVONIAN
Dtfd THREE FORKS MEMBER D
Dtfc MEMBER C
Dtfb MEMBER B
Dtfa MEMBER A
Db BIRDBEAR
VERTICAL SCALE IN FEET
200
100
0
FORMATION CONTACT
MEMBER CONTACT
UNCONFORMITY
G.R. GAMMA RAY
RS. RESISTIVITY
S.P. SELF POTENTIAL
MILES

Underlying Units

In North Dakota, the Three Forks Formation is everywhere underlain by the Birdbear Formation. Consisting of fossiliferous limestone and dolomitic limestone, the Birdbear Formation is approximately 120 feet (37 meters) thick. The contact between the Three Forks and Birdbear is generally conformable in the deeper portions of the basin and becomes unconformable nearing the basin flanks. The Three Forks is less widespread than the Birdbear, and probably experienced more intense erosion due to its stratigraphic position.

The relationship between the Birdbear and Three Forks is best seen on the well log cross-sections (Figure 7). The structural attitude of the members of the Three Forks parallels that of the Birdbear. Due to this paralleling of attitudes, a conformable contact with the Birdbear is inferred. Along the flanks of the basin, the Three Forks rests unconformably on the erosional edge of the Birdbear. The contact with the Birdbear can only be inferred from well logs, since no contact was ever found in the seventeen cores which were used in this study.

Overlying Units

Within the study area, the Bakken Formation of Late Devonian and Early Mississippian age is everywhere underlain by the Three Forks Formation. The Bakken consists of two radioactive black shale beds separated by a fine-grained sandstone. The contact between the Bakken and Three Forks is conformable in the deeper portions of the basin and unconformable on the basin flanks as seen on well logs (Figure 7). Since the Bakken is less widespread than the Three Forks, the Lodgepole Limestone of the Madison Group (Mississippian) unconformably overlies

Devonian rocks. As with the Birdbear, the Bakken also has a structural attitude parallel to the members of the Three Forks, and thus again a conformable contact is inferred.

The Three Forks-Bakken contact can be observed in a core taken from the deeper portion of the basin (NDGS Well No. 9351). A probable unconformity is indicated by the presence of small light brown to beige intraclasts and lag deposits of fossil debris occurring at the contact. The contact is undulatory, perhaps due to soft-sediment deformation. Along the Nesson Anticline, the Bakken overlies a coarse-grained siltstone which has been informally referred to by workers in the Williston Basin as the "Sanish Sand". Kume (1963) states that the erratic occurrence of the Sanish Sand might be indicative of beach sand deposits or shallow water sand bars.

Age and Paleontology

In the Logan, Montana area, the Three Forks Formation is considered to be Late Devonian and Early Mississippian in age. This age assignment was determined by studies of fossil fauna, specifically, brachiopods, mollusks, bryozoans, and conulariids, by Berry (1943), Sandberg and Hammond (1958), Robinson (1963), and Sandberg (1965). Fossils indicating an Early Mississippian age are found mainly in the Sappington Sandstone Member (Sandberg and Hammond, 1958). Other workers (Sloss and Laird, 1947; Peale, 1893; Raymond, 1909) have included this sandstone member in the lower shale member of the Three Forks. In a more recent study, Sandberg and Poole (1977) used conodonts to give an age designation of Late Devonian and Mississippian (?) to the uppermost units of the Sappington Member.

The Three Forks in the Williston Basin is assigned to the Upper Devonian since the age of the Bakken Formation and its surface equivalent, the Sappington, is given as Late Devonian-Early Mississippian. On the southern margin of the basin, the Three Forks is overlain by beds correlated with the Early Mississippian Englewood Limestone (Sandberg and Hammond, 1958). Where the Bakken is not present on the eastern margin, the Three Forks is overlain by the Lodgepole Limestone of the Madison Group of Mississippian age. Thus, in North Dakota, the Three Forks is assigned a Late Devonian age, specifically Famennian, due to its stratigraphic position between the Bakken and the Frasnian Birdbear Formation. Fossils are rare in the Three Forks in North Dakota, but brachiopods are present in the standard subsurface section (Sandberg and Hammond, 1958). The Three Forks is also, in part, equivalent to the Stettler and Big Valley Formations of the Wabamun Group of Late Devonian age in southern Alberta.

LITHOLOGY AND SEDIMENTARY STRUCTURES

Introduction

The majority of previous work done on the Three Forks Formation has considered this unit to be of detrital origin. In this core study, the use of a clastic classification scheme did not, in itself, seem adequate. Several rock samples were analyzed, by the use of acid baths, to indicate the variation in clastic and carbonate quantities. Since thin sections were used in this study, a better approximation of micritic and argillaceous content was possible. Consequently, it was decided to utilize a carbonate classification scheme while using clastic modifers where appropriate.

As a result of this study, five lithofacies were found to adequately describe the variability of the Three Forks Formation. These are: 1) micrite; 2) argillaceous micrite; 3) dolomicrite; 4) argillaceous dolomicrite; and 5) argillaceous biomicrite.

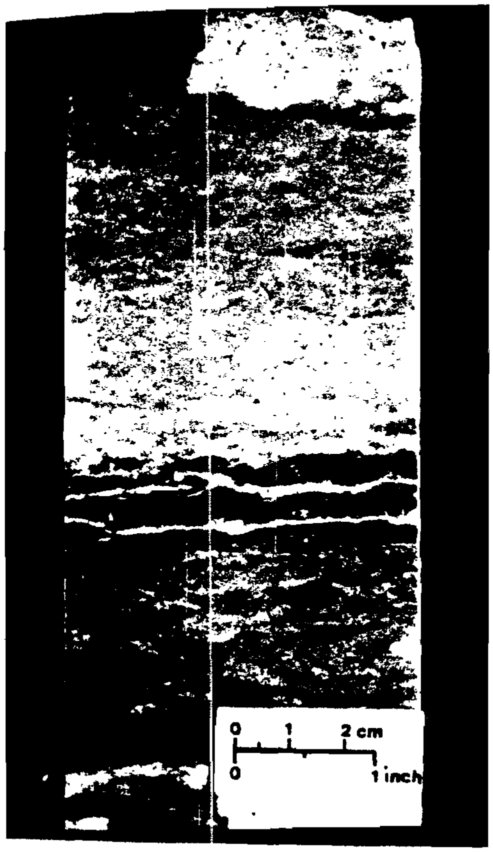
From the study of core samples and detailed petrographic analysis of thin sections (see Appendix B), each lithofacies was recognized and its extent determined. Each lithofacies was distinguished by various criteria. Major criteria used in categorization were fossil biota, non-skeletal particles, calcareous or dolomitic content, and terrigenous or argillaceous content.

This study utilized both core and thin sections, and consequently Folk's (1959) carbonate classification scheme best represented both description types. The term micrite describes those rocks which consist of microcrystalline calcite and contain less than 1% allochems. Dolomicrite refers to those rocks which consist of microcrystalline dolomite and again, contain less than 1% allochems. Argillaceous micrite and argillaceous dolomicrite describe the microcrystalline calcite and dolomite rocks which contain clays. Argillaceous biomicrite is used to describe those rocks which contain varying amounts of fossil material. The term argillaceous is used wherever clay is present, and is not intended to describe the abundance of this material.

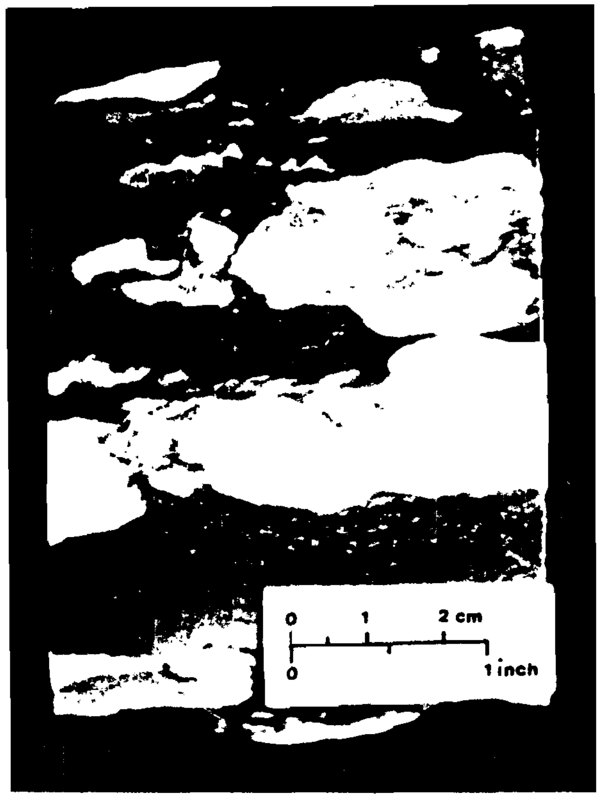
The vertical succession of lithofacies is similar from one core to another. Throughout the study area, however, the Three Forks exhibits extreme lateral and vertical variability, thus making correlation within the formation a difficult process. In general, the dolomicrite and argillaceous dolomicrite are the most widespread and abundant facies throughout the study area. These are followed, in abundance, by the argillaceous micrite and micrite facies. The argillaceous biomicrite facies is present only in eastern McKenzie, northwestern Dunn, and southwestern Mountrail Counties. Only in NDGS Well 793 in Dunn County is the entire Three Forks cored, although the upper and lower contacts were not recovered. No contact with the Birdbear Formation was ever located, and the only upper contact with the Bakken Formation is in NDGS Well 9351 in Billings County.

Anhydrite is a very common constituent in the Three Forks Formation and occurs in a variety of forms. Structural types of anhydrite are based on the classification introduced by Maiklem et al. (1969). A total of eight structural types are present in these rocks. These are: 1) nodular; 2) distorted nodular; 3) bedded nodular; 4) distorted bedded nodular; 5) distorted nodular mosaic; 6) bedded nodular mosaic; 7) distorted mosaic; and 8) bedded massive. Figure 8 illustrates five of the most prominent structural types.

Figure 8. Anhydrite structural types. A) Nodular anhydrite in argillaceous dolomicrite. Core slab 793-10238. B) Distorted nodular anhydrite in argillaceous dolomicrite. Core slab 793-10243. C) Bedded nodular anhydrite in argillaceous dolomicrite. Core slab 793-10211.



A



B

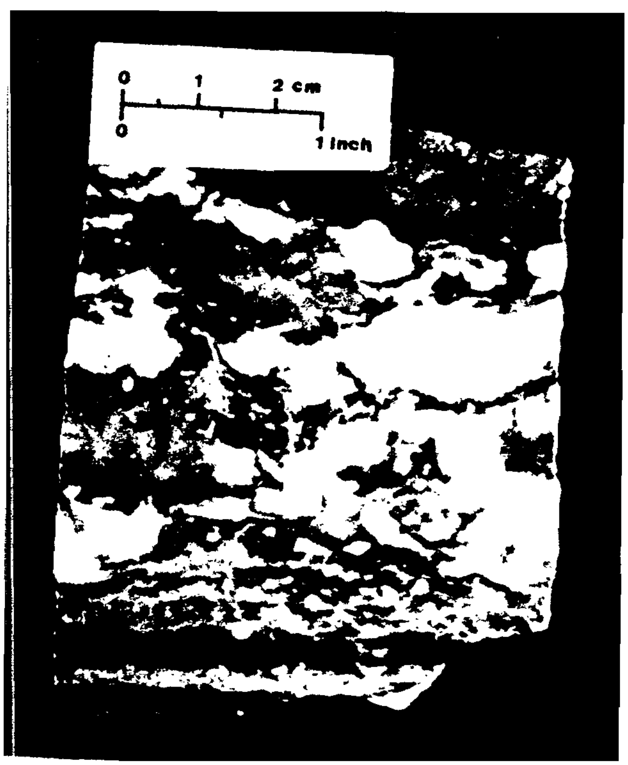
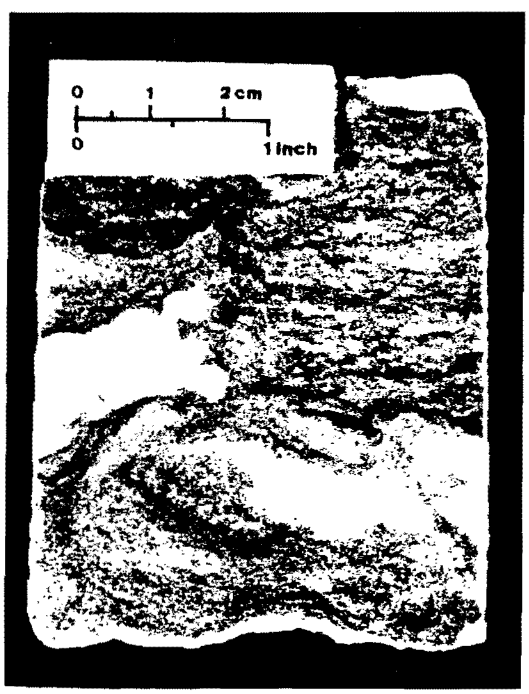


Figure 8. (Continued) Anhydrite structural types. D) Distorted bedded nodular anhydrite in argillaceous dolomicrite. Core slab 793-10243. E) Distorted nodular mosaic anhydrite in argillaceous dolomicrite. Core slab 793-10248.

D



E

The anhydrite nodules range from 2-56 mm in longest dimension, with the average size being 15-17 mm. The color of the nodules varies from white to reddish-orange, though pale orange is the most common. In thin section, the anhydrite nodules are composed of blocky, felted, or lath-shaped crystals. Stringers of dark carbonate or clay can be found within or surrounding the nodules, producing a "chicken-wire" anhydrite.

Micrite

Rocks of the micrite lithofacies range in color from grayish-green to pale yellowish-brown. These rocks are usually interbedded, with the pale yellowish-brown showing either laminations or cross-laminations. Brecciation is a common feature which is, in part, responsible for producing intraclasts. Some micro-faults are also present.

Laminations vary from 1-2 mm in width, while entire beds range from 1.5-2.5 cm in thickness, though 7-cm-thick cross-laminated units are common also. Intraclasts are found associated with water escape structures, which may be responsible for occurrences of micro-faulting.

Minor features in this facies are burrowing and the presence of anhydrite and pyrite. Burrows are most obvious in thin section and are infilled with quartz grains and muddy sediments. In several instances where burrows have terminated, stylolites have formed. Anhydrite is rare and is of the distorted nodular variety (0.7-2.5 cm). It also forms in 1 mm long nodules and more closely resembles birds-eye dolomite than anhydrite.

Argillaceous Micrite

Argillaceous micrite varies in color from yellowish green, dark yellowish to dusky brown, or olive to dark gray. Structurally, this facies is very similar to the micrite facies. In addition to interbedded and cross-laminated units, this facies is highly mottled (Figure 9) and displays cryptalgal laminations (Figure 10). In NDGS Well 793, sediments rich in intraclasts and clays have accumulated in deposits 20 feet (6 meters) thick.

Laminations are approximately 1 mm thick, with entire beds ranging in thickness from 0.5-1.0 cm. Clays and pyrite grains also contribute to the distinctness of laminations. Cross-laminated units may be as thick as 9 cm. Intraclasts are a common allochem and vary in size from 0.5-2.5 cm.

Secondary features are anhydrite, micro-faulting, and water escape structures (Fig. 10 and 11). Some structures in the Three Forks Formation occur only once, for example, pattern dolomite formation, felted, lath, and blocky anhydrite, pyrite, glauconite, and hematitic clays are also present. Microspar and pseudospar occur sporadically and indicate a diagenetic change in micritic material.

Evidence for microspar, according to Folk (1965), is uniformity of fine crystal size, translucent crystals, and occurs as patches in otherwise unaltered micrite. Pseudospar evidence includes curved intercrystalline boundaries and thus a low percentage of enfacial angles between crystals, and impure crystals in which silt, clay, or organic matter is trapped

Figure 9. Mcttled structure in argillaceous micrite lithofacies. Core slab 2967-1C329.

Figure 10. Water escape and cryptalgal structures in argillaceous micrite lithofacies. Core slab 2967-10303.


0 1 2 cm
0 1 inch

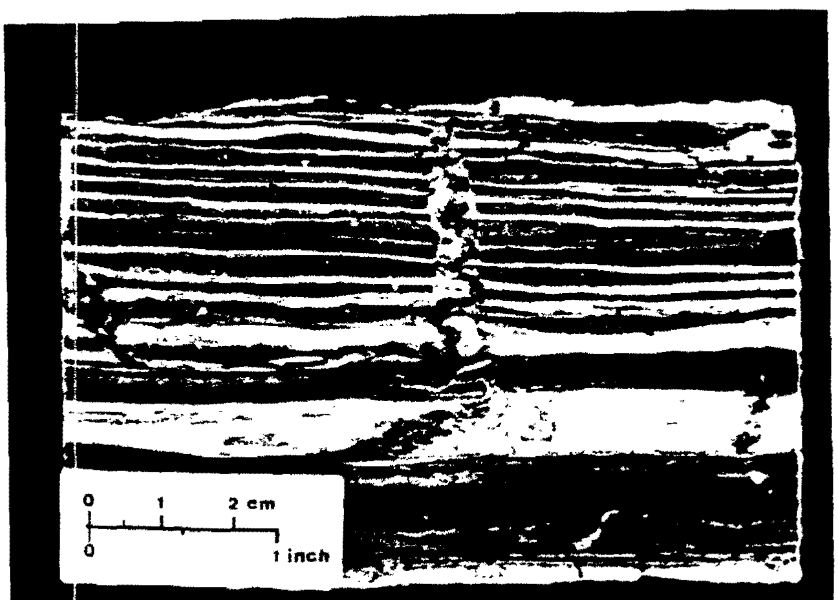

0 1 2 cm
0 1 inch

Figure 11. Micro-faulting in argillaceous micrite lithofacies. Core slab 793-10207.


0 1 2 cm
0 1 inch

Dolomicrite

Rocks of the dolomicrite lithofacies are interbedded, laminated, and mottled, and range in color from grayish green and brown to olive gray and pale yellowish brown. Intraclasts are the dominant allochem, and result from mottling and brecciation. Stylolitization was also responsible for the formation of intraclasts (Fig. 12), which vary in size from 3.0-5.5 cm. Of lesser importance is micro-faulting and water escape structures.

Other features include pyrite, quartz silt, and calcite replacement. Figure 12 also illustrates two varieties of pyrite found in this facies. Nodular pyrite ranges in size from 3-6 mm, while minute (less than 1 mm) black pyritic grains are disseminated throughout the rock. Quartz silt is a common constituent and in some instances has been replaced by calcite. At the Bakken-Three Forks contact, the quartz grain-size difference between the formations is well illustrated as in Figures 13 and 14 which also illustrate the possible unconformable contact between the formations.

Argillaceous Dolomicrite

Argillaceous dolomicrite is the most common lithofacies within the Three Forks Formation. Color varies from grayish blue green and pale yellowish brown to olive gray and grayish brown. Common sedimentary structures include interbedding, cross-lamination, mottling, brecciation, and cryptalgal laminations. Other features consist of stylolitization which has produced intraclasts, micro-faulting caused by anhydrite formation, water escape and tepee structures, and mudcracks (Fig. 15 and 16).

Figure 12. Stylolites producing intraclasts, and nodular and disseminated pyrite in dolomicrite lithofacies. Core slab 105-7604.


0 1 2 cm
0 1 inch

Figure 13. Photomicrograph of Bakken-Three Forks contact in polarized light. Quartz grains (Q). Thin Section 9351-10469.5. Dolomicrite lithofacies. Width of area shown in photograph is about 4 mm (0.16 inch).

Figure 14. Photomicrograph of Bakken-Three Forks contact in plane polarized light showing conodonts (C) and quartz grains (Q). Thin section 9351-10469.5. Dolomicrite lithofacies. Width of area shown in photograph is about 4 mm (0.16 inch).

Figure 15. Cross-stratification in argillaceous dolomicrite lithofacies. Core slab 607-10634.

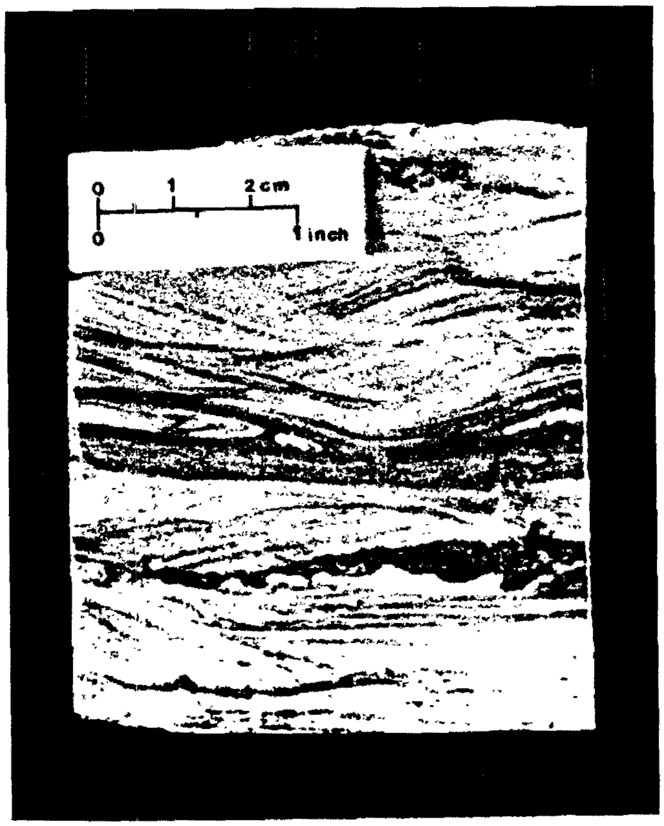
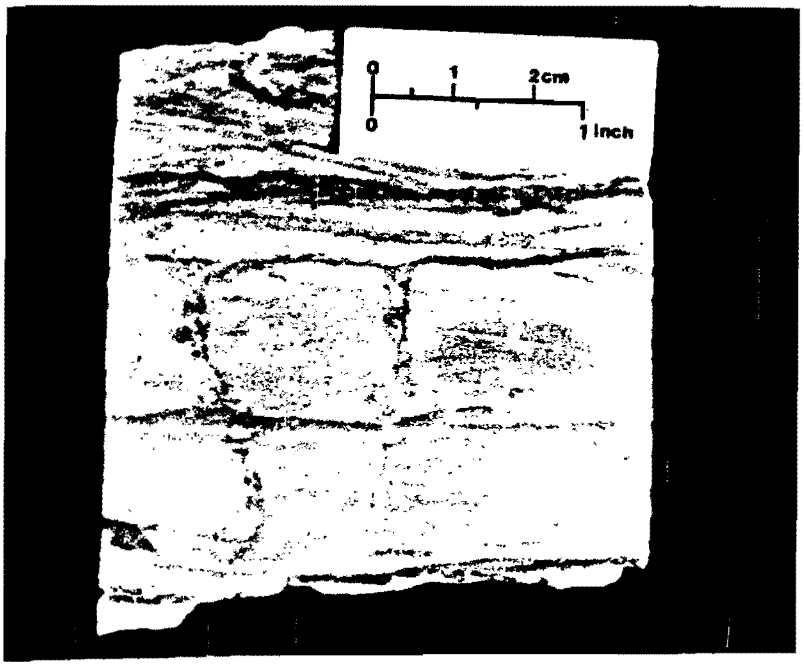
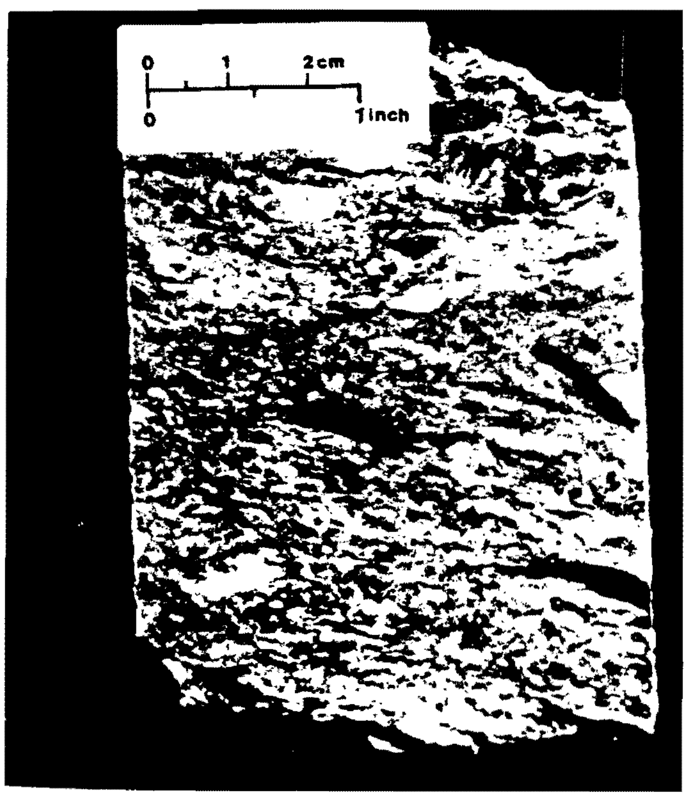

0 1 2 cm
0 1 inch

Figure 16. Mudcracks in argillaceous dolomicrite lithofacies. Core slab 793-10097.

Figure 17 Presumed storm deposit in argillaceous dolomicrite lithofacies. Core slab 793-10165.


0 1 2cm
0 1 inch


0 1 2cm
0 1 inch

This facies is unique for two reasons: 1) thick deposits of intraclast-rich sediments (Fig. 17); and 2) it contains the eight varieties of anhydrite structural types listed previously (Fig. 8). In addition to cryptalgal laminations, oncolite formation has also occurred. Common throughout the Three Forks are gradational color changes from reddish brown to grayish green (Fig. 18). This change is probably diagenetic in origin, as discussed below in the section on diagenesis. Features visible in thin section consist of cross-laminations accentuated by hematitic clays, microspar, quartz and calcite replacement, sucrosic dolomite, anhydrite, glauconite, and mudcracks (Fig. 19-22).

Argillaceous Biomicrite

The argillaceous biomicrite facies varies in color from dark brown to medium to dark gray. This facies is mottled, interbedded, and laminated. Bioturbation and to a lesser degree, stylolites are common in this facies. Stylolites have produced intraclasts which vary in size from 0.75-2.0 cm. Large geopetal-infilled brachiopods (1 cm) are shown in Figure 23. Other large fossil fragments include echinoderms which consist of ossicles and longitudinal fragments and vary in size from 1-4 mm.

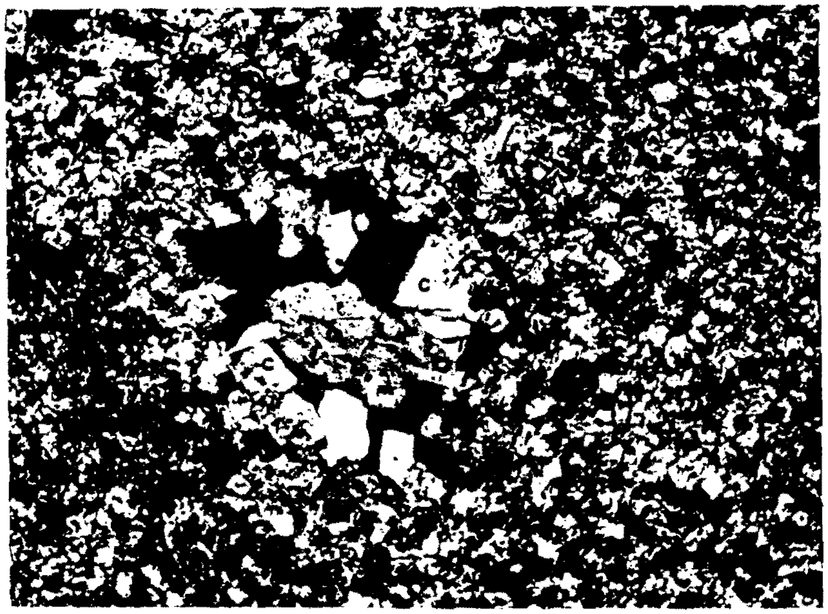
In thin section, numerous fossil fragments, stylolitization and other compaction features, and diagenetic changes can be observed. Fossil fragments include partially micritized crinoid ossicles, brachiopods, bryozoans which show compaction, ostracodes, and gastropods (Fig. 24-26). Geopetal infilling is common in the brachiopod fragments. Both shelter porosity (Fig.27) and megascopic geopetal structures show

Figure 18. Gradational color change in argillaceous dolomicrite lithofacies. Core slab 793-10238.


0 1 2cm
0 1inch

Figure 19. Photomicrograph of quartz (Q) replacement followed by calcite (C) replacement in polarized light. Thin section 956-10686.5. Argillaceous dolomicrite lithofacies. Width of area shown in photograph is about 1 mm (0.04 inch).

Figure 20. Photomicrograph of calcite-filled (C) ostracode in polarized light. Thin section 511-8949.7. Argillaceous dolomicrite lithofacies. Width of area shown in photograph is about 1 mm (0.04 inch).



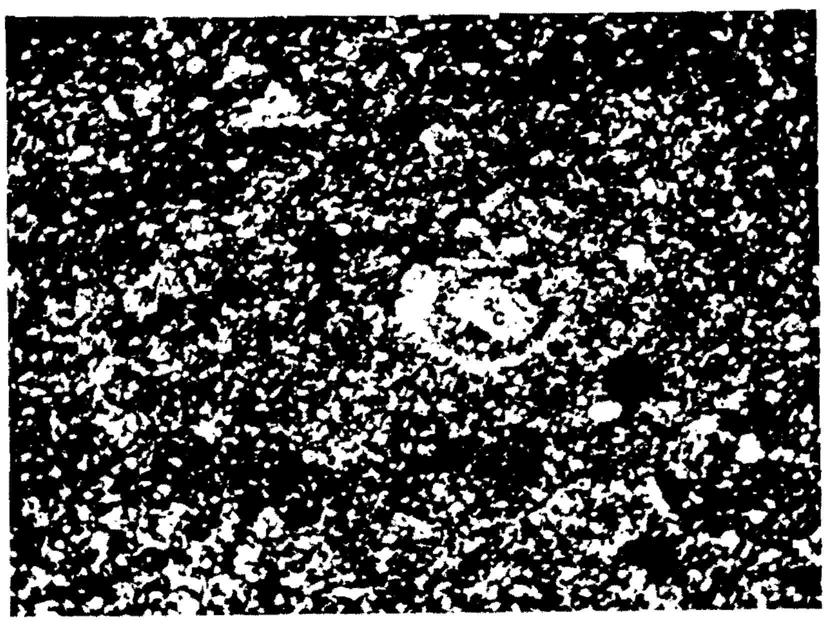
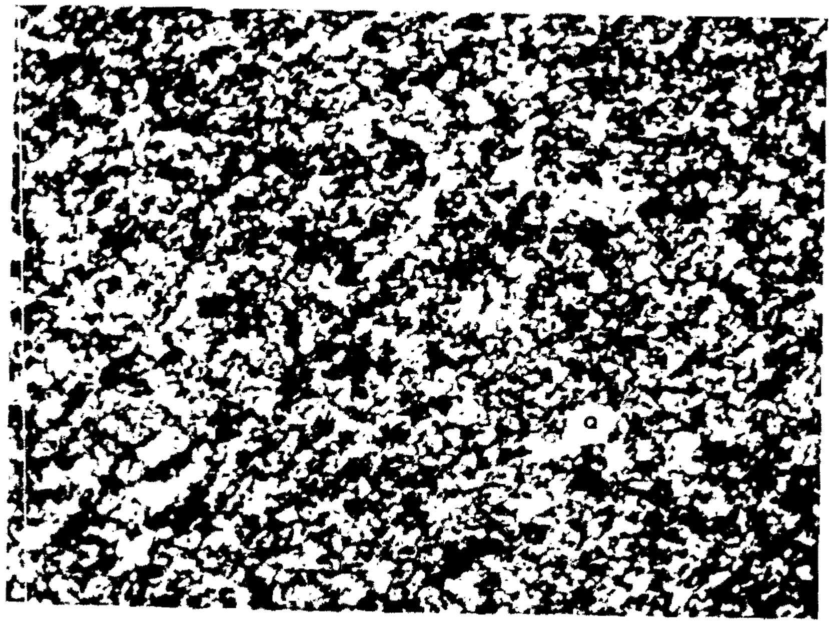


Figure 21. Photomicrograph of sucrosic dolomite in polarized light with quartz (Q) grains. Thin section 956-10687.1. Argillaceous dolomicrite lithofacies. Width of area shown in photograph is about 1 mm (0.04 inch).

Figure 22. Photomicrograph of glauconite (G) and quartz (Q) grains in sucrosic dolomite in polarized light. Thin section 511-8949.7. Argillaceous dolomicrite lithofacies. Width of area shown in photograph is about 1 mm (0.04 inch).



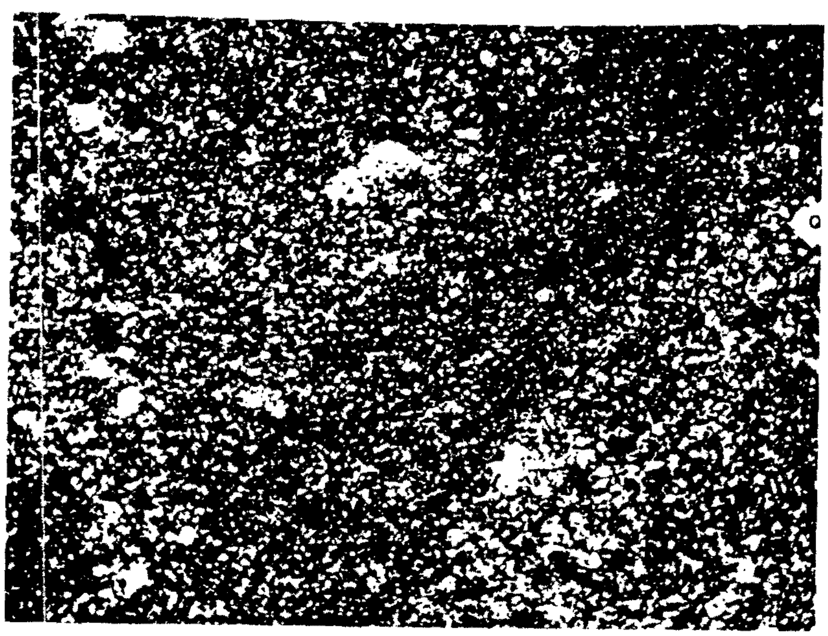


Figure 23. Geopetal infill in brachiopod shell in argillaceous biomicrite lithofacies. Core slab 607-10607.

Figure 24. Photomicrograph of crinoid ossicle showing micritization in polarized light. Thin section 527-11287.2. Argillaceous biomicrite lithofacies. Width of area shown in photograph is about 4 mm (0.16 inch).

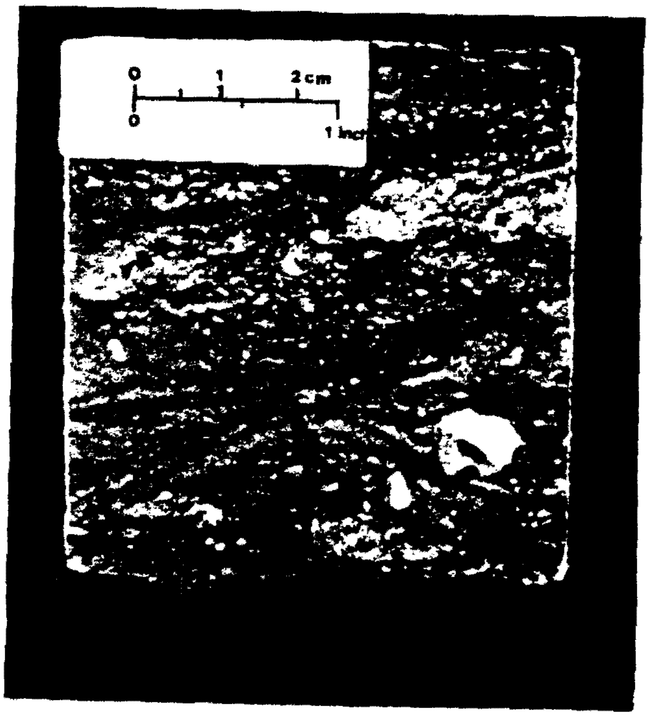

0 1 2 cm
0 1 inch

Figure 25. Photomicrograph of brachiopod fragment infilled with micrite in polarized light. Thin section 527-11287. Argillaceous biomicrite lithofacies. Width of area shown in photograph is about 4 mm (0.16 inch).

Figure 26. Photomicrograph of bryozoans showing compaction with stylolites in polarized light. Thin section 527-11287. Argillaceous biomicrite lithofacies. Width of area shown in photograph in about 1 mm (0.04 inch).

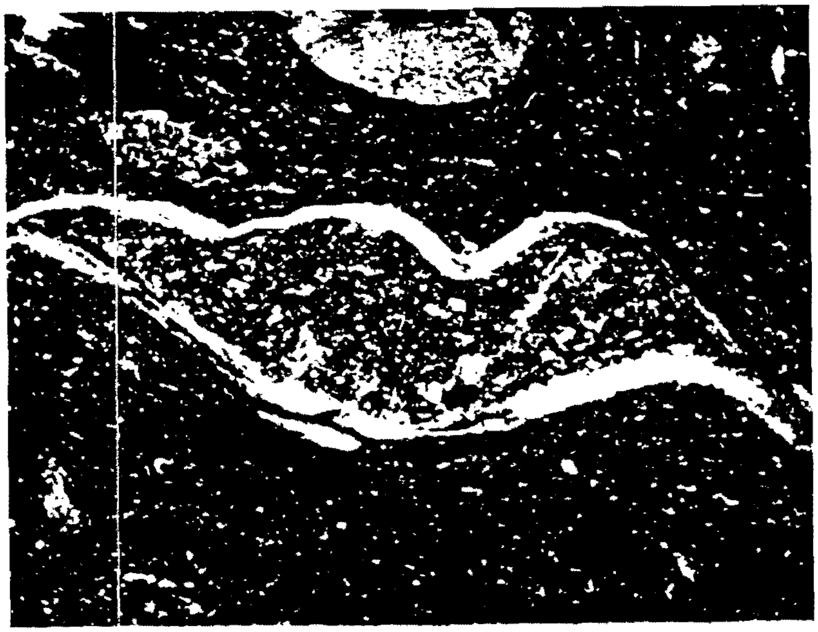
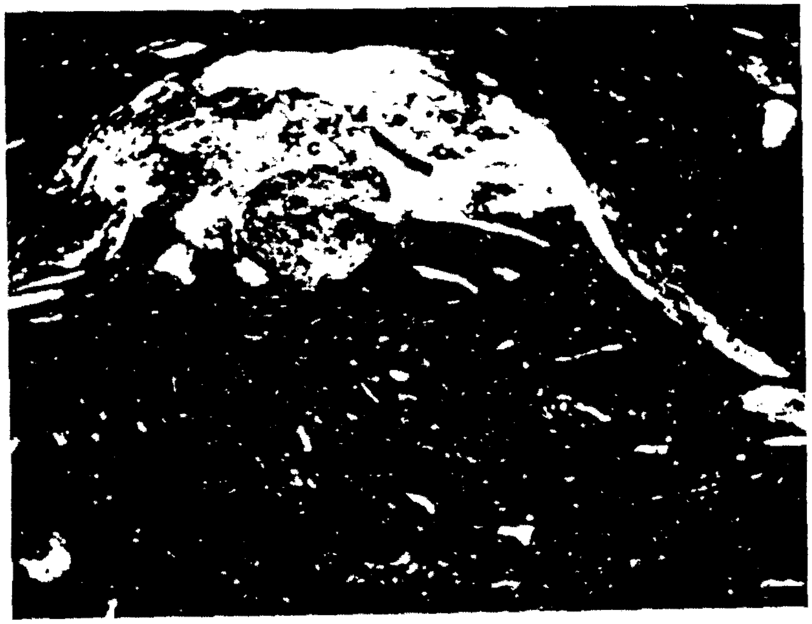


Figure 27. Photomicrograph of shelter porosity, now infilled with calcite (C), in a brachiopod fragment in polarized light. Thin section 607-10608.2. Argillaceous biomicrite lithofacies. Width of area shown in photograph is about 4 mm (0.16 inch).

Figure 28. Photomicrograph of compaction features; broken ostracode (O) valves and minor realignment of fossil fragments in polarized light. Thin section 607-10608.2. Argillaceous biomicrite lithofacies. Width of area shown in photograph is about 2.5 mm (0.10 inch).



calcite recrystallization. Broken ostracode valves and the realignment of fossil debris attests to the fact that compaction occurred (Fig. 28).

Diagenetic occurrences are the most common in this facies and Figures 29 and 30 display several of these features. These are: 1) calcite recrystallization of fossil fragments; 2) recrystallization of sparry calcite (micrite) to pseudospar; 3) chalcedony replacement of fossils; and 4) calcite recrystallization of fossil fragment to pseudospar followed by micritization.

Figure 29. Photomicrograph showing calcite (C) recrystallization to pseudospar which in turn is being replaced by chalcedony (Ch) in polarized light. Thin section 1606-10965.7. Argillaceous biomicrite lithofacies. Width of area shown in photograph is about 4 mm (0.16 inch).

Figure 30. Photomicrograph showing recrystallization of brachiopod fragments in polarized light. Thin section 527-11287.2. Argillaceous biomicrite lithofacies. Width of area shown in photograph is about 4 mm (0.16 inch).

DEPOSITIONAL ENVIRONMENTS AND DIAGENESIS

Introduction

Environmental interpretations of the lithofacies within the Three Forks Formation are the result of a detailed core and petrographic study of Three Forks rocks. The facies model selected best represents the data accumulated in this study as compared with information published on modern and ancient carbonates. Deposition of sediments which comprise the Three Forks occurred in an epeiric sea which extended throughout North Dakota and into surrounding areas. In the past, shallow seas covered much of the continental interiors (Hallam, 1981, p. 90). Since no epeiric seas exist today, marginal marine settings are used as the standard in interpreting data, even though these environments may have been very different.

The most obvious difference between epeiric and marginal seas is dimension, and hence facies extent. Epeiric seas had dimensions of an entirely different order of magnitude; Shaw (1964, p. 4) stated that epeiric seas had an extent which was some multiple of that found in marginal seas. From the foregoing statement, it would be reasonable to assume that rocks of the same sedimentary type would be deposited over vast areas. Consequently, facies within epeiric seas would not only be of great areal extent, but would develop in broad lateral bands (Shaw, 1964, p. 13).

Another dissimilarity between epeiric and marginal seas is the difference in bottom slope. Shaw (1964, p. 5) in assuming that epeiric sea depths of the past reached 90 feet (27 meters) over thousands of square miles (thousands of square kilometers), calculates the average slope would range from 0.1 to 0.3 feet per mile (0.02 to 0.06 meters per kilometer). These values range well below those of marginal seas which are 2 to 10 feet per mile (0.4 to 2.0 meters per kilometer). The steepness of the slope of the bottom surface thus limits the water depth. Because of low overall bottom slopes envisioned for epeiric seas, even small irregularities in topography would have disproportionately large effects on water depth and also on sedimentation.

Currents, such as those in open oceans, could not exist in epeiric seas. The shallowness of the seas would dissipate the energy due to friction on the bottom surface. "Epeiric-size" currents would have been created by winds. These prevailing winds, if persistent enough, would have a marked effect on orienting sedimentary structures (Shaw, 1964, p. 10). Even currents and waves generated some distance offshore would dissipate their energy before reaching the shore. Thus vast expanses of sediment would be subject to little, if any, disturbance due to waves generated in distant areas. The only effective water energy in epeiric seas would be that of locally generated wind waves (Hallam, 1981,p. 91).

Tides generated in the open ocean, and thus affecting the epeiric sea connected to it, would probably not be sufficient enough to influence the entire extent of an epeiric sea, to its shoreline. Thus in a similar manner as currents, tides would be reduced by friction with the bottom surface and dissipate their energy a great distance from shore (Shaw, 1964) or, if extensive enough, that the tidal range would be reduced almost to zero at the shorelines remote from the open ocean (Hallam, 1981).

From a study done in Florida Bay, Ginsburg (1956) notes that, due to shallowness, there is an area which is out of range of tidal influence. In this restricted area, tides are caused by the piling-up of waters due to the influence of the wind. Shaw (1964, p. 7) states, that due to shallow water conditions in an epeiric sea extending much further inland than do the waters of Florida Bay, that tides would not exist except for the piling-up effects of wind. It is possible that resonance alone would guarantee some tidal activity in an epeiric sea, but this would cause the most shoreward zone to be very narrow or non-existent (Hallam, 1981, p. 94). In general, tidal activity in an epeiric sea would be limited by friction, and would thus create a zone of impingement behind which a large expanse of sea would be limited to the influence of wind-induced waves.

In an epeiric sea setting, the existence of tides is questionable. Hedgpeth (1957), in dealing with terminology used in classifying marine environments stated that terms such as supratidal, intertidal, and subtidal inferred the presence of tides. Even though these terms are presently used in carbonate writings, this writer agrees with Hedgpeth that tidally-related terms should not be used when discussing depositional environments and sedimentation in epeiric seas. Since wind-driven waves and currents are the probable major influence in epeiric seas, the terms supralittoral, littoral, and sublittoral will be utilized in this paper.

The supralittoral zone is considered to be that area above the average high position of the strandline and which encounters marine waters only during storms. Since sediments in this zone are subaerially exposed the majority of the time, common features are desiccation cracks, evaporites, and cryptalgal laminations. The littoral zone is that area between the normal high and low fluctuations of the strandline. Due to the low angle of the bottom slope, this zone could have been many miles wide. Sediments in this zone would be reworked by waves and any fauna which was present, thus making laminations a less common feature. Between the lowest supralittoral and highest littoral zones would lie the littoral flat complex. Seaward of the lowest littoral zone and constantly submerged is the sublittoral zone (Shinn, 1983). As it is less influenced by terrigenous influx and of more normal salinity than landward areas, a normal marine fauna could exist in this zone. Features of the sublittoral facies are dependent upon their stratigraphic position relative to average wave base. Low-energy conditions would affect those sediments below average wave base, while sediments above average wave base would be affected by higher energy conditions.

Environmental interpretations of the aforementioned lithofacies will be discussed in the order in which they were described. Due to fluctuations in water depth and thus of the influx of terrigenous material during low water levels, or as a result of shoreline migration, it is not possible to discuss these facies in a stratigraphic sense or in order from deepest to shallowest environments, as fluctuation of the water depth has produced an interbedded succession of these five lithofacies types.

Environmental Interpretations

Micrite

The depositional environment of the micrite lithofacies is interpreted as a predominantly low-energy environment. Characteristic of this facies are thin, smooth, flat to very gently undulating, parallel to sub-parallel laminae. The lighter-colored laminae are more silty than the darker-colored laminae, and form cross-beds.

Cross-stratification is indicative of substantial hydraulic flow. The degree of steepness in bedding planes also implies significant water energy. The concentration of water energy within channels of the littoral zone or within the littoral flats could be sufficient enough to produce cross-stratification. Regardless of depth, all channels will become shallower in a landward direction until they disappear (Shinn, 1983, p. 193).

Sheetwash on littoral flats or in the littoral zone produces horizontal stratification. Wind-induced waves or storm-induced flooding are both capable of producing sheets of water (Hardie and Ginsburg, 1977). Algal mat surfaces are excellent collection sites for sediments and form laminations, but these are not present in this lithofacies.

Burrowing and bioturbation are probably responsible for the absence of laminations in some parts of this facies. The almost complete absence of anhydrite is also an indication that this facies was not formed in a subaerially exposed environment.

<u>Argillaceous Micrite</u>

Rocks of the argillaceous micrite lithofacies are similar to rocks of the micrite lithofacies, except that this facies displays cryptalgal laminations and thick deposits of intraclast-rich sediments. These constituents suggest that deposition occurred in a littoral flat complex.

Deposition within the highest littoral to lowest supralittoral zone would allow for the formation of cross-stratification within runoff channels, for the deposition of storm deposits, and for the formation of cryptalgal laminations. As a result of intense storms, surges of water coming in toward the shore could easily tear up the bottom surface of an epeiric sea. As the storm surge would again impinge upon the bottom, it would disrupt the sediment producing rip-up clasts and lag deposits. Algal mats act as collection sites for sediments carried in by waves. Thin horizontal laminae form when sediment becomes entrapped in the mucilaginous secretions of algae (Wilson, 1975, p. 82). In arid climates, algal mats can form in the upper littoral zone and extend into the supralittoral zone (Shinn, 1983). Many criteria are used in recognizing cryptalgal laminations (Aitken, 1967). Probably the most important characteristics are that the laminations are not explainable as due to settling of sediment and that there is an encrusting relationship between the laminae and the underlying surface.

Characteristic of high littoral and low supralittoral environments are desiccation features, such as mudcracks and birdseye dolomite (Shinn et al., 1969; Lucia, 1972). These features are absent within this lithofacies of the Three Forks. According to Kinsman (1969) and Hardie and Ginsburg (1977), intraclasts are common within this depositional zone. The formation of anhydrite is further evidence for deposition within the supralittoral zone (Butler, 1969). In the Persian Gulf, evaporites also form in the upper littoral zone, largely preventing burrowing by organisms (Shinn, 1983).

Thus, the evidence which points to deposition within the littoral flat complex is the presence of cross-stratification, cryptalgal laminations, anhydrite, and the paucity of fauna. The occurrence of intraclast-rich sediments would indicate storm deposits or periods of intense energy.

Dolomicrite

The dolomicrite lithofacies is interpreted as having been deposited in a supralittoral environment. Along the Trucial Coast, in the Persian Gulf, Butler (1969) found carbonate mud, subsequently altered to dolomite, to be a dominant feature in the supratidal environment. The Manlius Formation (Lower Devonian) of New York is considered by LaPorte (1967; 1969) to be indicative of a supratidal environment, based on the presence of non-fossiliferous, laminated, dolomitic carbonate mudstone. Shearman (1973, p. 9) also noted that supratidal sediments consist of aragonite muds that are washed in from the lagoonal area by high spring tides or storms. In the Persian Gulf, studies have shown that aragonite mud in lagoons did not originate from abraded skeletal material, but that blue-green algae were responsible for precipitation of non-skeletal aragonite (Kendall and Skipwith, 1969).

Seawater which washes in during spring tides and storms is concentrated by evaporation and precipitates evaporite minerals, such as gypsum and anhydrite. This precipitation causes the Mg^{++}/Ca^{++} ratio to increase, which in turn, causes the dolomitization of pre-existing aragonite and calcite by the reaction (Butler, 1969, p. 71):

$$\underset{\text{sediment}}{2CaCO_3} + \underset{\text{brine}}{Mg^{++}} = \underset{\text{dolomite}}{CaMg(CO_3)_2} + \underset{\text{brine}}{Ca^{++}}$$

The reason for the lack of evaporite minerals, such as anhydrite, in this lithofacies is unclear, although the argillaceous dolomicrite facies is characterized by abundant anhydrite of numerous anhydrite types.

Other features are intraclasts, which are common in supralittoral zones (Kinsman, 1969; Hardie and Ginsburg, 1977; Shinn, 1983), and quartz silt. Silt-size quartz particles were probably transported into this environment by air currents. Heckel and Witzke (1979, p. 104) state that the great amount of quartz silt found in Devonian carbonates may have been carried in by the trade winds from the emergent part of the craton.

In summary, sediments of the dolomicrite lithofacies were probably deposited in the supralittoral environment. Evidence includes non-fossiliferous, laminated, dolomitic carbonate muds. Intraclasts are the dominant allochem, and are probably, at least in part, due to brecciation.

rather than enlargement of existing crystals. The crystals are usually lath-shaped, having a sub-parallel alignment (Shearman, 1978, p. 16). With compaction, distorted and bedded varieties of anhydrite occur.

Argillaceous Biomicrite

This lithofacies, composed mainly of dark gray, thick bedded to massive micrite with fragmented and disarticulated remains of a variety of fossils, represents the sublittoral environment. Argillaceous material is extremely abundant, suggesting the absence of strong current or wave action which would remove fine particles. However, the presence of abraded and disarticulated fossil remains may indicate that they were brought in from a more seaward environment.

There is abundant bioturbation and mottling throughout the facies, and the absence of laminations is indicative of burrowing organisms. In the supralittoral environment, algal mats and the settling out of sediment produces stratification, which is preserved because of the absence of burrowing organisms. Current action in the littoral environment, having a greater effect than the reworking by organisms, results in the preservation of stratification. The relatively higher rate of burrowing in the sublittoral facies obliterates any stratification formed by wave or current action (LaPorte, 1967, pp. 86-87), or any storm-deposited layers (Shinn, 1983, p. 179).

Brachiopods, bryozoans, and echinoderms comprise a fauna which is indicative of a sublittoral environment of normal salinity (Heckel, 1972, p. 234). This fossil assemblage has a restricted salinity and temperature tolerance. Ostracodes and gastropods possess a greater tolerance for fluctuations in salinity and temperature and are found in many environments (Heckel, 1972).

A major problem of environmental interpretations from fossil assemblages is that of fossil transport. According to Heckel (1972, p. 235) transport of large fossils is indicated by broken and abraded fragments. Disarticulation does not necessarily suggest transport, since disarticulation can occur in quiet water environments. On the other hand, microfossils are much more difficult to fragment and abrade.

Disarticulation which has occurred, is evidenced by single ostracode valves, crinoid, and echinoderm fragments. The abundance of argillaceous material and both microscopic and megascopic geopetal structures again indicate deposition in a quiet water environment. Since the majority of fossils in this facies represent a normal salinity environment, this facies is interpreted as having been deposited in a low-energy sublittoral environment. The dark grayish color of this facies is also similar to the sediments in the subtidal lagoons along the Trucial Coast (Reading et al., 1978; Shinn, 1983).

Heckel (1972, p. 237) devised a modern distribution scheme of major nonvertebrate groups relative to water depth. The distribution of the aforementioned fossils fall within the subtidal water depth as given by Heckel. Both the gastropod and ostracode fauna can range over a variety of environments, according to this scheme, indicating their adaptability to temperature and salinity fluctuations.

Depositional Model

Tidal flats and their lagoonal counterparts, according to Hardie (1977), are subject to the widest range of environmental conditions, and consequently display the widest variety of sedimentary structures and diagenetic features found in carbonate rocks. These deposits are sensitive to many variables; the sedimentary record indicates that no two tidal flat deposits, either ancient or modern, are very similar. This point is clearly stressed in a casebook of modern and ancient siliciclastic and carbonate tidal flats edited by Ginsburg (1975). This dissimilarity is emphasized in modern tidal flats that are protected by barrier islands producing interbedded sequences of mud and sand (Reineck, 1972), and those marginal to river deltas forming interbedded silt and clay sequences (Thompson, 1975). Kahle and Floyd (1971, pp. 2092-2093), working with Cayugan (Silurian) tidal flat carbonates in Ohio, demonstrated the overlapping of diagnostic features of specific tidal flat sub-environments, especially supratidal and intertidal.

Evidence from modern carbonate environments, such as the Bahamas, Shark Bay, and the Persian Gulf, is useful when studying ancient carbonate environments. Numerous authors (Braun and Friedman, 1969; Clifton, 1983; LaPorte, 1967; 1969; Lucia, 1972; Matter, 1967; Roehl, 1967; Wilson, 1975) list criteria which are indicative of supralittoral (Table 1), littoral (Table 2), and sublittoral (Table 3) environments. Models for tidal flat deposition have been used to recognize ancient tidal flat deposits and to estimate paleotidal range (Klein, 1971).

Studies of modern tidal flat sediments indicate that the smallest differences in environmental conditions are recorded in the sediment

Table 1. Criteria indicative of supralittoral environments.

Supralittoral Environment

Roehl (1967)	laminated dolomite algal mats
LaPorte (1967;1969)	laminated, dolomitic carbonate muds mudcracks scarcity of fossils birdseye structures algal mat laminations possible burrows
Braun and Friedman (1969)	mottled and laminated dolomite birdseye textures undulating stromatolitic structures absence of fossils
Lucia (1972)	irregular laminations lithoclasts desiccation features quartz silt scarcity of fossils

Table 2. Criteria indicative of littoral environments.

Littoral Environment

Roehl (1967)	argillaceous burrows
LaPorte (1967;1969)	pelletal carbonate muds few fossil types, but abundant individuals cross-stratification organo-sedimentary structures (algal stromatolites) few mudcracks thin bedding quartz silt and argillaceous partings few burrows
Braun and Friedman (1969)	mottled, dolomitic muds mudcracks cross-bedding shale stringers sporadic birdseye texture abundant fossil fragments
Lucia (1972)	distinct burrows wispy-mottled structures quartz silt algal stromatolites fractures few fossils cross-stratification (in channels)

Table 3. Criteria indicative of sublittoral environments.

Sublittoral Environment

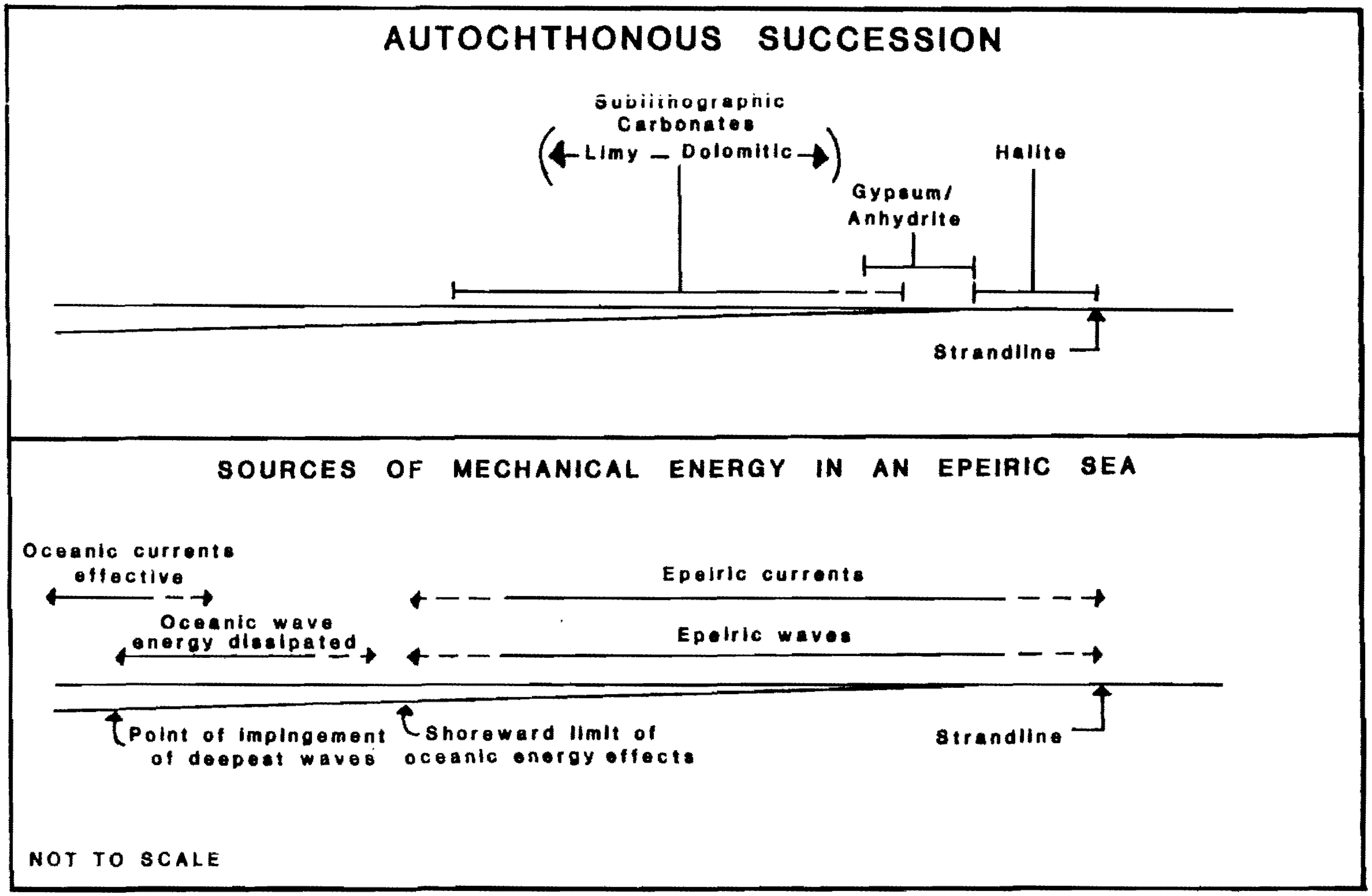
Roehl (1967)	churned rocks bioclastic rocks
LaPorte (1967;1969)	skeletal, pelletal, carbonate muds diverse fossil biota abundant burrow-mottling absence of stratification
Braun and Friedman (1969)	biomicrite abundant skeletal fragments intraclasts
Lucia (1972)	burrowed, churned rocks abundant fossils cross-stratification (in channels)

record. Minor surface elevation differences in these environments result in major differences in frequency of exposure and in sedimentary structures such as laminations, mudcracks, and burrows (Ginsburg et al., 1977). This would be consistent with sedimentary facies distributions related to water energy and water circulation within shallow epeiric seas (Figure 31).

Variations in sedimentary facies patterns in epeiric seas are the result of many factors, of which one is fluctuating water levels. The finer fractions of allochthonous sediments can be easily transported into epeiric seas. Rivers may have been the transporting mechanism for argillaceous material in the Three Forks, though it is more plausible that progradation caused by a fluctuating strandline is responsible. If the supply of argillaceous material were great enough, allochthonous sediments could be easily spread across an extensive area of an epeiric sea.

Dominant water movement in the beginning of flood tides is essentially perpendicular to the shoreline (Evans, 1965, p. 213). If tidal influence or resonance did extend to the shoreline in the form of piled up waves, then argillaceous material could easily be transported back into the deeper portions of the epeiric sea as the waves receded. In the littoral zone of epeiric seas, channels are created by water flow and these may be responsible for bringing argillaceous material from more landward areas into deeper water zones. Kent (1964, p. 66) stated that the source of argillaceous material for the Three Forks Formation and equivalent strata is the Cambridge Arch and Transcontinental Arch. The lateral and vertical variability of lithofacies in the Three Forks

Figure 31. Mechanical energy in an epeiric sea and resultant sedimentary facies (Modified after Shaw, 1964).

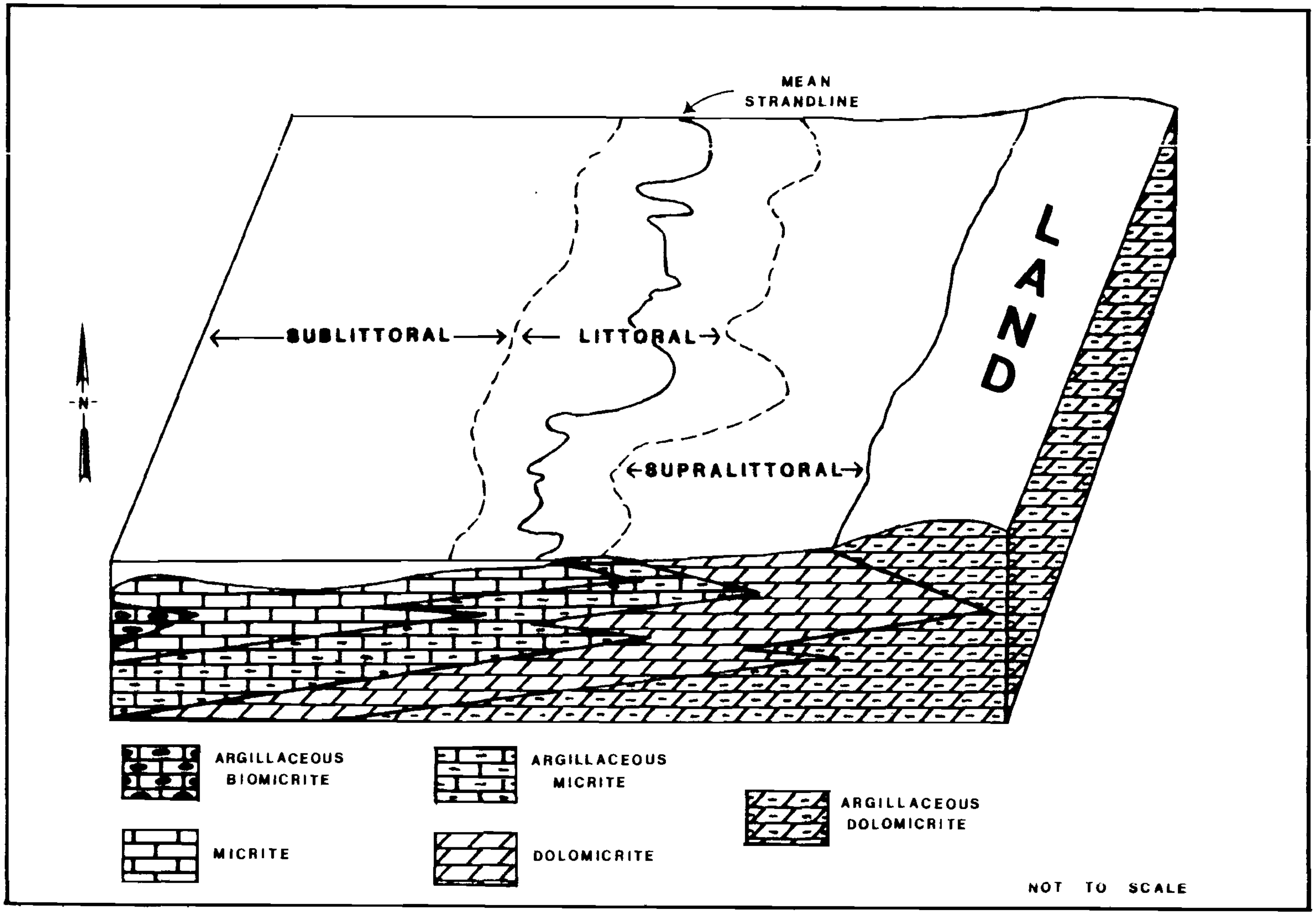

AUTOCHTHONOUS SUCCESSION
Sublithographic Carbonates
Limy — Dolomitic
Halite
Gypsum/ Anhydrite
Strandline
SOURCES OF MECHANICAL ENERGY IN AN EPEIRIC SEA
Oceanic currents effective
Epeiric currents
Oceanic wave energy dissipated
Epeiric waves
Point of impingement of deepest waves
Shoreward limit of oceanic energy effects
Strandline
NOT TO SCALE

is thus due to water fluctuation and progradation which makes detailed correlation a difficult task.

Consequently, the depositional model for the Three Forks Formation consists of the development of supralittoral and littoral zones and a low-energy sublittoral zone in an epeiric sea setting (Figure 32). The lateral shifting of these environments and thus the resultant vertical succession of rock is caused by a fluctuating strandline. As the water depth would decrease, a regressive sequence would form and progradation of the shoreline would bring in argillaceous material. As the water level would rise, transgressive conditions would occur and the influx of argillaceous material would cease. This model allows for the formation of evaporites on the periphery of the basin and carbonates within the deeper portions. It is similar to the depositional environment of the Devonian Stettler Formation in Canada, in that limestones formed in the basin center and evaporites on the periphery, and it also has a modern analog in the Arabian Gulf (Fuller and Porter, 1969).

Characterized by a high argillaceous content, the sublittoral zone was a quiet water, low energy environment. The abundance of clay particles and disarticulated fossil remains indicates that low energy conditions prevailed in this environment (argillaceous biomicrite lithofacies). Gastropod shells comprise the only intact fossils, though this may be due to their small size. The lower littoral zone, a slightly higher energy environment, would allow the formation of cross-stratification in channels and thin, mainly flat, laminae elsewhere. Higher energy conditions may be responsible for the absence of argillaceous material, though terrigenous influx would probably not have

Figure 32. Depositional model for Three Forks Formation.


MEAN
STRANDLINE
SUBLITTORAL
LITTORAL
SUPRALITTORAL
LAND
N
ARGILLACEOUS
BIOMICRITE
ARGILLACEOUS
MICRITE
ARGILLACEOUS
DOLOMICRITE
MICRITE
DOLOMICRITE
NOT TO SCALE

occurred during transgressive conditions (micrite lithofacies). Sediments deposited in the high littoral and low supralittoral areas (argillaceous micrite lithofacies) display cryptalgal laminations, intraclasts, cross-stratification, and paucity of fauna. A decrease in water depth is interpreted from increased clay content. Higher energy conditions are indicated by channel cross-bedding and intraclasts. Rocks of the supralittoral environment (dolomicrite lithofacies) are non-fossiliferous, laminated, dolomitic muds. Intraclasts, a common feature, are interpreted as having been brought in by storm waves which could have covered a great expanse of the supralittoral zone. The expanse to be covered by storm waves would have been increased since water levels, during deposition of these sediments, were at or near their highest position. Intraclasts may have been derived from either the littoral zone or from brecciation occurring on the supralittoral region. With arid conditions prevailing in the supralittoral environment, evaporite minerals were precipitated. In sediments deposited away from the strandline, desiccation features formed and fossils were absent (argillaceous dolomicrite lithofacies). Intraclasts are abundant and indicate high energy conditions for at least part of the time. Algal mats formed, and argillaceous sediment could have been carried in by waves from the littoral zone or prograded in from more landward areas during the fluctuating level of the strandline.

Of major importance in this depositional model are the extreme fluctuations of the strandline. In response to changing positions of the strandline, lateral migration of major environments occurred and significant quantities of allochthonous material were brought in and dispersed over a vast region. This model allows for these lithofacies to develop contemporaneously in laterally adjacent environments and yet permits the vertical succession of rock to display both regressive and transgressive qualities, based on the presence or absence of argillaceous material.

There is a significant difference between depositional models for tidal flat sediments accumulated in temperate regions and those in hot, arid climates. In the geologic record, temperate tidal-flat deposits can be distinguished by the predominantly sandy facies and negligible evaporite deposits (Thompson, 1975). Where barrier island development is insignificant, tidal deposits would consist of silts and clays, and include abundant evaporites due to the arid climate.

Sediments deposited in modern arid settings most closely resemble those in the Three Forks Formation. The most obvious differences between these two depositional settings and their resultant sediments are (Thompson, 1975, p. 64): 1) silts and clays deposited from suspension are found in the sublittoral and lower littoral zones, rather than cross-bedded sands; 2) on the littoral flats, laminations and bedding are horizontal, rather than lenticular or flaser bedded; and 3) due to the predominance of silt and clay, fining-upward sequences are lacking.

Storm deposition is a characteristic feature of many modern carbonate environments (Hardie and Garrett, 1977). Extremely high water levels and onshore storms are the primary cause for inundation of supralittoral areas. Studies have shown that littoral flat sediments are derived from adjacent seaward environments (Shinn et al., 1969). In shallow epeiric seas, storm effects would have a significant effect on sublittoral zones. As the storm waves impinge on the sea bottom, rip-up clasts would be produced by the disruption of the sediment. These intraclasts and suspended sediments would then be transported into the littoral and supralittoral zones.

Storms play a major role in forming thin, coarse-grained beds in fine-grained subtidal facies and also fining upward sequences in open-shelf facies (Kreisa, 1981). In the Three Forks Formation, storm deposits consist of small to large, angular intraclasts in a muddy, argillaceous matrix. The occurrence of storm deposits like those in the Three Forks suggest high energy conditions (Kinsman, 1969). Sedimentation by storms is a major depositional process across broad shelf environments (Kreisa, 1981, p. 824) and probably also affected sedimentation in shallow epeiric seas. In the Three Forks Formation these storm-generated features have accumulated and been preserved on the littoral flat and supralittoral zones.

Another feature in the Three Forks is the occurrence of quartz silt which may have been transported into the environment by trade winds coming off the emergent part of the craton. The quartz grains are present throughout the Three Forks, but also occur as local accumulations in western North Dakota, and have been informally named the "Sanish Sand". These fine silts occur erratically and are not continuous for any great distance. The presence of carbonate mud and burrowing implies a low energy environment, and may indicate deposition as sand bars in shallow water (Kume, 1963, p. 34).

Depositional History

Introduction

Sedimentary environments and their resultant mosaic pattern of lithofacies are influenced by tectonic elements and their relative activity in the sedimentary source and depositional areas (Dineley, 1979). As a result of plate convergence, epeirogenic warping of the continents, and eustatic rise in sea-level, major transgressive and regressive cycles occurred which controlled sedimentation on continental margins and throughout the interior of the cratons (Johnson, 1971). These cycles of transgression and regression in epeiric seas between the continental margins and cratonic centers produce sequences of strata (i.e., the intracratonic sequences of Sloss, 1963) which are separated by major unconformities.

Throughout the Devonian Period, the Canadian Shield was the exposed cratonic nucleus of the continent. One of the most prominent negative elements of the craton during Paleozoic time was the Williston Basin (Sloss, 1950, p. 426). The Williston Basin area was connected with the geosynclinal area by a narrow, east-west trending zone called the Central Montana trough. Local warping of the craton influenced sea-level changes, and in Late Devonian time the Kaskaskia transgression covered much of the continental interior (Dineley, 1979). Thus from west to east there existed normal marine conditions in the Cordilleran geosynclinal area grading into very shallow water depths in epeiric seas, producing carbonates, restricted conditions for evaporite deposition, and leaving exposed areas to supply terrigenous sediments (Sloss, 1953).

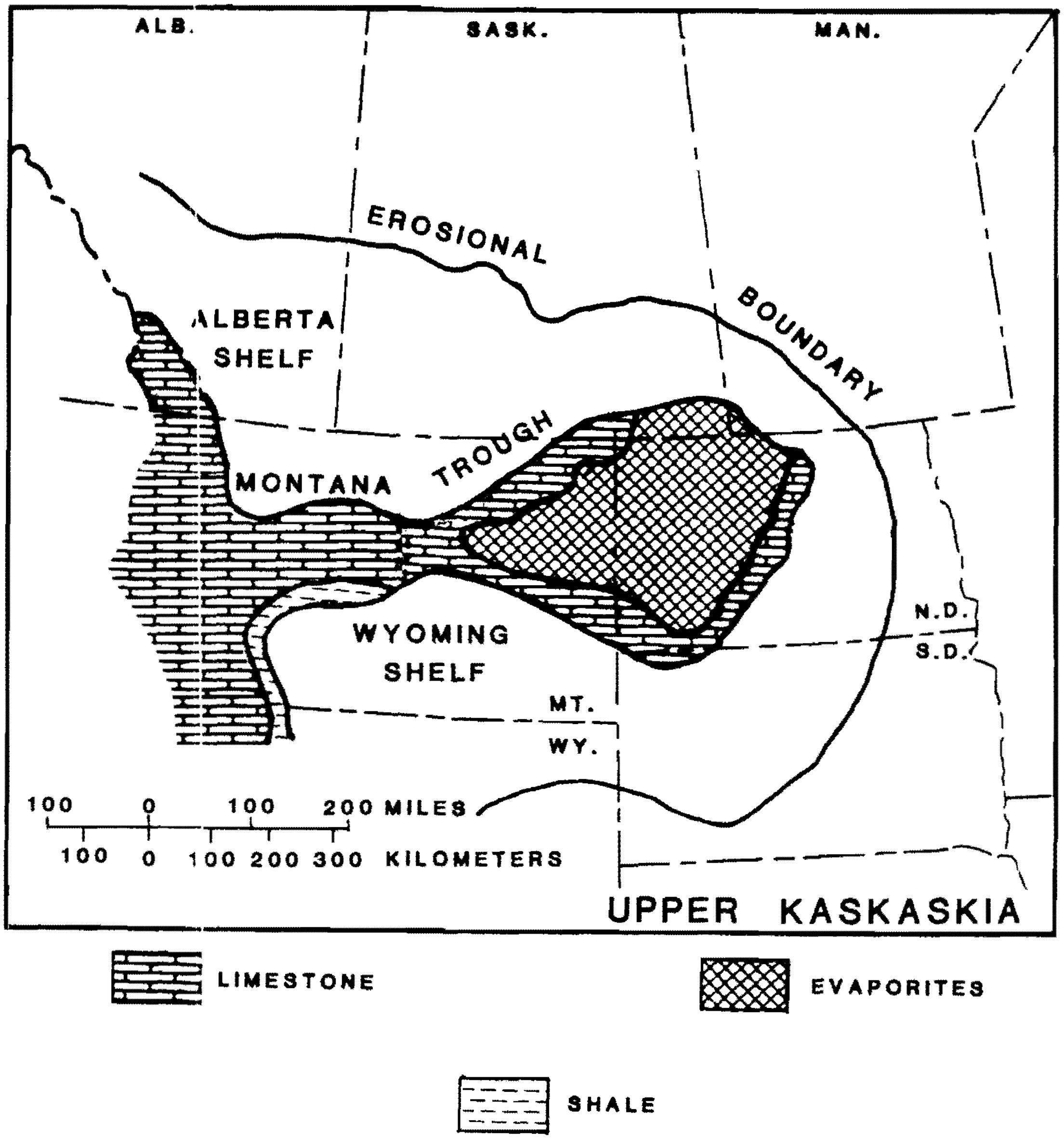
During the Early Devonian, renewed uplift along the Transcontinental Arch tilted the Williston Basin northward, causing the connection with the Elk Point Basin. The regional geologic setting changed in late Middle to Late Devonian time. A seaward connection to the Cordilleran geosyncline through the Central Montana trough was established with the subsidence of the Transcontinental Arch (Gerhard et al., 1982, p. 999; Figure 33). Thus, the initial transgression of the epeiric sea came from the westward connection to the Cordilleran geosyncline. It is this communication between the Williston Basin and Cordilleran geosyncline that makes plausible the extreme fluctuations of the strandline in the depositional model of the Three Forks and thus the influx of argillaceous material on three sides. Occasional surges of marine waters through the Central Montana trough brought in nodules of algal origin, oncolites, and crinoid and brachiopod debris (Gutschick, 1964, p. 176).

Depositional History

Epeiric seas extended far into continental interiors, were of large areal extent, had low average bottom slopes, and extreme shallowness of waters which was sufficient to restrict or eliminate circulation (Shaw, 1964, p. 5; Irwin, 1965). These factors, along with tectonic activity and variations in local topography, controlled sedimentation in epeiric seas.

The average bottom slope in epeiric seas probably ranged from 0.1 to 0.3 feet per mile (0.02 to 0.06 meters per kilometers) (Shaw, 1964, p. 5). Due to shallow water depths and gentleness of bottom slope, any

Figure 33. Seaward connection of the Williston Basin to the Cordilleran Geosyncline through the Central Montana Trough (Modified after Gerhard et al., 1982).

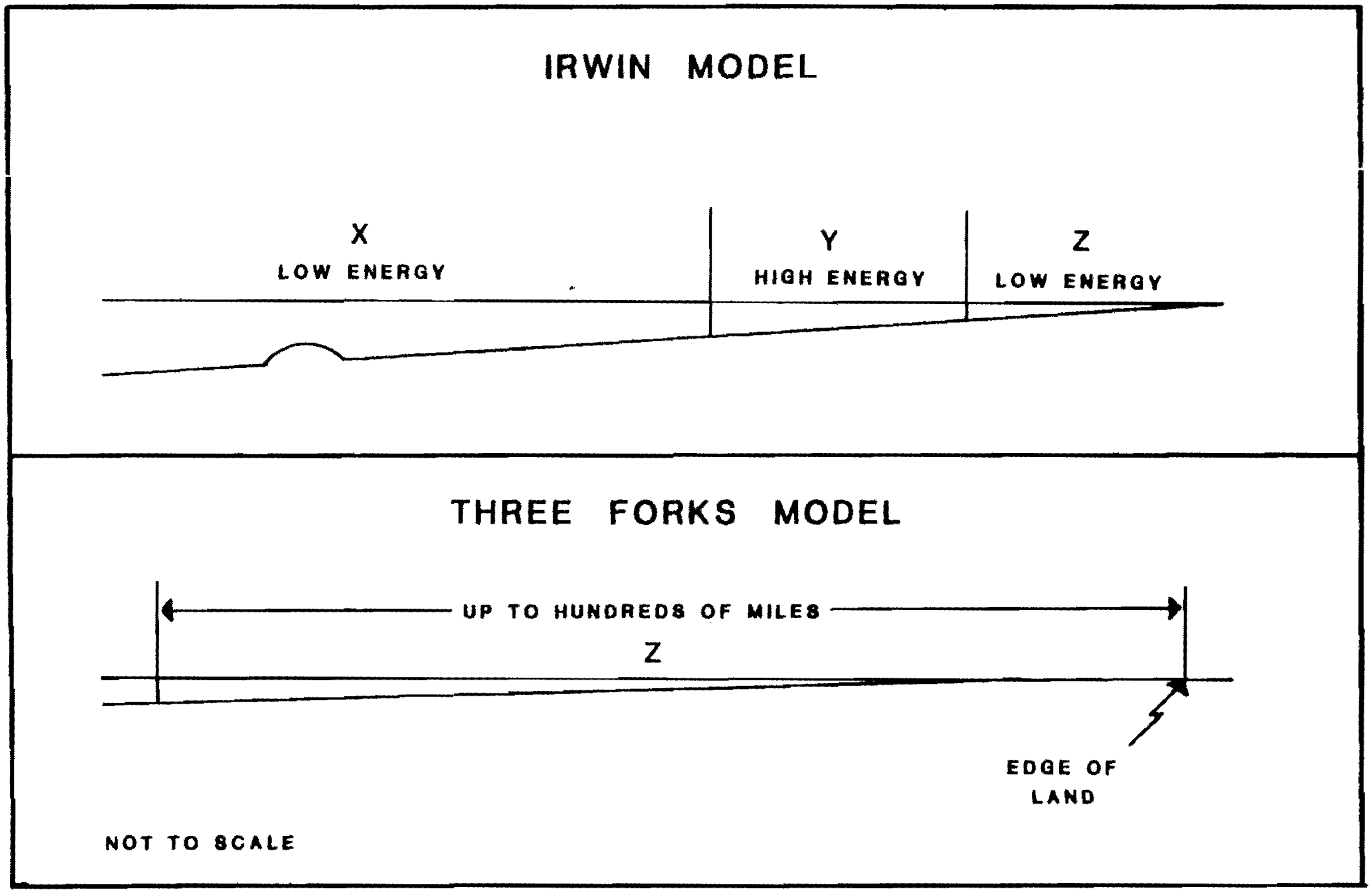

ALB.
SASK.
MAN.
EROSIONAL
BOUNDARY
ALBERTA
SHELF
MONTANA
TROUGH
WYOMING
SHELF
N.D.
S.D.
MT.
WY.
100 0 100 200 MILES
100 0 100 200 300 KILOMETERS
UPPER KASKASKIA
LIMESTONE
EVAPORITES
SHALE

change in local relief or subsidence would drastically influence sedimentation. Shaw (1964) and Irwin (1965) predicted that sedimentary facies, differentiated into three major belts based on varying hydraulic energy, would occur in an epeiric sea sedimentation model.

These three energy zones are as follows (Irwin, 1965, p. 450; Figure 34): 1) A wide, low energy zone occurring in the area farthest offshore beneath wave depth, where currents form the only hydraulic energy acting upon the bottom (Zone X); 2) A narrow, intermediate, high energy zone beginning where waves first impinge on the sea floor, expending kinetic energy, and extending landward to the limit of tidal action (Zone Y); and 3) An extremely shallow, low energy zone extending landward of Zone Y, having limited water circulation, and where the only wave action is produced by storms (Zone Z). These three zones are dependent upon depositional slope and magnitude of wave and current agitation. Oriented approximately parallel to the strandline, the width of these sedimentary environments, specifically Zone Z, would be dependent upon the bottom slope. If the slope is gentle, Zone Z could extend hundreds of miles. The lithofacies within the Three Forks Formation are thought to have been deposited solely within Zone Z.

The nearly flat slope of zone Z permits a wide expanse of very shallow water. A consequence of such extreme shallowness is the constraint placed on water circulation. In coastal areas where steeper slopes are common, zone Z would be narrow and produce beach deposits because of waves and tides extending to the shore. In epeiric seas, on the other hand, waves would dissipate hundreds of miles from shore prohibiting the formation of beach deposits (Irwin, 1965, p. 453).

Figure 34. Comparison of Irwins (1965) model for the distribution of environmental zones in epeiric seas to the Three Forks model.


IRWIN MODEL
X
LOW ENERGY
Y
HIGH ENERGY
Z
LOW ENERGY
THREE FORKS MODEL
UP TO HUNDREDS OF MILES
Z
EDGE OF
LAND
NOT TO SCALE

Binary System

Sediments within the Three Forks belong to two systems - an autochthonous system that produced sediments within the basin, and an allochthonous system which brought sedimentary particles into the basin from outside its limits. The autochthonous sediments are derived from the seawater itself through chemical precipitation, while sediments of the allochthonous system may be scoured from the sea bottom, brought in during inundation of the supralittoral zone or during progradation, or derived in some manner from sources other than the chemical or biogenic activities of the sea (Shaw, 1964).

During transgressive conditions, the more basinward sediments would onlap those sediments deposited in more landward areas. The reverse effect would be true in regressions. Allochthonous material would enter the basin along its periphery and its distribution would be controlled by varying transporting mechanisms. Probably the most effective transporting agent for carrying sediment out across the sea bottom are wind-induced currents impinging on the shore (Shaw, 1964, p. 36). The widespread nature of fine-grained sedimentary particles is dependent not only on the transporting mechanisms, but also on the extent of sea level fluctuation. The degree of sea level fluctuation and thus progradation envisioned for the Three Forks Formation (Figure 32) could have allowed for deposition of clays throughout the Williston Basin, as attested to by the presence of argillaceous material in core samples taken from the westernmost region of McKenzie County.

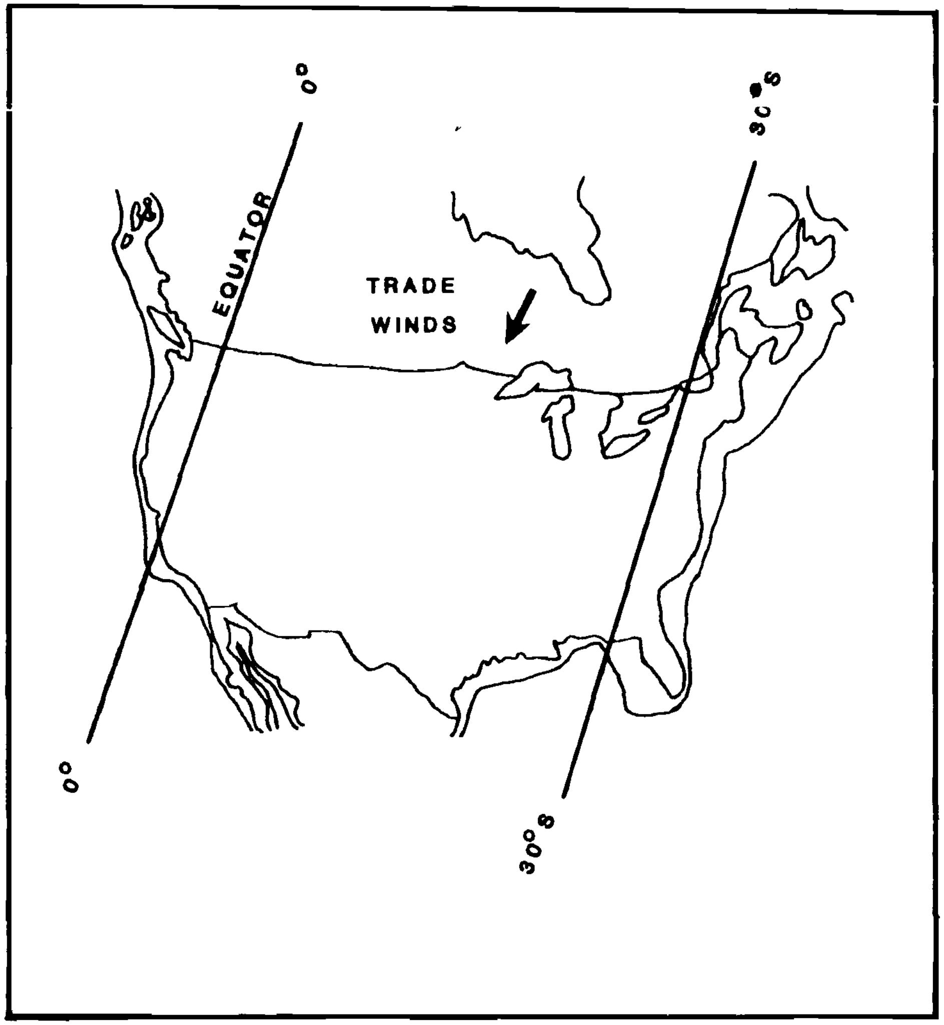
In latest Devonian time, the Williston Basin may have become oxygen stratified (Lineback and Davidson, 1982). With these conditions, carbonate production would occur along the extreme shoreward areas, greenish-gray mudstones would be deposited in shallow waters, and organic-rich black shales would form in the basin center. If this is the case, then some facies of the Three Forks were deposited shoreward of the Bakken Formation and the Lodgepole Limestone was deposited on the basin periphery (Lineback and Davidson, 1982, p. 130). This would cause the Bakken to grade laterally into the Three Forks and the Bakken-Three Forks to grade laterally into the Lodgepole. To some degree this is apparent on cross-sections (Figure 7), but this appearance may be due to the less widespread Bakken pinching out against the Three Forks.

Carbonate Precipitation

Carbonate production in modern environments is greatest in clear, warm, shallow water and occurs in a zone between 30° N and 30° S latitude. The increase in temperature promotes the precipitation of calcium carbonate, while also causing evaporation in dry climates (Heckel and Witzke, 1979). In clear, warm water, invertebrates precipitate thicker calcite and aragonite shells and calcareous algae are abundant (Wilson, 1975). Dilution of the carbonate-producing system by the influx of terrigenous material may inhibit carbonate formation.

Lime mud can be derived from several sources: from the death and decay of calcareous algae, abrasion of larger carbonate particles to micrite-size particles, and from direct precipitation from seawater. In the Williston Basin, photosynthetic or direct precipitation may have been a source of carbonate mud due to its association with large volumes of evaporites (Gerhard, 1978, p. 39). In areas where green algae are rare (e.g., Trucial Coast of the Persian Gulf), lime mud precipitates directly from seawater where the environments are warm and saline (Heckel and Witzke, 1979). Heckel and Witzke (1979) have postulated that the climate during the Devonian was hot and dry, allowing for abundant lime mud and thick evaporite sequences to form. In Late Devonian time, the Williston Basin was situated between the paleoequator and 30° S latitude (Figure 35). Lithological characteristics (e.g., thick carbonate-evaporite sequences) are indicative of such a paleolatitude. The great amounts of quartz silt present in Devonian rocks were probably deposited by trade winds blowing from the Canadian Shield; silt-size quartz can be transported over long distances by wind (Wilson, 1975, p. 91), thus making the Canadian Shield a plausible source.

Figure 35. Position of paleoequator and direction of trade winds during the Upper Devonian (Modified after Heckel and Witzke, 1979).


0°
EQUATOR
0°
TRADE
WINDS
30°S
30°S

Diagenesis

Several types of diagenetic features occur within the Three Forks Formation, of which dolomitization and anhydritization are of primary concern. Of lesser importance is calcite recrystallization of fossil fragments, recrystallization of micrite-size calcite to microspar and pseudospar, and formation of authigenic pyrite.

Dolomite

Dolomitization has occurred in the dolomicrite and argillaceous dolomicrite lithofacies. Both facies are interpreted as supralittoral deposits and the occurrence of dolomite was penecontemporaneous with sedimentation. Modern analogs to penecontemporaneous dolomite are given by Illing et al. (1965) in the sabkhas of the Persian Gulf, and Shinn et al. (1965) from Andros Island, Bahamas.

Evaporation, high salinities, and high Mg^{++}/Ca^{++} ratios are involved with dolomitization by near-surface brines. Buried algal mats form a permeability barrier, preventing the brines from percolating into and dolomitizing underlying sediments (Bush, 1973). Replacing calcite during and shortly after deposition, the resultant dolomite is generally fine-grained and may be finely laminated. The movement of near-surface brines to explain lateral and shallow subsurface (penecontemporaneous) dolomitization has been involved in the seepage refluxion model (Adams and Rhodes, 1960; Deffeyes et al., 1965), in the evaporative pumping model (Hsu and Siegenthaler, 1969; McKenzie et al., 1980), and in the capillary concentration model (Shinn et al., 1965).

Of those listed, the most appropriate for the dolomitization of the Three Forks Formation is the evaporative pumping model. Three hydrologic processes are involved in this dolomitization model: 1) Flood recharge which involves flooding of the supralittoral surface by wind-generated waves or storms waves. The level of the water table rises as available pore space is filled by seawater. This downward groundwater movement lasts only a short time, since the groundwater table will sink quickly to its original level before the flooding; 2) Capillary evaporation concentrates ions from evaporating seawater, and causes the lowering of the water table; and 3) Evaporative pumping maintains the level of the water table by the upward flow of groundwater to replace water lost to evaporation.

As seawater is brought onto the supralittoral surface, it begins to evaporate and form brine. With evaporation, ions become concentrated and calcium carbonate and calcium sulfate begin to precipitate aragonite and gypsum, respectively. The removal of Ca^{++} ions causes the Mg^{++}/Ca^{++} ratio to increase. As the Mg^{++} -rich brines sink into the supralittoral sediments, dolomitization occurs. Inundation of the supralittoral zone in an epeiric sea is infrequent since it is dependent on high wind- and storm-generated waves. Consequently, the capillary evaporation process is responsible for the continual supply of dolomitizing fluids being brought to the surface. As the pore water moves landward, there is a constant rise in the Mg^{++}/Ca^{++} ratio to the point that the most landward edge of the supralittoral zone would be nearly pure dolomite (Bathurst, 1975, p. 525).

Reduction Spots and Pyrite

Within the reddish-brown argillaceous dolomicrite facies, irregular subspherical greenish-gray spots are found. Ranging from 1 mm to 1 cm in diameter, these have been called "reduction spots" in the literature (Morad, 1982, p. 55). Morad (1982) established that the reddish sediments were characterized by hematite, which was probably derived from the wind-blown sediments from the exposed craton to the northeast, whereas the reduction spots were depleted of hematite. Three sediment samples were examined by the Scanning Electron Microscope (SEM), X-ray Diffraction (XRD), and X-ray Fluorescence (XRF) to determine iron content. The SEM indicated that the FeO content of the greenish-gray sediments was greater than the reddish sediments. Since this result did not seem plausible, it was felt that contamination of the samples occurred during the core slabbing process. After washing and drying the samples, the XRF results indicated that the Fe_2O_3 (hematite) in the red was 3.5% greater than in the green sediments. XRD results showed that the greenish sediments were dolomitic and pyritic, and that the reddish sediments were calcareous and hematitic.

Reduction spots indicate that local reducing conditions were developed in the course of reddening of the sediments (Morad, 1982, p. 56). During oxidation, the iron in the reddish sediments was oxidized into hematite. The iron in the reduction spots was reduced to the ferrous state and may have reprecipitated in the reddish sediments as hematite (Morad, 1982). In thin section, hematite is found in the reddish sediments, however, pyrite is absent in the reduction spots.

The presence of local concentrations of residual organic material is related to these reducing conditions. The occurrence of authigenic biotite, which corrodes detrital particles, have been found in reduction spots. In the red host rock, the biotite is highly oxidized, whereas it is chloritized in the reduction spots (Morad, 1982, p. 57). Small amounts of pyrite in reduction spots would support the stronger local reduction conditions, though this is not found in the Three Forks.

Pyrite is a common diagenetic feature and is found solely in the greenish-gray sediments of the Three Forks. In low salinity waters, the transformation of FeS to pyrite is prevented due to a deficiency of sulfate (Berner et al., 1979, p. 1349). Abundant sulfate is present in marine sediments, however, and pyrite can form in only a few years (Berner, 1970, p. 22), and be used as paleosalinity indicators.

Anhydrite

Anhydrite is found almost solely within the argillaceous dolomicrite lithofacies, which is interpreted to have been deposited in an arid supralittoral environment. Anhydrite is thought to form by direct dehydration of gypsum (Butler et al., 1982), though replacement evidence is lacking within the Three Forks. Anhydrite, typically nodular and mosaic, characterizes supralittoral environments, is diagenetically emplaced (Shearman, 1966; 1978; Kinsman, 1969; Butler, 1969), and may originate from brines by evaporative pumping (McKenzie et al., 1980, p. 27-28). Nodular and mosaic anhydrite is also distinctive in thin section, displaying a felted texture (Kinsman, 1969, p. 834). Lath and blocky crystal form is common in later anhydrite.

Some workers (Wilson, 1967; Wood and Wolfe, 1969) have found carbonate-evaporite cycles both in ancient (Duperow Formation of the Williston Basin) and modern (Arab/Darb Formation of the Trucial Coast) sedimentary environments. These cycles do not apply to the Three Forks, however. As progradations or regressions occurred, the evaporative-supralittoral belt moved progressively basinward, offlapping more seaward sediments, while during transgressions, the seaward sediments onlapped the more shoreward sediments. This caused a sequence of carbonates and evaporites to be present throughout the stratigraphic section.

Calcite Recrystallization

Both microspar and pseudospar are present in the Three Forks, and indicate the occurrence of neomorphism. Neomorphism involves recrystallization (calcite to calcite) where gross composition remains constant (Folk, 1965, p. 21).

The transition from micrite to microspar to pseudospar is termed aggrading neomorphism. For this transition to occur, Mg^{++} ions must be removed from the system. Mg^{++} ions are easily lost in the subsurface through dolomitization and by clay seizure (Folk, 1974). In a burial environment, slow crystallization aids in the formation of coarser-grained calcite.

CONCLUSIONS

1) Extending over the western two-thirds of North Dakota, the Three Forks Formation attains a maximum thickness of 265 feet (81 meters). It is thickest in the central basin, east and south of the Nesson Anticline.

2) The Three Forks Formation, divided into five lithofacies, has considerable vertical and lateral variability due to the degree of onlap and offlap between adjacent depositional environments.

3) Three Forks rocks were deposited in supralittoral, littoral, and sublittoral environments, probably in a hot, arid setting, in an epeiric sea which covered most of North Dakota.

4) The initial transgression of the epeiric sea during Devonian time came from the westward connection to the Cordilleran geosyncline through the Central Montana trough.

5) Extreme sea level fluctuations and thus progradations are responsible for the widespread nature of argillaceous material. Allochthonous material entered the basin along its periphery and was distributed by wind-induced currents and waves.

6) Repeated transgressions and regressions caused the lateral migration of environments and the complex mosaic of lithofacies in the stratigraphic section.

7) Diagenetic features within the Three Forks Formation include dolomitization, which is probably eogenetic in origin, anhydritization,

calcite recrystallization (neomorphism), reduction spots and pyrite formation.

APPENDICES

APPENDIX A

WELL LOCATIONS, LEGAL DESCRIPTIONS, FORMATION DATA, AND KELLY BUSHING ELEVATIONS

Well information is arranged alphabetically by county and numerically by North Dakota Geological Survey well numbers within counties. Well locations are based on the standard Land Office Grid System. In the appendix heading, QTR stands for the first and second quarter of a section. SEC, T, and R stand for section, township (north), and range (west) respectively. Kelly Bushing (KB) elevations are in feet above sea level. Depths for the top and bottom of the Three Forks are in feet below the Kelly Bushing. Formation thickness is in units of feet and was determined by calculating the difference between the top of the Three Forks and the top of the underlying Birdbear, where log depth was sufficient to penetrate the top of the Birdbear Formation.

ADAMS

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Bottom	Thickness
6050	SWSW	30-129-98	Amerada Hess Corporation Holmquist #1	2695	8040	8122	82
6322	NESW	7-130-91	Energetics, Incorporated Soelberg #23-7	2453	7219	7343	124
7639	SENE	2-129-91	Crystal Exploration and Prod. Worley #42-2-X	2429	6933	7041	108
7642	NWSE	28-130-95	Amoco Production Company Jacob Christman #1	2804	8012	8119	107
6939	SESW	32-131-98	Amoco Production Company Hirsch #1	2805	8485	8587	102
8091	NESW	7-129-94	Supron Energy Corporation Miller #1	2648	7707	7817	110

BENSON

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Bottom	Thickness
616	NESW	5-156-68	Shell Oil Company Betsy Jorgenson #1	1584	-	2626	-
632	NWSE	31-154-70	Calvert Exploration Company John Stadum #1	1637	-	3203	-
683	NENE	2-154-69	Shell Oil Company H. R. Hofstrand #1	1767	-	2979	-

BILLINGS

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Bottom	Thickness
859	SWNE	31-144-100	The Texas Company Government M.S. Pace #1	2463	10660	10886	226
3268	NESW	10-139-101	Amerada Petroleum Corp. Unit 8	2540	10190	10367	177

BILLINGS (con't.)

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Three Forks Bottom	Three Forks Thickness
3927	NWNE	21-139-101	Amerada Petroleum Corp. USA Hodge #1	2548	10253	10363	110
4254	SENW	28-137-100	Pan American Petroleum Corp. USA-Adah G. Macauley "B" #1	2864	10102	10268	166
5195	SENE	2-137-100	Lone Star Producing Company Alfred Schwartz "B" #1	2800	10139	10291	152
5769	SWSE	27-141-100	Southern Union Production Burlington Northern #1-27	2641	10548	10737	189
6310	SENW	6-144-101	Supron Energy Corporation Federal 6-144-101-#1	2198	10460	10671	211
6418	SWSW	29-143-100	Tenneco Oil Company B. N. #2-29	2647	10708	10933	225
6472	NESW	16-144-98	Gulf Oil Explor. and Prod. State #2-16-4B	2536	10994	11244	250
6658	SESE	15-141-101	Jerry Chambers-Oil Producer Franks Creek State #1-15	2436	10354	10545	191
6667	NENW	36-143-98	Mosbacher Prod./Pruet Oil State Gresz #1b-36-1	2690	10991	11228	237
6709	SESW	34-139-100	McAlester Fuel ND Federal #34-14	2705	10292	10458	166
6744	NENW	22-142-99	W. H. Hunt Trust Estate Hlebechuk #1	2712	10988	11233	245
7011	SWNE	10-142-100	W. H. Hunt Trust Estate Gregory #1	2782	10853	11070	217
7348	SWSW	2-143-99	Amoco Production Company Hecker #1	2722	11154	11406	252
7384	NWNW	23-142-98	Crystal Exlor. and Prod. Kuntz #11-23	2648	10872	11102	230
7508	NENW	2-140-100	Conoco, Incorporated Conoco Federal Saddle #2-1	2783	10890	11111	221

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	 Bottom	 Thickness
			BILLINGS (con't.)				
7618	NWNE	3-142-99	W. H. Hunt Trust Estate Baranko #1	2728	11050	11297	247
7652	SWSE	4-142-102	Diamond Shamrock Corporation Cenex-Federal 34-4	2557	10534	10707	173
7690	SWSW	19-143-101	Jerry Chambers Explor. Co. Blacktail Federal #3-19	2373	10440	10635	195
7996	NESE	33-141-98	Mosbacher Prod./Pruet Oil Volesky 33-1	2618	10604	10810	206
8075	NESE	8-142-101	Conoco, Incorporated Hanson-Federal 8-1	2523	10433	10631	198
8079	SESW	34-143-99	W. H. Hunt Trust Estate Damaniaw #1	2747	11080	11328	248
8337	NESE	30-141-102	Patrick Petroleum Patrick-Harris-Federal #1-30	2603	10341	10487	146
8474	NESW	15-144-102	Tenneco Oil Company Graham USA #1-15	2173	10380	-	-
8487	SESE	13-143-102	Conoco, Incorporated Conoco Federal Blacktail #13-1	2344	10428	10626	198
8558	NWSE	29-144-99	Amoco Production Company A. W. Thompson #B-1A	2675	11105	11350	245
8582	NESE	24-138-100	Monsanto Company Gaylord #1	2712	10227	10400	173
9351	NWSE	6-144-101	Supron Energy Corp. F-6-144-101, #3	2203	10469	10698	229
			BOTTINEAU				
38	SWSE	31-160-81	The California Company Blanche Thompson #1	1526	5364	6460	96

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Three Forks Bottom	Thickness
			BOTTINEAU (con't.)				
110	NWNW	23-163-75	Lion Oil Company G. A. Huss #1	2205	4013	4054	41
170	SESW	2-163-77	Lion Oil Company Magnussen #1	1669	3819	3880	61
348	SWSW	12-161-75	Cardinal Drilling Company Bennison et al #1	1603	3606	3640	34
359	SWSE	36-164-74	Ward Williston State #1	2256	3727	3785	58
457	NWSW	34-164-78	Calvert Exploration Company Anderson #1	1539	3904	3973	69
895	NWNW	14-162-76	Lion Oil Company Wallace #1	1683	3805	3854	49
1069	NWNW	1-159-82	Cardinal Drilling Company B. M. Keeler #1	1536	5250	5371	121
1102	SWNE	2-161-74	Cardinal Drilling Company Joseph Andrieux #1	1664	3433	3475	42
1673	NESW	23-163-74	General Crude Oil Company Martin Rude #1	2160	3768	3805	37
2219	SESW	6-161-79	The California Company Bert Henry #4	1494	3253	3409	156
2596	SENW	19-160-80	Phillips Petroleum Company Brandt #1	1511	5009	5102	93
3827	SESE	20-162-78	Amerada Petroleum/Arex Corp. Lila Stark #1	1502	4200	4246	46
4347	NESW	9-163-78	Cardinal-National Bulk et al. Ekrehagen Estate #1-A	1532	3957	4032	75
4655	SESW	31-162-78	Amerada Petroleum Corp. Lillestrand #1	1486	4185	4325	140
4790	SESE	20-159-81	Union Oil Company of Calif. Steen #1	1517	5381	5545	164

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	 Bottom	 Thickness
			BOTTINEAU (con't.)				
4846	NENW	8-163-81	Lamar Hunt William Cranston #1	1518	4493	4580	87
4924	NENE	2-161-81	Union Oil Company of Calif. Huber #1-A-2	1514	4851	4937	86
5071	NWSW	34-160-81	Estate of William G. Helis E. Van Horn #1	1503	5240	5324	84
5141	SWNE	33-164-77	Gemini Corporation et al Carl #1-X	1598	3752	3818	66
5147	SESW	2-160-82	Hickerson Oil Company Streich #1	1534	5246	5340	94
5184	SENE	14-162-77	Champlin Petroleum Company Champlin-Bridger #1 Dunbar	1552	3888	3931	43
5280	SWSW	24-161-76	McMoron Exploration Company Deraas #1	1527	3785	3823	38
6021	SWNW	27-161-82	Cities Service Oil Company Wiley Rice A #1	1553	5183	5291	108
6126	SWNW	36-163-80	Placid Oil Company Rosendahl 36-5	1499	4441	4505	64
6535	NENE	2-161-83	Shell Oil Company Greek #41-2	1584	5260	5392	132
			BOWMAN				
516	NWSW	13-132-102	Western Natural Gas Company Traux Traer #1	3074	9273	9343	70
4673	NWNE	25-131-102	International Nuclear Corp. Stewart #1-63	2922	8888	8910	22

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Bottom	Thickness
			BOWMAN (con't.)				
4922	SESW	5-130-100	Pel-Tex Incorporated Superior Landa #1	2944	8743	8813	70
4952	SWSW	32-130-100	Pel-Tex Incorporated Superior-Boor #1	2958	8574	8615	41
5227	NWSE	26-129-103	Depco Incorporated Greni #33-26	2938	8161	8179	18
5347	NWNE	8-131-104	Depco Incorporated Homquist #31-8	3042	-	8798	-
5402	NENW	28-129-101	Kenneth D. Luff et al Jett #1-28	2889	8242	8290	48
5584	SESW	22-130-102	Kenneth D. Luff et al Faris #1-22	2888	8398	8438	40
5772	NWNW	5-131-100	True Oil Co., Incorporated Fisher #11-5	2892	8944	9028	84
5888	NWSW	15-132-104	Kenneth D. Luff et al Gundvalsen #1-15	3167	-	9115	-
5904	NWNE	34-131-103	Petroleum Incorporated Hilton #1	3043	8782	8806	24
6074	SESE	2-129-102	Farmland Int'l Energy Co. Richards-Southland Royalty #1-2	2857	8281	8320	39
6094	SESE	33-129-102	Kenneth D. Luff Fandrick #1-33	2903	8071	8102	31
6370	SWNE	21-129-100	C. F. Braun Palczewski #1	2787	8285	8339	54
6398	SWNE	7-130-102	Kenneth Luff, Incorporated Mrnak #1-7	2951	8617	8657	40
6600	NESE	28-129-104	Petroleum Incorporated Arithson "E" #1	3039	-	8270	-
6639	SESE	8-130-103	Florida Gas Explor. Co. Gross #1-8	3051	8616	8635	19

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Bottom	Thickness
			BOWMAN (con't.)				
6657	SENE	4-129-101	Consolidated Oil & Gas Inc. Lewison Drilling Unit #1	2813	8377	8429	52
6814	SESE	31-130-103	Terra Resources Incorporated T. Nygaard #1-31	3015	-	8451	-
8232	SESE	5-130-104	Davis Oil Voight #1	3167	-	8795	-
8250	NENW	1-131-104	Anadarko Production Company Bowman Federal "A" #1	3161	9039	9049	10
			BURKE				
2033	SWSW	30-160-94	Hunt Oil Company Carl Overlee #3	2389	9209	9426	217
3154	NENE	12-163-92	Mar-Win Development Company R. M. Hanson #3-D	1952	7102	7306	204
4508	SWNE	7-161-90	Northern Pump Company Peterson #1	1975	7566	7785	219
4599	SWSE	25-162-90	The Anschutz Corporation Ormiston #1	1957	7245	7450	205
4958	SWNE	2-161-91	John B. Hawley Jr. Trust #1 Florence M. Ingerson #2	1973	7649	7866	217
5908	NWNE	33-164-90	Chandler and Assoc., Inc. Wilson #2-33	1901	6720	6926	206
5919	SESW	30-161-94	Home Petroleum Corporation Sunflot Heirs #1	2459	8970	9180	210
5956	NENW	3-161090	Chandler and Assoc., Inc. Ewing #3-3	1969	7390	7602	212
6607	NENE	5-161-94	North Central Oil Corp. Priebe State #1	2404	8678	8890	212

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Three Forks Bottom	Three Forks Thickness
			BURKE (con't.)				
6802	SWNW	24-160-93	Brownlie, Wallace et al. Western Investment Co. #24-12	2394	8965	9192	227
			BURLEIGH				
701	NENE	36-144-75	Caroline Hunt Trust Estate University Land #1	2023	-	4588	-
756	SESE	32-137-77	Caroline Hunt Trust Estate Robert Nicholson #1	1891	-	-	-
763	SESE	14-144-77	Caroline Hunt Trust Estate Anton Novy #1	1947	-	5097	-
765	SWSW	31-142-76	Caroline Hunt Trust Estate Soder Investment Company #1	2027	-	5045	-
772	NWNW	23-140-79	Caroline Hunt Trust Estate Paul Ryberg #1	2007	-	5455	-
1409	NWSE	11-410-77	Calvert Drilling Inc. et al. Patterson Land Company #1	2019	-	4918	-
4389	SWNE	33-141-80	Tom Vessels and Perry Bass Helen Bourgois #1	2126	6037	6077	40
4685	SWSW	19-140-80	E. C. Johnston Jr. Edwards #1	1865	5737	5780	43
6264	NENE	9-139-76	Tom Marsh Funston #1	1938	-	-	-
8674	SWSW	17-141-76	Sunmark Exploration Company Thorson #1	1874	-	4819	-

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Bottom	Thickness
			DIVIDE				
2010	NWNE	7-163-102	Carter Oil Company D. Moore #1	2206	7828	7995	167
3491	NWSE	13-160-98	Hunt Petroleum Corporation Joseph Thvedt #1	2345	9306	9489	183
4074	NENE	20-162-95	Calvert Drilling & Prod. Co. Legein #1-A	2136	8179	8388	209
4394	SWSW	20-161-97	Texaco Incorporated R. W. Redlin (NCT-1) #1	2157	8851	9046	195
4423	NWSW	26-162-101	Pan American Petroleum Corp. Orville C. Raaum #1	2249	8552	8728	176
4507	NENE	21-163-101	Petroleum Incorporated Ole Hellen #1	2214	8073	8239	166
4837	SWNE	12-160-100	Miami Oil Producers, et al. Roy Hagen #1	2112	8946	9129	183
5135	CNW	29-161-95	Ashland Oil and Refining Co. Fenster #1-29	2291	8762	8967	205
5192	NENE	3-160-95	H. L. Hunt A. B. Ericson #1-A	2373	8952	9160	208
5248	NENE	10-160-98	Oil Development Co. of Texas Rogers #1	2242	9077	9250	173
5404	NWSE	23-163-99	Edward Mike Davis Mathews #1-23	2209	8140	8318	178
5989	NESE	31-164-95	W. A. Moncrief Keba Oil and Gas #31-1	1903	7472	7686	214
6429	SWSE	26-162-103	W. H. Hunt Trust Estate Skabo #1	2144	8283	8444	161
6541	SENE	13-162-100	Tipperary Oil & Gas Corp. Olsen #1	2349	8514	8686	172
6603	SWSW	36-160-96	Chapman Exploration State #1-A	2295	9236	9444	208

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Three Forks Bottom	Three Forks Thickness
			DIVIDE (con't.)				
6673	NESW	30-160-102	W. H. Hunt Trust Estate Nelson #1	2100	8960	9133	173
6705	SWSE	25-161-103	Mosbacher Prod./Pruet Oil George C. Anderson #1	2101	8528	8688	160
6751	NWNW	3-161-101	Patrick Petroleum Company Johnson #1	2244	8573	8742	169
6798	NESE	16-162-96	Shell Oil Company State Rindel #43-16	2140	8207	8404	197
7116	NESW	24-169-99	Terra Resources Simle Federal #1-24	2236	9245	9429	184
			DUNN				
505	SENE	6-141-94	Socony Vacuum Dvorak F-32-6-P	2296	10080	10299	219
607	SWNE	24-149-93	Mobil Producing Company Kennedy F-32-24-P	2146	10602	10846	244
793	SENW	22-149-91	Mobil Producing Company Solomon Birdbear #1	2092	10076	10310	234
2618	SWSE	15-145-91	Pan American Petroleum Corp. Jack Huber #1	2212	9838	10073	235
2724	NWSE	15-148-96	Amerada Petroleum Corp. Signalness Unit "A" #1	2383	10956	11196	240
3044	NENE	27-143-92	Amerada Petroleum Corp. Marie Selle Tract 1, #1	2200	9666	9890	224
4611	SWSW	36-146-96	Helmerich and Payne Inc. ND State #1	2435	11075	11316	241
4725	SWSE	24-148-97	Kathol Petrol.-Tidden Petrol. Little Missouri #1-24	2373	11200	11452	252

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	 Bottom	 Thickness
			DUNN (con't.)				
4957	NWNW	8-147-93	Miami Oil Producers Inc. Hairy Robe Estate #1	2212	10537	10766	229
5621	NENW	23-142-07	Mesa Petroleum Company Roshau #1	2583	10674	10871	197
6034	NWNW	32-145-97	Gulf Energy & Minerals Co. P. Marinenko #1	2518	10958	11203	245
6105	SWNW	11-146-96	Amoco Production Company William C. Lubke Unit #1	2673	11260	11489	229
6148	SWSW	2-141-96	Amoco Production Company Andrew N. Heiser #1	2615	10518	10720	202
6251	SWSW	6-145-97	Gulf Energy & Minerals Co. Blackburn #1-6	2574	11096	11338	242
6448	NWNW	24-146-94	Smokey Oil Company O'Neil #11-24	2256	10640	10874	234
6464	NWSE	19-147-95	Gas Prod. - Al Aquitaine 19-147-95-B.N. #1	2526	11168	11397	229
6477	SESW	2-142-95	Amoco Production Company Ficek #1	2287	10330	10552	222
6489	NENE	30-144-96	Amoco Production Company Roy F. Karey #1	2310	10736	10989	253
6530	SENE	18-141-95	Amoco Production Company Wolberg #1	2594	10399	10598	199
6591	NWNW	35-143-94	Amoco Production Company Anderson #1	2130	10007	10229	222
6828	NENE	8-145-94	Amoco Production Company Merrill Unit #1	2337	10710	10931	221
6887	SWNE	35-146-95	Amoco Production Company Richardson #1	2324	10776	11005	229
7584	NENW	8-145-95	Amoco Production Company Roshau #1	2322	10840	11075	235

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Three Forks Bottom	Three Forks Thickness
			DUNN (con't.)				
7707	NESW	35-145-93	Terra Resources Incorporated Borth #1-35	2257	10303	10536	233
7745	NENE	10-147-92	Oil Development Co. of Texas Young Bear #1	2048	10136	10373	237
7760	SESW	24-146-93	Mosbacher Prod./Pruet Oil Thomas-Cook 24-1	2318	10463	10694	231
7978	NWSE	17-145-91	Terra Resources Incorporated Tozier 1-17	2223	9912	10142	230
8095	SWNW	17-149-93	Shell Oil Company Packineau 12-17	2330	10885	11121	236
8107	SWNE	23-147-96	Amoco Production Company Engvold 1-A	2538	11184	11415	231
8115	NESW	24-142-92	Keldon Oil Company Dressler #1	2277	9551	9757	206
8235	SESE	36-144-92	Santa Fe Energy Company State Coyote Creek 1-36	2258	9746	9981	235
8374	NENE	4-144-96	Adobe Oil and Gas Corp. Federal Killdeer 41-4	2435	10957	11207	250
8394	SESE	14-146-93	Anr Production Company FLB Askew 1-14A	2417	10589	10815	226
8396	SENE	15-141-97	Puma Petroleum Company Hecker #1-15	2546	10588	10801	213
8491	NESW	30-142-96	Vanderbilt Resources Bullinger #1-30	2635	10681	10881	200
8536	SWSE	7-144-93	Terra Resources Incorporated Kling #1-7	2251	10271	10503	232

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	 Bottom	 Thickness
			EMMONS				
16	NWSW	35-133-75	Northern Ordnance Corp. Franklin Investment 1	2027	-	3930	-
23	NENE	35-133-76	Roeser and Pendleton Inc. Weber #1	2012	-	4065	-
43	NESE	8-132-78	Peak Drilling Company Ohlhauser #1	1820	-	4233	-
742	SENW	30-134-75	Mobil Producing Company Kruse F-22-30-P	2044	-	4159	-
7101	SWSW	10-132-76	Keldon Oil Company Horner #3	1887	-	3915	-
7936	NWNW	13-136-75	Chevron et al. Rambough #1	1925	-	4026	-
			GOLDEN VALLEY				
470	NESE	15-140-105	Blackwood and Nichols Gilman #1	2867	10347	10403	56
4130	SWNW	9-138-105	Amerada Petroleum Corp. Ramona Waldron #1	2867	9872	9905	33
5438	NENW	27-141-105	Texas Gas Exploration Corp. Guy M. Brown et al. #1	2710	10194	10250	56
6272	NWNW	22-137-106	Shell Oil Company Kremers #21X-22R	3034	-	9549	-
6531	SESE	12-144-104	Terra Resources Incorporated Federal #1-12	2527	10670	10796	126
6562	NENW	23-144-105	Tenneco Oil Company Rose Gasho #1-23	2579	10568	10674	106
6563	NWNE	4-139-105	Shell Oil Company Smith #31-4	2744	10147	10191	44

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks		
					Top	Bottom	Thickness
			GOLDEN VALLEY (con't.)				
6813	SENE	26-143-103	Diamond Shamrock Corporation Williamson Federal #42-26	2616	10612	10746	134
6947	NESW	18-144-103	Terra Resources Incorporated Mosser #1-18	2531	10764	10895	131
7753	SENE	7-141-104	Moran Exploration Inc. Kunick #1	2759	10373	10457	84
7842	SWSW	28-137-103	Bass Enterprises Bullion Butte Federal 28-1	2728	9801	9857	56
7969	NWSE	32-142-105	Moran Exploration Inc. Stecker #1	2692	10190	10263	73
8460	NWNE	31-141-103	Jake L. Hamon Tescher #3	2726	10404	10500	96
			GRANT				
232	SWSW	26-133-83	Youngblood and Youngblood Kelstrom #1	1997	5466	5506	30
3636	SWNE	1-133-90	Cardinal Petroleum et al. Bierwagen #1	2350	7413	7571	158
5097	NENW	27-131-88	Helmerich and Payne Inc. Burlington Northern #J-27-1	2531	6695	6770	75
5118	NWSW	23-130-88	Helmerich and Payne Inc. Burlington Northern "L" #23-1	2206	6219	6269	50
5496	SENW	5-134-90	Wainoco Incorporated Krause #22-5	2420	7767	7914	147
5572	NENW	27-132-86	Gas Prod.-Al Aquitaine Burlington Northern #1	2172	6156	6268	112
6420	SWSW	7-132-86	Marshall R. Young Oil Co. Burlington Northern #1	2285	6430	6517	87

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks		
					Top	Bottom	Thickness
			GRANT (con't.)				
7020	SENE	5-137-88	Texas Pacific Oil Co., Inc. William Steckler #1	2342	7962	8139	177
			HETTINGER				
511	SWSW	24-134-96	Socony Vacuum Pegasus Div. Jacobs F-14-24-P #1	2616	8785	8949	164
4984	NWNE	12-135-92	Pubco Petroleum Corporation Haberstroh #12-2	2524	8343	8520	177
5447	SESW	15-136-92	W. H. Hunt Valentine Senn #1	2429	8415	8615	200
5783	NWNE	35-136-93	Farmers Union Central Exch. Crosz #2-35	2548	8695	8889	194
6413	NWSE	21-133-92	Energetics Incorporated Harsch-Mehrer #44-21	2508	7927	8098	171
6795	SENE	19-136-97	Wexpro Company Jirges #1	2692	9582	9761	179
7075	SWSE	26-133-93	Amoco Production Company Charles Rokusek #1	2517	8101	8266	165
7231	SESW	22-134-93	Diamond Shamrock Corporation Blickendorf #24-22	2367	8268	8434	166
7819	SESE	23-133-96	Amoco Production Company Redetzke #1	2694	8741	8887	146
7876	NENW	14-136-96	Amoco Production Company Kenny #1	2738	9410	9594	184
7965	NENE	31-134-96	Gulf Oil Explor. & Prod. Co. Zenker 1-31-2B	2829	9047	9201	154
8206	NESW	16-132-93	Supron Energy Corporation Alexander State 1-16	2556	7948	8095	147

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Bottom	Thickness
			McHENRY				
39	NESW	3-157-78	Hunt Oil Company Shoemaker #1	1480	4666	4729	63
61	NWSE	17-153-77	Hunt Oil Company Peter Lenertz #1	1570	4838	4904	66
769	NWNW	14-154-78	Calvert Exploration Company Fred and Signa Wright #1	1481	4834	4900	66
1354	NWNW	26-156-77	Lion Oil Company ED #1	1489	4397	4462	65
2675	NWNW	34-159-79	Amerada Petroleum Corp. Ted Pfau #1	1478	4760	4854	94
5279	NESW	34-157-76	McMoran Exploration Company State #1	1476	4211	4256	46
5281	SWSW	16-158-75	McMoran Exploration Company State #2	1470	3882	3923	41
5283	NENE	34-158077	McMoran Exploration Company Fairbrother #1	1477	4357	4405	48
8307	NENW	31-155-77	Asamera Oil Incorporated Larson #1	1516	4715	4791	76
			McKENZIE				
33	SWSE	12-149-96	Amerada Petroleum Corp. Ben Homer Risser #1	2438	10988	11210	222
341	SWSE	21-152-94	Stanolind Oil and Gas Woodrow Starr #1	2140	10522	10716	194
527	NWNE	13-148-98	The California Company Rough Creek Unit #1	2472	11273	11527	254
956	NWSW	28-148-104	Gulf Oil Corporation Bennie-Pierre Federal #1	2339	10659	10854	195
1254	SWSE	17-152-94	Northern Pump Company Gilbert T. Rohde #1	2168	-	-	-

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Bottom	Thickness
			McKENZIE (con't.)				
1606	NESW	35-150-97	Amerada Petroleum Corp. H. H. Shelvik #1, Tract #1	2334	10962	11195	233
1886	NWSE	33-153-94	Amerada Petroleum Corp. John Dinwoodie #1	2259	10721	-	-
2169	NESE	3-152-96	Texaco Incorporated L. Wisness #2	2320	10317	10527	210
2226	SWNW	18-153-94	Amerada Petroleum Corp. U.S.A. Thomas #1	2134	10595	10824	229
2326	SWSE	34-154-96	Amerada Petroleum Corp. Harry Mendenhall #1	2144	10158	10384	226
2602	SENE	6-153-95	Texaco Incorporated S. A. Garland #5	1983	9804	10026	222
2820	NWSW	5-151-95	Texaco Incorporated F. P. Keogh #4	2416	10650	10863	213
2967	NWSE	3-152-96	Texaco, Incorporated A. S. Wisness #2	2317	10314	10519	205
3387	NWNW	7-152-94	Amerada Petroleum Corp. Antelope Unit - F #1	2190	10287	10476	189
4061	NWNW	16-152-93	Mobil Oil Corporation Grady Heirs F-11-16-1	2020	10520	10759	239
4095	SESE	34-151-96	Amerada Petroleum Corp. Signalness - Tank Unit #1	2432	10805	11022	217
4264	NENW	3-153-95	Texaco - Amerada - et al. A - (NCT-2 Well #3)	2193	10036	10244	208
4439	NESE	18-151-103	J. H. Moore, et al. Olson #1	2200	10697	10893	196
4594	NWNW	10-151-94	Petrel Oil Corporation Dragswolf #1	1956	10421	10634	213
4723	SENE	23-151-101	Consolidated Oil & Gas Inc. Federal Land Bank #1	2048	10730	10955	225

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Bottom	Thickness
			McKENZIE (con't.)				
5182	SENW	27-148-101	True Oil Company Burlington Northern #22-27	2165	11319	11426	107
5345	NENE	27-150-103	Chandler and Associates Federal #1-27	2248	10822	11004	182
5727	SESW	33-154-95	Amerada Hess Corporation Federal #33-1	1923	9756	9964	208
5821	SWSW	31-149-104	Shell Oil Company USA #34X-31-1	2128	10349	10512	163
5866	NWSW	11-149-99	Kerr-McGee Corporation Robert Peterson #1	2194	11054	11304	250
5936	NWNE	29-149-95	Ashland Exploration Company Nelson #1-29	2294	10949	11188	239
6049	SESE	8-148-102	Kerr-McGee Corporation Florence Hinnman #1	2446	11007	11201	194
6122	NWNE	24-145-98	Gulf Energy & Minerals Co. Pete Glovatsky #1-24	2578	11070	11310	240
6207	NWNE	27-153-95	Hunt Oil Company Haugen #1	2375	10378	10588	210
6501	NESW	6-152-101	Gulf Oil Explor. & Prod. Co. Eckert Foundation #1	2214	10794	10999	205
6544	SENE	29-145-103	Terra Resources Incorporated BN RR #1-29	2466	10684	10804	120
6616	NENW	26-153-101	Mosbacher & Pruet Oil Co. F. L. B. #1-26	2100	10662	10868	206
6710	SWNE	33-148-104	Pennzoil - Depco Federal - #33-32	2278	10582	10756	174
6790	SWNW	35-152-102	Superior Oil Company Donald Link #1	2276	10867	11076	209
6826	SWNE	19-149-97	Samedan Oil Corporation Kelly #1	2244	11130	11376	246

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Top	Three Forks Bottom	Thickness
			McKENZIE (con't.)				
6839	NESE	11-150-104	Shell Oil Company U.S.A. #43-11	2065	10555	10740	185
6846	SESE	15-146-101	Pennzoil Company Pennzoil-Depco #15-44-BN	2443	10877	11090	213
6904	SENW	3-147-104	Brownlie, et al. Federal #3-22	2196	10493	10668	175
6959	SESW	30-145-99	Ladd Petroleum Corporation Duncan Federal 30-24	2493	10902	11129	227
6984	NENE	10-147-101	Pennzoil Company Federal #10-41	2244	10811	11029	218
7008	NWNW	11-151-97	Supron Energy Corporation Rolfsrud #1	2291	10887	11130	243
7233	NWSW	16-153-97	Getty Oil Company Tobacco Garden #16-12	2052	11052	11283	231
7314	SENE	25-145-101	Belco Petroleum Corporation Sheep Creek BN #16-25	2353	10679	10900	221
7579	SENE	24-145-104	Shell Oil Company USA #42-24A	2664	10882	11020	138
7611	NENW	21-146-99	Pennzoil Explor. & Prod. Co. Grassy Butte Federal #21-21	2628	11252	11504	252
7631	NENE	33-151-99	Texaco Incorporated Torstenson #1	2137	11015	11227	212
7647	SESW	4-149-104	Shell Oil Company USA #44-4	2204	10581	10752	171
7648	SENW	24-148-103	Shell Oil Company USA #22-24	2474	11000	11187	187
7650	NESW	31-150-102	Tenneco Oil Company Buder USA #1-31	2262	10835	11029	194
7673	SWSW	20-150-94	Helmerich and Payne Inc. Matthew #1-20	2231	10799	11025	226

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Bottom	Thickness

McKENZIE (con't.)

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Top	Bottom	Thickness
7685	SWNW	34-147-99	Pennzoil Explor. & Prod. Co. Slawson #34-12	2581	11306	11571	265
7704	NESE	23-150-98	Gulf Oil Explor. & Prod. Co. Shafer State #1-23-3B	2021	10965	11199	234
7810	NWSW	5-150-95	Texaco Incorporated Loomer #11	2339	10651	10862	211
7879	NENE	22-149-100	Champlin Petroleum Company State - Rogness #1	2209	10976	11219	243
7943	NENW	23-149-99	Amoco Production Company Hamre #1	2380	11251	11503	252
8013	SENE	1-145-100	Amoco Production Company Storm #1	2442	11011	11252	241
8020	SWNE	34-150-99	Alpar Resources Incorporated Rogness #1-34	2114	11011	11255	244
8090	NESE	6-152-95	Amerada Hess Corporation Grimestad #4-6	2331	10438	10644	206
8193	SENW	3-146-102	Pennzoil Exploration et al. Covered Bridge #3-22 BN	2185	10630	10829	199
8215	SESE	25-147-98	Gulf Oil Explor. & Prod. Co. Mormon Butte Federal #1-25-3C	2512	11128	11377	249
8238	NESE	6-146-103	Shell Oil Company USA #43-6-117	2328	10604	10792	188
8285	SWNE	8-152-102	Gulf Oil Explor. & Prod. Co. Rehberg #1-8-2D	1989	10553	10758	205
8287	NWSE	18-146-104	Shell Oil Company U.S.A. #33-18-123	2450	10627	10781	154
8302	NWSE	24-149-101	Traverse Oil Company Nygaard #1-24	2418	11090	11319	229
8314	SENE	8-147-103	Shell Oil Company USA #42-8	2221	10622	10817	195

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Three Forks Bottom	Three Forks Thickness
			McKENZIE (con't.)				
8322	SWSE	34-151-102	H. N. G. Oil Company Link #34-1	2269	10847	11050	203
8372	NWNE	26-150-100	Mobil Oil Corporation Rogness #1	2331	11160	11404	244
8399	NENE	29-150-101	Texas Gas Explor. Company Nygaard #1-29	2320	10970	11195	225
8400	NWSW	17-145-102	Pennzoil Company Six Creek #27-13-BN	2205	10493	10687	194
8409	SWNE	34-149-103	Patrick Petroleum Corp. Winter Federal #1-34	2375	10892	11079	187
8471	NENW	22-149-96	Apache Corporation Federal #22-1	2406	11069	11303	234
8535	SENE	3-146-98	W. H. Hunt Trust Estate Brockmier #1	2552	11277	11544	267
8592	NWSW	32-149-102	W. H. Hunt Trust Estate Cross #1	2426	10967	11152	185
			McLEAN				
49	SWSW	28-150-80	Stanolind Oil & Gas Co. McLean County #1	2100	6362	6455	93
432	SWSE	2-146-81	Herman Hanson Oil Syndicate N. E. Hanson #1	1957	6400	6510	110
7783	SENW	1-150-90	Home Petroleum Company Tribal 1-1	2212	9637	9853	216
8060	SWNE	7-148-89	Apache Corporation Solcum #1	2109	9430	9660	230

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Three Forks Bottom	Three Forks Thickness
			MERCER				
21	NWNE	28-142-89	F. F. Kelly F. Leutz #1	2285	8997	9223	226
377	SWSW	10-144-88	Williston Oil and Gas Co. Boeckel et al. #1	2059	8715	8927	212
3492	SWSE	25-146-90	Continental Oil Company Gust Schuh #1	2309	9668	9897	229
6683	NWSW	13-143-90	True Oil Company Hauck #13-13	2097	9176	9401	225
7616	SWNW	29-144-90	Conoco Conoco Entze #29-1	2080	9358	9585	227
			MORTON				
133	SWSW	30-139-86	Deep Rock Oil Company Hilda Johnson "A" #1	2204	7604	7762	158
1620	NESW	27-139-90	Pan American Petroleum Corp. Raymond Vetter #1	2426	8614	8800	186
3859	SENE	34-135-83	Amerada Petroleum Corp. James Meyer #1	2125	5983	6050	67
3978	SENW	34-137-83	Austral Oil Company, Inc. John J. Leingang Unit 6524 #1	2281	6455	6525	70
5379	NWNE	5-138-83	Campbell and Partners Picha #1	1980	6461	6534	73
5979	NWNW	18-136-81	Houston Oil and Minerals Corp. Haider et al. #1	1907	5603	5650	47
7340	NWSE	26-140-88	Amoco Production Company Richter #1	2230	8123	8301	178
7691	SENW	19-138-85	Amoco Production Company Olin #1	2094	7102	7236	134
7770	NWSW	6-138-85	Amoco Production Company Karch #1	2075	7168	7319	151

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Bottom	Thickness

MORTON (con't.)

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Top	Bottom	Thickness
7797	SESE	14-137-87	Texas Pacific Oil Company Bachler #1	2281	7470	7632	162
7818	NESE	5-140-89	Amoco Production Company Wehri #1	2284	8684	8894	210
7937	NENE	19-138-86	Amoco Production Company Olsen #1	1965	7192	7339	147
8395	SWSE	1-137-87	Sunmark Exploration Company Jacob Larson Sun #1	2211	7446	7616	170
8553	SENW	17-140-82	Shell Oil Company Vogel 22-17	1994	6433	6530	97
8630	SESW	2-134-83	Pennzoil Company Railroad Bend #2-24	2146	5949	5998	49

MOUNTRAIL

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Top	Bottom	Thickness
528	NWNE	25-157-89	William Herbert Hunt Anderson #1	2271	8465	8674	209
2695	NENW	9-150-92	Hunt Petroleum Corporation Josephine Dancing Bull #1	2115	10441	10691	250
4113	SENW	4-150-93	Texaco, Inc. - Skelly Oil Co. Fort Berthold - Allottees #1-A	2198	10737	10975	238
5072	NENE	22-158-94	Amerada Hess Corporation Erickson #2X	2367	9768	10000	232
5088	NENW	35-156-93	Shell Oil Company Shell - Texel #21-35	2409	10286	10536	250
5257	NWSW	34-151-90	McCulloch Oil Corporation Wahner #1-34	2223	9783	10012	229
6087	SWSE	9-157-94	Brownlie, Wallace, et al. Jorstad #9-34	2325	9689	9909	220

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Bottom	Thickness
			MOUNTRAIL (con't.)				
6289	NESW	10-155-91	Thomson Petroleum Inc. Harstad et al. #1	2281	9595	9837	242
6677	NESE	14-157-90	True Oil Company Halvorson #43-14	2305	8769	8989	220
6764	NENW	2-155-90	Donald C. Slawson Kuamme 2-1	2220	9062	9294	232
6872	NESE	16-153-88	Marathon Oil Company Olson State #1	2108	8746	8967	221
7570	NENE	9-155-94	Kissinger Petroleum Corp. Grondale #1-9	2072	10234	10472	238
7741	SWSW	28-156-94	Kissinger Petroleum Corp. Ortloff #13-28	2331	10382	10634	252
8071	NENW	3-152-90	Lear Petroleum School District #3, Well #1	1967	9225	9460	235
8371	SWSW	17-157-91	True Oil Company Kuster #14-17	2308	9381	9614	233
			OLIVER				
95	SESW	3-141-81	Youngblood and Youngblood Wachter #1	1924	6136	6213	77
3277	NESE	14-142-85	Sunray DX Oil Company Henke #1	2193	7567	7738	171
4940	SESW	24-142 85	General American Oil Co. Henke #1-24	2252	7606	7774	168

Well No.	Qtr.	Sec T-R	Operator Well Name	KB	Three Forks Top	Three Forks Bottom	Three Forks Thickness
			PIERCE				
435	SWNE	12-158-69	Elbert Jackson Brown Brown Heckman #1	1589	2567	2580	13
538	NESE	17-154-72	Calvert Exploration Ranberg #1	1566	-	3528	-
706	SESE	23-157-70	Shell Oil Company Gifford Marchus	1652	2963	2992	29
716	NWNE	3-158-70	Shell Oil Company Joseph Bacher #1	1608	2794	2822	28
780	NWSW	3-157-73	Earl F. Wakefield Christianson #1	1486	3396	3442	46
3920	SESE	23-152-74	A. J. Hodges Industries Martin #1	1605	-	3973	-
5576	SWSW	34-152-73	Getty Oil Company Ludwig Vetter #1	1579	-	3838	-
			RENVILLE				
1689	NENW	7-158-81	Anschutz Drilling Company Einar Christianson #1	1532	5442	5552	110
6436	SESE	5-163-87	Shell Oil Company Duerre #43-5	1822	6019	6210	191
6466	SWNE	3-163-87	Shell Oil Company Mott #32-3	1734	5846	6033	187
6504	SWNE	1-162-87	Stone Oil Company Ones #1	1716	6069	6261	192
6624	SENW	1-161-85	Shell Oil Company Osterberg #22X-1	1715	5838	6003	165
6684	NENW	2-161-85	Shell Oil Company Dennel - Osterberg #21-2	1713	5839	6001	162

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB		Three Forks	
					Top	Bottom	Thickness
			RENVILLE (con't.)				
7577	SWNW	15-160-86	Shell Oil Company Dewing #12-15	1842	6540	6733	193
			ROLETTE				
83	SENW	23-161-73	Lion Oil Company Sebelius #1	1627	3268	3301	33
316	NWSW	23-160-70	Evans Production Corporation Johnson #1	1691	2785	2823	38
553	NWSW	16-163-69	S. D. Johnson Lawston #1	1868	2594	2628	34
579	SWSE	3-163-70	S. D. Johnson Tinglestad - State #1	1902	2763	2802	39
615	SENE	20-162-69	Sun Oil Company William Wayne #1	1807	2658	2695	37
702	SESW	10-159-71	Shell Oil Company Ella M. Amble #1	1599	2974	2997	23
754	SWSW	18-161-70	British American Oil Prod Co. S. Grenier #1	1734	2925	2955	30
806	NESE	14-163-73	British American Oil Prod Co. H. Dietrich #1	2180	3565	3611	46
917	NESE	22-160-72	Lion Oil Company Nelson #1	1602	3060	3095	35
981	SENE	26-163-72	Lion Oil Company Lion #1 Danielson	2218	3445	3491	46
1630	NWSE	19-161-72	General Crude Oil Company A. Higgens #1	1633	3214	3248	34

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Bottom	Thickness
			SHERIDAN				
665	NENE	15-148-76	Caroline Hunt Trust Estate John Waltz Sr. #1	1793	4805	4834	29
684	NENE	1-147-75	Caroline Hunt Trust Estate Julius R. Matz #1	1849	-	4430	-
693	SWSW	19-146-76	Caroline Hunt Trust Estate Walter E. Bauer #1	1984	5189	5208	19
735	SWSW	16-146-74	Caroline Hunt Trust Estate C. A. Pfieffer #1	1994	-	4623	-
			SIOUX				
631	NESW	29-131-80	The Ohio Oil Company Standing Rock Sioux Tribal #1	1731	-	4508	-
6654	SESE	27-129-85	Unichem International Inc. Jacobs #1	2331	5759	5810	51
7930	SWSW	28-129-84	Chevron - Sonat Mortenson #1	2338	5897	5931	34
			SLOPE				
3588	SESE	21-134-105	Sun Oil Company Greer - Federal #1	2895	-	8978	-
4280	NESW	18-135-103	Amerada Petroleum Corp. Ivan Mitchell #1	2971	9677	9710	33
4749	SWNW	33-133-101	States Oil Company Sedevie #1	2976	9298	9371	73
5929	SWSW	10-135-101	Jerry Chambers-Oil Producer William Rabe #1	2788	9685	9789	104

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Three Forks Bottom	Thickness
			SLOPE (con't.)				
5933	SESW	9-133-102	Jerry Chambers-Oil Producer Burke #1	2897	9250	9300	50
6412	NWNE	34-136-101	Patrick Petroleum Company Federal #1	2751	9765	9871	106
6855	SENW	4-136-102	Gulf Oil Explor. & Prod Co. Federal Doty #1	2658	9788	9905	117
7016	SESW	23-133-100	Ladd Petroleum Corporation Sanders #23-24	2879	9198	9305	107
7132	SWSE	22-136-99	Terra Resources Inc. Witman #1-22	2686	9671	9820	149
7548	SENE	22-133-106	Terra Resources Inc. Wang #1-22	2828	–	8893	–
7890	SENW	23-134-100	Gulf Oil Explor. & Prod. Co. Gulf-Pogo-Narum 1-23-1C	2955	9527	9641	114
7987	NWSE	17-135-98	Cities Service Company Schmitt B #1	2870	9630	9783	153
			STARK				
344	SWNE	11-137-98	Plymouth Oil Company F. Fischer #1	2798	10042	10228	186
3515	NWNW	9-140-93	Continental Oil Company Stoxen #1	2292	9436	9613	177
5143	NENW	9-137-97	Lone Star Producing Company Wanner #1	2688	9862	10089	227
5255	NESW	22-137-95	Continental Oil Company Feimer - Anger #1	2717	9550	9752	202
6243	SENW	26-137-92	Energetics Incorporated Martin - Kilzer #22-26	2357	8534	8722	188

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Top	Three Forks Bottom	Thickness
			STARK (con't.)				
6307	NWSE	21-138-99	Impel Energy Corporation Beaudoin #10-21	2696	10213	10401	188
6447	SWNW	8-139-97	Anadarko Production Company Kostelecky #1	2496	10039	10212	173
6797	SESW	16-139-92	W. H. Hunt Trust Estate Rummel State #1	2494	9217	9379	162
7007	SESE	26-138-98	Supron Energy Corporation Privratsky #1	2756	10090	10278	188
7127	NWNE	30-139-96	Shell Oil Company Kostelecky #31-30	2520	9938	10118	180
7247	NESW	5-140-95	Hunt Energy Corporation Barta #1	2455	10115	10344	229
8088	NWNE	28-141-93	Mobil Oil Corporation Bernhardt #1	2165	9474	9655	181
8098	SENE	9-139-99	Monsanto Company Froelich #1	2611	10421	10632	211
8169	NENW	21-138-92	Gulf Oil Explor. & Prod. Co. Leviathan #1-21-1B	2272	8841	9009	168
8342	NWNW	36-140-95	Supron Energy Corporation Lawrence #1	2418	9818	10047	229
			TOWNER				
100	SWSE	35-161-68	Union Oil Co. of Calif. A. Saari #1	1717	-	2493	-
227	SESW	31-158-66	National Bulk Carriers Inc. Edna Louise Hild #1	1465	-	2151	-
390	SWSE	24-160-67	Midwest Exploration Corp. U. C. L. I. Amann #1	1544	-	2222	-

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Bottom	Thickness
			TOWNER (con't.)				
434	NWNW	27-163-68	Midwest Exploration Company Juntunen #1	1713	2292	2329	37
3980	SWSE	7-162-68	National Assoc. Petroleum Keith Dunlop #1	1761	2461	2497	36
4976	SWNE	22-163-65	Eagle Oil Company Elmer Cole #1	1634	-	-	-
4979	SWSW	24-163-67	James T. Wamsley, Trustee Wamsley #1 Johnson	1542	1921	1930	9
6372	NESE	11-158-66	Hawn Brothers & Gragg Drill. Rader et al. #1	1480	-	2010	-
			WARD				
47	SESW	23-155-81	Herbert Hunt Trust Wald #1	1596	5730	5848	118
52	NENE	24-156-85	Wanette Oil Company et al. M. O. Lee #1	1839	6764	6954	190
105	SWNE	2-153-85	Stanolind Oil & Gas Company W. Waswick #1	2175	7576	7797	221
126	SWSE	33-156-83	Quintana Production Company Chris W. Linnertz #1	1772	6388	6560	172
392	SWSW	21-157-85	Sam G. Harrison J. E. Anderson #1	1875	6997	7190	193
588	SWSE	33-152-82	W. H. Hunt F. C. Neumann	2087	6815	6973	158
656	NWNE	13-155-82	W. H. Hunt Guy Almy #1	1632	6042	6177	135
4923	NWNE	5-156-81	Union Oil Co. of Calif. Olson #1-B-5	1573	5679	5809	130

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Top	Three Forks Bottom	Thickness
			WARD (con't.)				
4990	NWSW	22-156-84	Anschutz Corporation et al. Musch #1	1788	6605	6778	173
4992	NESE	2-156-82	Union Oil Co. of Calif. Harold Anderson #1-1-2	1618	5831	5982	151
5105	NWNW	28-152-86	General Crude Oil Company Jerome Jensen #1	2120	8146	8360	214
5158	NENW	13-153-85	Union Oil Co. of Calif. Hanson #1-C-13	2117	7551	7758	207
6540	NENE	30-153-84	Koch Exploration Company Jacobson Federal #1-30	2123	7540	7740	200
7612	SESW	15-155-87	Marathon Oil Company Berg #15-24	2219	8151	8357	206
			WELLS				
207	SESE	27-146-73	Continental Oil Company Lueth #1	1933	-	4256	-
609	SWSE	14-148-71	Caroline Hunt Trust Estate George Leitner #1	1612	-	3392	-
642	NWNE	32-150-70	Caroline Hunt Trust Estate Obed Larson #1	1599	-	3293	
689	NENE	31-147-71	Caroline Hunt Trust Estate Norris Thormodsgard #1	1702	-	3622	-
			WILLIAMS				
2828	NWNW	15-154-98	Texaco Incorporated L. J. Hovde #1	2233	11142	11370	228

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Bottom	Thickness
			WILLIAMS (con't.)				
2887	SWSE	20-159-103	Hunt Oil Company Isabelle Legge #1	2001	9001	9170	169
3392	SESE	12-159-96	Co-op Refinery Association Goetz #1	2317	9343	9548	205
3442	CSW	19-159-95	Calvert Drilling and Prod. F. E. McCoy #1	2367	9480	9683	203
4323	NESW	26-158-95	Amerada Petroleum Corp. Hjalmer Ives #B-1	2460	9623	9810	187
4340	SWSW	2-154-95	Pan American Petroleum Corp. Clifford Marmon #1	1972	10010	10248	238
4572	SWNW	18-157-103	Miami Oil Producers, Inc. Nellie Miller #1	2293	9857	10029	172
4754	NESE	21-154-103	Sam Boren Rooke #1	2223	10589	10780	191
5114	SENW	21-158-103	Universal Resources Corp. Agnes Burns #1	2192	9560	9734	174
5315	CSE	26-156-96	Amerada Hess Corporation BLDU D-311	2357	9818	10012	194
5528	SWNE	29-157-95	Tiger Oil Company Olson #1-29	2313	9685	9880	195
5656	SWSW	3-157-95	Texacota Incorporated H. Borstad #1	2468	9725	9910	185
5762	SENW	32-156-103	True Oil Company Aafedt #22-32	2433	10475	10660	185
6362	NESW	18-155-95	Amerada Hess Corporation Marvin Iverson #23-18	2305	9866	10060	194
6388	NENE	35-155-96	Amerada Hess Corporation Capa Deep Unit 31-35 #1	2032	9654	9853	199

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	 Bottom	 Thickness

WILLIAMS (con't.)

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Top	Bottom	Thickness
6687	SWNE	16-154-95	Amerada Hess Corporation State E 32-16 #1	2300	10104	10315	211
6702	NWSW	30-157-101	Union Texas Petroleum Melvin Anderson #1	2383	10366	10556	190
6723	NESW	2-157-96	Apache Corporation et al. Delaney #1-2	2423	9996	10194	198
6745	SESW	10-159-97	Hunt Energy Halvorson #1	2317	9685	9889	204
6806	NWNE	8-155-101	Tenneco Oil Company Booke #1-8	2192	10580	10764	184
6847	SWNE	10-158-101	W. H. Hunt Trust Estate Tangen #1	2033	9547	9732	185
6896	NESE	22-157-100	W. H. Hunt Trust Estate KNOS #1	2075	10186	10380	194
6915	SWSW	26-156-95	Kissinger Petroleum Corp. Olson #13-26	2411	10216	10447	231
7004	NESE	30-155-100	Lamar Hunt Treffry #1	1898	10532	10725	193
7054	NENW	14-156-102	Patrick Petroleum Company Fedje #1	2151	10280	10461	181
7063	SWNW	22-157-97	Hunt Energy Corporation Johnson #1	2339	10524	10734	210
7330	NENE	33-159-100	W. H. Hunt Trust Estate Dragseth #1	2011	9463	9650	187
7405	SWNE	8-155-99	Al Aquitaine Explor. Ltd. R. B. Brown #1-8	2116	10779	10982	203
7470	NESE	1-153-99	Northwest Explor. Company Long Creek #2	2342	11266	11479	213
7632	SWNW	25-153-104	Gulf Oil Explor. & Prod. Co. Nordell #1-25-1D	2172	10567	10756	189

Well No.	Qtr.	Sec-T-R	Operator Well Name	KB	Three Forks Top	Bottom	Thickness
			WILLIAMS (con't.)				
7665	SESE	10-158-96	Northwest Explor. Company Sundhagen #2	2372	9840	10047	207
7712	SWSW	21-155-98	Shell Oil Company Kirk Patrick #14-21	2248	11076	11281	205
7848	NWSE	2-158-100	Depco Incorporated Smith #33-2	2140	9735	9927	192
7870	SWSE	4-158-103	Donald C. Slawson et al. T. M. Tribal #4-1	2146	9352	9523	171
7931	NWSE	33-155-97	Mapco Incorporated NCGA #14-33	2124	10809	11028	219
8239	SWNE	17-158-97	Lear Petroleum Oase #1	2298	10057	10253	196
8256	SWSW	13-154-100	Samedan Oil Corporation Soc Minerals #1	2241	11002	11192	190
8316	SWSE	18-159-102	Depco Incorporated Fischer #34-18	2157	9248	9429	181
8413	SENW	14-156-97	Depco Incorporated Whittrock #22-14	2255	10259	10452	193
8423	SESW	9-154-102	Gulf Oil Explor. & Prod. Co. Alfson #1-9-4C	2155	10614	10818	204
8441	NENE	1-153-100	Mapco Production Company Tofte #1-1	2313	11165	11360	195
8571	SWNW	9-155-102	Al Aquitaine Explor. Ltd. Jorgenson #1-9	2309	10581	10764	183

APPENDIX B

CORE AND THIN SECTION DESCRIPTIONS

Cores and thin sections are arranged alphabetically by county and numerically by North Dakota Geological Survey (NDGS) well numbers within counties. Core and thin section depths are recorded from core-box labels as filed with the NDGS Wilson M. Laird Core and Sample Library. Core descriptions are given in intervals listed on the left side of the page. Thin section descriptions are indented, and are listed by depth below the Kelly Bushing. Each core description is preceded by a legal description which includes well number (NDGS), location (section, township, and range), well operator, and well name. The elevation of Kelly Bushing (KB) in feet above sea level is included in the legal description.

Core description format is as follows: Rock name; color; fossil content; bedding structures; mineralogy; and miscellaneous features. Thin section description format is as follows: rock name; color; fossil content; bedding structures; mineralogy; and miscellaneous features. Standard terminology used in the descriptions have been proposed by the following authors: Folk (1959), rock name; Goddard et al. (1948), color; and Maiklem et al. (1969), anhydrite morphology and structures.

BILLINGS COUNTY

NDGS #9351

LEGAL: Supron Energy Corp./F-6-144-101, #3 NWSE 6-144-101 KB: 2203

Core depth	Core description	
	Thin section depth	Thin section description
10469.5	Dolomicrite; grayish-brown (5 YR 3/2) with grayish-olive green (5 GY 3/2) stringers; wavy laminations; intraclasts; pyritic; unconformable contact with Bakken Formation.	
	10469.5	Dolomicrite; grayish-brown; conodonts; intraclasts, spar calcite, dolomite, pyrite; unconformable contact with black shales of Bakken Formation.

DUNN COUNTY

NDGS #505

LEGAL: Socony Vacuum/Dvorak F-32-6P SENE 6-141-94 KB: 2296

Core depth	Core description	
	Thin section depth	Thin section description
10116-10126	Dolomicrite; olive gray (5 Y 3/2) and pale yellowish-brown (10 YR y/2); interbedded; quartz silt; micro-faulted.	
10126-10132	Dolomicrite; grayish-olive green (5 GY 3/2) and pale brown (5 YR 5/2); interbedded, cross-laminated; quartz silt.	
10132-10145	Argillaceous Dolomicrite; grayish-brown (5 YR 3/2); slightly mottled; pale orange (10 YR 8/2) nodular anhydrite.	
10145-10154	Argillaceous Dolomicrite; light olive gray (5 Y 5/2) and olive gray (5 Y 3/2); mottled; very pale orange (10 YR 8/2) to grayish-orange pink (5 YR 7/2) nodular anhydrite; micro-faulted.	
	10153.3	Argillaceous Dolomicrite; olive gray; gastropod, ostracode (?); mottled; intraclasts, microspar, dolomite, quartz silt, anhydrite; micro-faulted, fractured.
10154-10159	Dolomicrite; grayish-brown (5 YR 3/2) and pale yellowish-brown (10 YR 6/2); interbedded; quartz silt.	
10159-10169	Dolomicrite; light olive gray (5 Y 5/2) and grayish-brown (5 YR 3/2); interbedded; very pale orange (10 YR 8/2) distorted bedded nodular anhydrite.	
10169-10174	Missing	
10174-10183	Dolomicrite; light olive gray (5 Y 5/2) and light brown (5 YR 5/6); mottled.	
10183-10190	Argillaceous Micrite; dusky brown (5 YR 2/2); laminated; intraclasts.	
10190-10199	Argillaceous Micrite; grayish-brown (5 YR 3/2); laminated.	

10199-10205	Micrite; grayish-olive green (5 GY 3/2) and dark reddish-brown (10 R 3/4); interbedded; hematitic.
10205-10215	Argillaceous Micrite; grayish-brown (5 YR 3/2) and grayish-olive green (5 GY 3/2); mottled; grayish-orange pink (5 YR 7/2) distorted nodular mosaic anhydrite.

NDGS #607

LEGAL: Mobil Producing/Kennedy F-32-23-P SWNE 24-149-93 KB: 2146

Core depth	Thin section depth	Core description / Thin section description
10602-10604		Argillaceous Micrite; dark gray (N3); structureless to mottled.
10604-10607		Missing
10607-10610		Argillaceous Biomicrite; medium (N5) to dark gray (Ne); brachiopod; mottled; pyritic; bioturbated; geopetal infill.
	10607.5	Argillaceous Biomicrite; dark brown; brachiopod, echinoderm, and ostracode fragments; silicification; mottled; dolomite, quartz silt, blocky anhydrite, pyrite; organic partings, stylolites, burrowed.
	10608.2	Argillaceous Biomicrite; dark brown; brachiopod, bryozoan, echinoderm, and ostracode fragments; mottled; spar calcite, pseudospar, dolomite; organic partings, stylolites.
	10609.3	Argillaceous Biomicrite; dark brown; brachiopod, bryozoan, gastropod, echinoderm, mollusk, and ostracode fragments; mottled; spar calcite, pseudospar, dolomite, anhydrite, pyrite; stylolites, geopetal infill.
10610-10612		Argillaceous Dolomicrite; moderate blue-green (5 BG 4/6) and pale yellowish-brown (10 YR 6/2); interbedded, cross-laminated; quartz silt.
10612-10613		Dolomicrite; grayish-brown (5 YR 3/2); brecciated; quartz silt, intraclasts, pyritic; micro-faulted.
10613-10615		Dolomicrite; pale yellowish-brown (10 YR 6/2); cross-laminated; quartz silt.

10615- 10616 Argillaceous Dolomicrite; grayish-blue green (5 BG 5/2) and pale yellowish-brown (10 YR 6/2); interbedded, brecciated; intraclasts; micro-faulted, water escape structures.

10615.5 Argillaceous dolomicrite; grayish-blue green and dark yellowish-brown; interbedded, brecciated, wavy laminations; intraclasts, dolomite, quartz silt, blocky and lath anhydrite, pyrite; organic partings, water escape structure.

10616- 10622 Argillaceous Dolomicrite; grayish-blue green (5 BG 5/2) and pale yellowish-brown (10 YR 6/2); interbedded, cross-laminated, mottled; quartz silt; micro-faulted.

10622- 10625 Argillaceous Dolomicrite; grayish-blue green (5 BG 5/2) and pale yellowish-brown (10 YR 6/2); interbedded, brecciated, cryptalgal (?); quartz silt, intraclasts, pyritic; water escape structure.

10625- 10627 Argillaceous Dolomicrite; grayish-blue green (5 BG 5/2) and pale yellowish-brown (10 YR 6/2); interbedded, brecciated, cross-laminated, cryptalgal; quartz silt, bioturbated.

10625.7 Argillaceous Dolomicrite; grayish-blue green and yellowish-brown, ostracode fragments; interbedded, mottled, brecciated, cross-laminated; dolomite, blocky anhydrite, pyrite, hematite; organic partings, micro-faulted.

10627- 10628 Argillaceous Dolomicrite; grayish-blue green (5 BG 5/2); mottled.

10628- 10631 Argillaceous Dolomicrite; grayish-blue green (5 BG 5/2) and pale yellowish-brown (10 YR 6/2); interbedded, mottled, brecciated, cross-laminated; quartz silt, pyritic.

10629.3 Argillaceous Dolomicrite; olive gray and yellowish-brown, interbedded, mottled, brecciated, cross-laminated; intraclasts, spar calcite, dolomite, quartz silt, blocky anhydrite, pyrite, hematite; organic partings.

10631- 10633 Argillaceous Dolomicrite; grayish-blue green (5 BG 5/2) and pale yellowish-brown (10 YR 6/2); brecciated, wavy laminations; intraclasts, pyritic; micro-faulted.

10633- 10634 Argillaceous Dolomicrite; grayish-blue green (5 BG 5/2) and pale yellowish-brown (10 YR 6/2); interbedded, mottled, cross-laminated; quartz silt, pyritic; mud-cracks (?).

10633.4 Argillaceous Dolomicrite; bluish-green and yellowish-brown; interbedded, cross-laminated; microspar, dolomite, quartz silt, blocky anhydrite, pyrite; organic partings, fractured, mudcracked.

10634- 10637 Argillaceous Dolomicrite; grayish-blue green (5 BG 5/2) and pale yellowish-brown (10 YR 6/2); interbedded, mottled, cross-laminated; quartz silt.

10637- 10640 Argillaceous Dolomicrite; grayish-blue green (5 BG 5/2) and pale yellowish-brown (10 YR 6/2); mottled, brecciated, oncolite; intraclasts, pyritic; stylolites, micro-faulted, water escape structures.

10637.7 Argillaceous Dolomicrite; olive gray; mottled, brecciated; dolomite, anhydrite, pyrite.

10638.2 Argillaceous Dolomicrite; yellowish-brown; ostracode fragments; mottled, dolomite, quartz silt, blocky anhydrite, pyrite; organic partings, stylolites, burrowed.

10640- 10651 Missing

10651- Argillaceous Dolomicrite; olive gray (5 Y 3/2) and grayish-orange pink (5 YR 7/2); mottled; carbonaceous streaks; micro-faulted.

NDGS #793

LEGAL: Mobil Producing/Birdbear #1 SENW 22-149-91 KB: 2092

(Core and thin section depths disagree by approximately 10 feet with the mechanical log and have been adjusted accordingly.)

Core depth — Core description

Thin section depth — Thin section description

10078- 10085 Micrite; dark gray (N3); laminated; quartz silt.

10085-10091 Argillaceous Dolomicrite; dark gray (N3) and light olive gray (5 Y 5/2); mottled; quartz silt, intraclasts, pyritic; bioturbated, micro-faulted.

10088.7 Argillaceous Dolomicrite; light brown; mottled; intraclasts, dolomite, quartz silt, blocky anhydrite, pyrite; organic partings, bioturbated.

10089.5 Argillaceous Dolomicrite; brownish-gray; brachiopod fragment; mottled; dolomite, quartz silt, blocky and replacement anhydrite, pyrite; bioturbated.

10090.5 Argillaceous Dolomicrite; yellowish-brown; mottled; spar calcite, dolomite, quartz silt, blocky anhydrite, pyrite; slightly bioturbated.

10091-10115 Argillaceous Dolomicrite; pale yellowish-brown (10 YR 6/2) and olive gray (5 Y 3/2); interbedded, cross-laminated, cryptalgal; quartz silt, intraclasts; micro-faulted, water escape structures, tepee structure, mudcracked.

10091.3 Argillaceous Dolomicrite; olive gray and yellowish-brown; mottled; intraclasts, dolomite, quartz silt, blocky anhydrite, pyrite.

10093 As above; dark yellowish-brown; intraclasts, replacement anhydrite.

10093.8 As above; olive gray; fracture-filling anhydrite; stylolites.

10097 Argillaceous Dolomicrite; yellowish-brown and olive gray, interbedded, laminated; intraclasts, dolomite, quartz silt, blocky and fracture-filling anhydrite, pyrite; organic partings, stylolites, water escape structures, fractured.

10098.7 As above; wispy laminations; spar calcite.

1012 As ahove

10115-10126 Argillaceous Dolomicrite; pale brown (5 YR 5/2); cross-laminated, cryptalgal; quartz silt, intraclasts; water escape structures.

10115.6 Argillaceous Dolomicrite; dark yellowish-brown; massive bedded; intraclasts, dolomite, quartz silt, blocky and replacement anhydrite.

10124.3 Argillaceous Dolomicrite; yellowish-brown and olive green; interbedded, laminated; intraclasts, dolomite, quartz silt, blocky anhydrite, pyrite; organic partings, stylolites, water escape structure.

10126-10135 Argillaceous Dolomicrite; olive gray (5 Y 3/2) and pale yellowish-brown (10 YR 6/2); massive bedded; intraclasts, stylolites.

10135-10155 Argillaceous Dolomicrite; pale yellowish-brown (10 YR 6/2) and grayish-green (5 G 5/2); interbedded, mottled; quartz silt, intraclasts; micro-faulted.

10152.7 Argillaceous Dolomicrite; yellowish-brown and grayish-green; ostracode fragments; mottled, laminated; intraclasts, spar calcite, dolomite, quartz silt, blocky anhydrite, pyrite; stylolites.

10154.8 As above.

10155-10165 Missing

10165-10185 Argillaceous Dolomicrite; dusky brown (5 YR 2/2) and olive gray (5 Y 3/2); mottled; intraclasts; micro-faulted.

10165-10185 (position in box unknown) Argillaceous Dolomicrite; olive gray; mottled; intraclasts, spar calcite, dolomite, quartz silt, blocky anhydrite, pyrite; organic partings, stylolites.

10185-10188 Missing

10188-10201 Argillaceous Micrite; grayish-brown (5 YR 3/2); mottled; intraclasts.

10201-10207 Argillaceous Micrite; grayish-brown (5 YR 3/2) and grayish-olive green (5 GY 3/2); interbedded, cross-laminated; quartz silt, intraclasts; micro-faulted, mudcracked.

10205 Argillaceous Micrite; grayish-olive green; mottled; intraclasts, microspar, dolomite, blocky anhydrite, pyrite; stylolites.

10207-10211 Argillaceous Micrite; grayish-olive (10 Y 4/2) and grayish-olive green (5 GY 3/2); slightly mottled, laminated; quartz silt; micro-faulted.

10210.8 Argillaceous Micrite; grayish-olive green; ostracode (?) fragments; laminated, graded bedding; intraclasts, microspar, dolomite, quartz silt, anhydrite, pyrite; micro-faulted.

10211-
10219 Argillaceous Dolomicrite; grayish-brown (5 YR 3/2) and grayish-olive green (5 GY 3/2); interbedded, mottled, finely laminated; light bluish-gray (5 B 7/1) and very pale orange (10 YR 8/2) distorted nodular anhydrite.

10215.1 Argillaceous Dolomicrite; grayish-brown and grayish-olive green; mottled; intraclasts, spar calcite, dolomite, quartz silt, blocky and felted anhydrite, pyrite, hematite; stylolites.

10217.8 As above; laminated; intraclasts.

10219.6 As above; intraclasts, spar calcite.

10219-
10237 Argillaceous Dolomicrite; grayish-brown (5 YR 3/2); wavy laminzations; white (N9) distorted mosaic anhydrite, intraclasts; micro-faulted.

10222.3 Argillaceous Dolomicrite; grayish-brown; wavy laminations; intraclasts, spar calcite, dolomite, quartz silt, felted anhydrite, pyrite, hematite, stylolites.

10222.8 As above; ostracode fragments; intraclasts, blocky anhydrite; stylolites.

10227.6 As above; yellowish-brown; ostracode (?) fragments; wispy laminations; intraclasts, blocky anhydrite.

10228.7 As above; grayish-olive green; massive bedded; intraclasts, blocky anhydrite.

10230.1 As above; massive bedded; intraclasts, blocky and felted anhydrite; stylolites.

10237-
10243 Argillaceous Dolomicrite; grayish-brown (5 YR 3/2) and grayish-olive green (5 GY 3/2); interbedded, wavy laminations, cryptalgal; very pale orange (10 YR 8/2) distorted nodular anhydrite; stylolites.

10238.2 Argillaceous Dolomicrite; grayish-brown grading into grayish-olive green; ostracode fragments; mottled; intraclasts, spar calcite, dolomite, quartz silt, blocky anhydrite, pyrite, hematite; micro-faulted.

10243-10248 Argillaceous Dolomicrite; grayish-brown (5 YR 3/2); slightly mottled; very pale orange (10 YR 8/2) distorted bedded nodular anhydrite; stylolites.

10243.2 Argillaceous Dolomicrite; grayish-brown; ostracode (?) fragments; massive bedded; intraclasts, dolomite, quartz silt, blocky anhydrite, hematite.

10246.1 As above; mottled; microspar, fracture-filling anhydrite.

10248-10253 Argillaceous Dolomicrite; grayish-green (5 G 5/2); mottled, wavy laminations; very pale orange (10 YR 8/2) distorted bedded nodular anhydrite, intraclasts, stylolites.

10248.2 Argillaceous Dolomicrite; grayish-green; mottled; dolomite, quartz silt, felted and lath anhydrite, pyrite.

10253-10255 Missing

10255-10269 Argillaceous Dolomicrite; dusky brown (5 YR 2/2) and grayish-olive (10 Y 4/2); interbedded; light bluish-gray (5 B 7/1) and very pale orange (10 YR 8/2) distorted nodular anhydrite, intraclasts; stylolites, mudcracked.

10256.5 Argillaceous Dolomicrite; yellowish-brown; massive bedded; dolomite, quartz silt, aligned-felted anhydrite, pyrite.

10265 As above; grayish-olive; mottled; intraclasts, spar calcite, blocky anhydrite, hematite; organic partings.

10269-10277 Argillaceous Micrite; dusky brown (5 YR 2/2); slightly mottled; intraclasts.

10277-10280 Argillaceous Micrite; dusky brown (5 YR 2/2) and olive gray (5 Y 3/2); mottled; very pale orange (10 YR 8/2) distorted bedded nodular anhydrite.

10279.1 Argillaceous Micrite; dusky brown; ostracode fragments; mottled; intraclasts, microspar, dolomite, quartz silt, blocky anhydrite, pyrite, hematite; stylolites.

10279.2 — As above; dusky brown and olive gray; interlaminted, wisphy laminated; intraclasts, spar calcite, felted anhydrite; organic partings, stylolites, micro-faulted, fractured.

10280-10283 — Argillaceous Dolomicrite; dusky brown (5 YR 2/2); faintly laminated; very pale orange (10 YR 8/2) massive anhydrite.

10281.6 — Argillaceous Dolomicrite; dusky brown; ostracode (?) fragments; wavy laminations; dolomite, felted anhydrite, hematite.

10283-10292 — Argillaceous Micrite; olive gray (5 Y 3/2) and grayish-brown (5 YR 3/2); interbedded, laminated; quartz silt, light bluish-gray (5 B 7/1) and very pale orange (10 YR 8/2) distorted nodular anhydrite, intraclasts; micro-faulted.

10283.4 — Argillaceous Micrite; olive gray; slightly mottled; intraclasts, microspar, dolomite, felted anhydrite.

10286.2 — As above; intraclasts, lath and blocky anhydrite, pyrite; stylolites.

10288.5 — As above; spar calcite, replacement anhydrite, pyrite, glauconite.

10289.8 — As above; grayish-brown; ostracode fragments; intraclasts, microspar, quartz silt, pyrite, hematite, glauconite; stylolites.

10292-10296 — Argillaceous Micrite; dark yellowish-brown (10 YR 4/2); wavy laminations; very pale orange (10 YR 8/2) distorted nodular anhydrite; carbonaceous streaks.

10292.3 — Argillaceous Dolomicrite; dark yellowish-brown; ostracode fragments; mottled; dolomite, felted anhydrite, pyrite; stylolites.

10296-10298 — Argillaceous Micrite; dusky brown (5 YR 2/2); wavy laminations; pale yellowish-brown (10 YR 8/6) nodular anhydrite; carbonaceous streaks.

10296 — Argillaceous Micrite; yellowish-brown; ostracode fragments; structureless; spar calcite, replacement anhydrite, pyrite; organic partings, stylolites.

10297.4 — As above; laminated; spar calcite, dolomite, blocky anhydrite; stylolites.

10298- 10302 Argillaceous Dolomicrite; grayish-brown (5 YR 3/2); wavy laminations, cryptalgal; white (N9) distorted nodular anhydrite, intraclasts; carbonaceous streaks.

10298.6 Anhydrite, felted to aligned-felted; white; wavy laminations; pyrite, argillaceous; organic partings, stylolites.

10301.5 Argillaceous Dolomicrite; grayish-brown; wispy laminations; dolomite, felted and blocky anhydrite, pyrite; organic partings, stylolites.

NDGS #511

LEGAL: Socony Vacuum/Jacobs #1 SWSW 24-134-96 KB: 2616

Core depth	Thin section depth	Core description / Thin section description
8932-8938		Argillaceous Micrite; grayish-brown (5 YR 3/2) and dusky yellow green (5 GY 5/2); interbedded, mottled; intraclasts.
	8936.2	Argillaceous Micrite; grayish-brown; ostracode and gastropod (?) fragments; mottled; intraclasts, microspar, dolomite, felted nodular anhydrite, hematite, glauconite.
8938-8944		Argillaceous Micrite; dusky brown (5 YR 2/2) and grayish-olive (10 Y 4/2); interbedded, mottled, faintly laminated; moderate reddish-orange (10 R 6/6) distorted bedded nodular anhydrite; micro-faulted.
	8942	Argillaceous Micrite; olive gray; ostracode fragments; mottled; spar calcite, dolomite, felted nodular anhydrite, pyrite, hematite, glauconite.
8944-8949		Argillaceous Dolomicrite; light olive gray (5 Y 5/2) and olive gray (5 Y 3/2); mottled; light bluish-gray (5 B 7/1) distorted bedded nodular anhydrite; carbonaceous streaks, micro-faulted, water escape structures.
	8947.3	Agrillaceous Micrite; olive gray; wavy laminations; intraclasts, spar calcite, dolomite, quartz silt, felted nodular anhydrite, pyrite, hematite; organic partings, stylolites.
	8948	Argillaceous Micrite; olive gray; wavy laminations; spar calcite, dolomite, quartz silt, felted nodular anhydrite, pyrite, glauconite; organic partings, stylolites, fractured.
8949-8950		Argillaceous Micrite; dusky yellowish-green (5 GY 5/2) and dark yellowish-brown (10 YR 4/2); interbedded; light bluish-gray (5 B 7/1) distorted bedded nodular anhydrite; carbonaceous streaks.

8949.2 Argillaceous Micrite; yellowish-brown; ostracode fragments; mottled; intraclasts, microspar, dolomite, quartz silt, felted nodular anhydrite, pyrite, glauconite.

8949.7 Argillaceous Dolomicrite; yellowish-brown; ostracode fragments; mottled; dolomite, quartz silt, felted nodular anhydrite, hematite; stylolites, fractured.

McKENZIE COUNTY

NDGS #33

LEGAL: Amerada Petroleum/Risser #1 SWSE 12-149-96 KB: 2438

Core depth	Core description	
	Thin section depth	Thin section description
11022-11042	Argillaceous Dolomicrite; dark yellowish-brown (10 YR 4/2) and olive gray (5 Y 3/2); interbedded, laminated; intraclasts.	
11042-11057	Argillaceous Dolomicrite; dark yellowish-brown (10 YR 4/2) and pale yellowish-brown (10 YR 6/2); mottled.	
11057-11079.5	Argillaceous Dolomicrite; pale brown (5 YR 5/2) and light olive (10 Y 5/4); interbedded; grayish-orange pink (5 YR 7/2) bedded nodular mosaic anhydrite.	
11079-5-11082	Argillaceous Micrite; light olive gray (5 Y 5/2); wavy laminations; intraclasts.	
11082-11093	Argillaceous Micrite; olive gray (5 Y 3/2); finely laminated.	
11093-11103	Argillaceous Micrite; grayish-olive (10 Y 4/2) and dark gray (N3); interbedded, slightly mottled, brecciated.	
	11099.7	Argillaceous Micrite; grayish-olive; wavy laminations, brecciated; intraclasts, microspar, dolomite, quartz silt, anhydrite, hematite.
11103-11107.5	Argillaceous Micrite; olive gray (5 Y 3/2) and pale yellowish-brown (10 YR 6/2); interbedded, wavy laminations; light bluish-gray (5 B 7/1) distorted bedded nodular anhydrite.	
11107.5-11112	Argillaceous Micrite; olive gray (5 Y 3/2) and dark reddish-brown (10 R 3/4); interbedded, wavy laminations; water escape structures, mudcracked.	
	11108.3	Argillaceous Dolomicrite; olive gray; ostracode fragments; wavy laminations; intraclasts, dolomite, felted nodular anhydrite.
	11110.1	Argillaceous Dolomicrite; olive gray and yellowish-brown, ostracode fragments; interbedded, contorted laminations; dolomite, blocky anhydrite.

11112- 11115	Argillaceous Dolomicrite; grayish-olive (10 Y 4/2); wavy laminations; grayish-orange pink (5 YR 7/2) distorted nodular anhydrite.
11115- 11138	Argillaceous Dolomicrite; grayish-olive (10 Y 4/2) and grayish-brown (5 YR 3/2); interbedded, finely laminated; light bluish-gray (5 B 7/1) and very pale orange (10 YR 8/2) distorted bedded nodular anhydrite, intraclasts.
11138- 11142	Argillaceous Dolomicrite; grayish-brown (5 YR 3/2) and grayish-olive green (5 GY 3/2); interbedded, finely laminated; light bluish-gray (5 B 7/1) and grayish-orange pink (5 YR 7/2) bedded nodular mosaic anhydrite.

NDGS #527

LEGAL: California Co./Rough Creek Unit #1 NWNE 13-148-98 KB: 2472

Core depth	Core description	
	Thin section depth	Thin section description
11286- 11292	Argillaceous Biomicrite; dark gray (N3); brachiopod; mottled; pyritic; bioturbated, geopetal infill.	
	11287	Argillaceous Biomicrite; dark brown; brachiopod, bryozoan, echinoderm, and ostracode fragments; mottled; spar calcite, anhydrite, pyrite; organic partings, stylolites, geopetal infill.
	11287.2	Argillaceous Biomicrite; dark brown; brachiopod, bryozoan (?), and echinoderm fragments; mottled; spar calcite, anhydrite, pyrite; organic partings, stylolites, geopetal infill.
	11290.3	Argillaceous Biomicrite; dark brownish-gray; brachiopod and ostracode fragments; mottled; dolomite, quartz silt, blocky anhydrite, pyrite; organic partings, stylolites, burrowed.
11292- 11295	Micrite; pale yellowish-brown (10 YR 6/2); cross-laminated; quartz silt, intraclasts, pyritic; fractured.	
11295- 11298	Dolomicrite; grayish-olive (10 Y 4/2) and dusky brown (5 YR 2/2); interbedded; intraclasts.	
11298- 11304	Dolomicrite; grayish-green (5 G 5/2) and grayish-brown (5 YR 3/2); mottled; fractured, mudcracked.	

11304- Argillaceous Micrite; grayish-green (5 G 5/2) and dark
11313 yellowish-brown (10 YR 4/2); interbedded, laminated, cross-laminated; quartz silt; micro-faulted.

11313- Micrite; grayish-green (5 G 5/2) and pale yellowish-brown
11316 (10 YR 6/2); interbedded, cross-laminated; quartz silt, pyritic.

11316- Micrite; olive black (5 Y 2/1); cross-laminated; grayish-
11319 orange pink (5 YR 7/2) bedded massive anhydrite; water escape structure.

11319- Argillaceous Micrite; grayish-brown (5 YR 3/2) and greenish-
11325 black (5 GY 2/1); interbedded, mottled; micro-faulted, mudcracked.

11320.4 Argillaceous Dolomicrite; grayish-brown; mottled, wispy laminations; intraclasts, dolomite, quartz silt, blocky anhydrite, pyrite, hematite.

11325- Dolomicrite; brownish-gray (5 YR 4/1); brecciated; micro-
11328 faulted.

11327 Dolomicrite; brownish-gray; ostracode fragments; slightly mottled; microspar, dolomite, blocky anhydrite, hematite.

11328- Argillaceous Micrite; grayish-brown (5 YR 3/2) and dark
11331 yellowish-brown (10 YR 4/2); interbedded, cross-laminated; quartz silt; micro-faulted.

11329.5 Argillaceous Micrite; grayish-brown; mottled; intraclasts, microspar, dolomite, quartz silt, blocky anhydrite, hematite.

11331- Dolomicrite; dark greenish-gray (5 GY 4/1); mottled;
11334 grayish-orange pink (5 YR 7/2) bedded nodular mosaic anhydrite.

11334- Dolomicrite; blackish-red (5 R 2/2) to grayish-brown
11337 (5 YR 3/2); intraclasts.

11337- Argillaceous Dolomicrite; dark gray (N3); wavy lamina-
11340 tions; carbonaceous streaks.

NDGS #956

LEGAL: Gulf Oil/Federal #1 NWSW 28-148-104 KB: 2339

Core depth	Core description	
	Thin section depth	Thin section description
10680-10690	Argillaceous Dolomicrite; dark gray (N3) and olive gray (5 Y 3/2); interbedded, mottled; light grayish-orange pink (5 YR 7/2) bedded massive anhydrite, pyritic; micro-faulted, fractured.	
	10686.5	Argillaceous Dolomicrite; yellowish-brown and olive gray; mottled; dolomite, quartz silt, pyrite.
	10687.1	Argillaceous Dolomicrite; yellowish-brown and olive gray; mottled; dolomite, quartz silt, blocky anhydrite, pyrite; stylolites.
10690-10696	Dolomicrite; dark gray (N3) and grayish-olive (10 Y 4/2); interbedded; very pale orange (10 YR 8/2) fracture-filling anhydrite and moderate orange pink (10 R 7/4) bedded nodular anhydrite; micro-faulted.	
10696-10698	Argillaceous Dolomicrite; light olive gray (5 Y 5/2) and dark gray (N3); interbedded, finely laminated.	
	10697.3	Argillaceous Dolomicrite; olive gray and yellowish-brown; interbedded, laminated; intraclasts, dolomite, quartz silt, anhydrite, pyrite.
10698-10701	Argillaceous Dolomicrite; grayish-olive (10 Y 4/2); wavy laminations; grayish-orange pink (5 YR 7/2) bedded massive anhydrite.	
10701-10724	Argillaceous Dolomicrite; grayish-brown (5 YR 3/2) and grayish-olive (10 Y 4/2); interbedded, wavy laminations.	
10724-10727	Argillaceous Dolomicrite; grayish-olive (10 Y 4/2) and pale yellowish-brown (10 YR 6/2); interbedded; quartz silt, pyrite, hematite.	
	0725.9	Argillaceous Dolomicrite; grayish-olive and yellowish-brown; mottled; intraclasts, dolomite, quartz silt, pyrite, hematite.

10727- 10729 Argillaceous Dolomicrite; grayish-brown (5 YR 3/2) and pale yellowish-brown (10 YR 6/2); interbedded; quartz silt; water escape structure.

10727.3 Argillaceous Dolomicrite; dark yellowish-brown; cross-laminated; intraclasts, dolomite, quartz silt, blocky anhydrite, pyrite, hematite.

10729- 10732 Argillaceous Dolomicrite; grayish-green (5 G 5/2) and grayish-brown (5 YR 3/2); mottled; moderate orange pink (10 R 7/4) bedded nodular mosaic anhydrite; micro-faulted.

NDGS #1254

LEGAL: Northern Pump/Rohde #1 SWSE 17-152-94 KB: 2168

Core depth — Core description

Thin section depth — Thin section description

10455- 10467 Dolomicrite; grayish-green (5 G 5/2) and grayish-brown (5 YR 3/2); interbedded, cross-laminated; quartz silt, pyritic; micro-faulted, water escape structures, fractured.

10467- 10475 Dolomicrite; grayish-green (5 G 5/2) and grayish-brown (5 YR 3/2); interbedded, brecciated, cross-laminated; pyritic; micro-faulted.

10475- 10485 Dolomicrite; grayish-green (5 G 5/2) and grayish-brown (5 YR 3/2); interbedded, cross-laminated; quartz silt, pyritic; stylolites, water escape structure.

10482.5 Dolomicrite; grayish-brown; laminated; dolomite, quartz silt, blocky anhydrite, pyrite; stylolites.

NDGS #1606

LEGAL: Amerada Petroleum/Tract #1 NESW 35-150-97 KB: 2334

Core depth — Core description

Thin section depth — Thin section description

10963- 10966 Argillaceous Biomicrite; olive black (5 Y 2/1); brachiopod; mottled; pyritic.

10965.7 Argillaceous Biomicrite; dark yellowish-brown; brachiopod, bryozoan, echinoderm, and ostracode fragments; mottled; microspar, pseudospar, chalcedony, quartz silt, anhydrite, pyrite.

10966-10969 Argillaceous Dolomicrite; dusky yellowish-brown (10 YR 2/2) and pale yellowish-brown (10 YR 6/2); interbedded, brecciated, cross-laminated; quartz silt, light bluish-gray (5 B 7/1) nodular anhydrite, pyritic; micro-faulted.

10969-10972 Argillaceous Dolomicrite; grayish-olive (10 Y 4/2) and grayish-brown (5 YR 3/2); interbedded, cross-laminated; quartz silt; micro-faulted, water escape structure.

10972-10996 Argillaceous Dolomicrite; grayish-green (5 G 5/2) and dark yellowish-brown (10 YR 4/2); interbedded, brecciated, finely laminated, cross-laminated; quartz silt, intraclasts, pyritic; micro-faulted, water escape structures, mudcracked, ripple marked.

10982.3 Argillaceous Dolomicrite; grayish-green and dark yellowish-brown; interbedded, wavy laminations; dolomite, quartz silt, blocky anhydrite, pyrite, hematite.

10989.2 Argillaceous Dolomicrite; grayish-green and dark yellowish-brown; interbedded, wavy laminations; intraclasts, dolomite, quartz silt, blocky anhydrite, pyrite, hematite; micro-faulted, mudcracked.

10991 Argillaceous Dolomicrite; grayish-green and yellowish-brown; mottled; intraclasts, dolomite, quartz silt, blocky anhydrite, pyrite.

10996-10999 Argillaceous Dolomicrite; grayish-olive (10 Y 4/2) and pale yellowish-brown (10 YR 6/2); interbedded, brecciated, cross-laminated; quartz silt, intraclasts, pyritic; micro-faulted.

10999-11003 Argillaceous Dolomicrite; grayish-olive green (5 GY 3/2) and dark yellowish-brown (10 YR 4/2); interbedded, brecciated, cross-laminated; quartz silt, pyritic; micro-faulted.

NDGS #1886

LEGAL: Amerada Petroleum/Dinwoodie #1 NWSE 33-153-94 KB: 2259

Core depth	Core description
	Thin section depth / Thin section description
10721-10735	Argillaceous Micrite; pale yellowish-brown (10 YR 6/2) and grayish-green (5 G 5/2); interbedded, brecciated; pyritic; micro-faulted, water escape structures.

NDGS #2820

LEGAL: Texaco Inc./Keogh #4 NWSW 5-151-95 KB: 2416

Core depth	Core description
	Thin section depth / Thin section description
10650-10653	Argillaceous Dolomicrite; grayish-green (5 G 5/2) and dark yellowish-brown (10 YR 4/2); interbedded, cross-laminated; quartz silt, pyritic; water escape structures.
10653-10660	Argillaceous Micrite; grayish-green (5 G 5/2) and pale brown (5 YR 5/2); interbedded, cross-laminated; quartz silt.
10660 10666	As above; pyritic.
10666-10673	Micrite; grayish-green (5 G 5/2) and dark yellowish-brown (10 YR 4/2); mottled; quartz silt, intraclasts, pyritic; micro-faulted.
10673-10680	Argillaceous Micrite; grayish-green (5 G 5/2) and pale yellowish-brown (10 YR 6/2); interbedded, brecciated, cross-laminated; quartz silt, intraclasts; water escape structure.
10680-10686	Dolomicrite; pale yellowish-brown (10 YR 6/2) and dusky brown (5 YR 2/2); mottled; quartz silt, intraclasts, pyritic.
10686-10689	Dolomicrite; pale olive (10 Y 6/2), moderate brown (5 YR 3/4), and dusky brown (5 YR 2/2); mottled; pyritic.

NDGS #2967

LEGAL: Texaco Inc./Wisness #2 NWSE 3-152-96 KB: 2317

Core depth	Core description	
	Thin section depth	Thin section description
10301-10303	Argillaceous Micrite; grayish-green (5 G 5/2) and pale brown (5 YR 5/2); interbedded, cross-laminated, contorted laminations; quartz silt, intraclasts; pattern dolomite, burrowed, micro-faulted, water escape structures.	
	10302.7	Argillaceous Micrite; grayish-green; brachiopod fragments; contorted bedding; dolomite, quartz silt, pyrite; burrowed.
10303-10317	Argillaceous Micrite; grayish-green (5 G 5/2) and pale brown (5 YR 5/2); interbedded, cross-laminated, cryptalgal; quartz silt, intraclasts, pyritic; water escape structures.	
	10305.2	Argillaceous Dolomicrite; grayish-green and pale brown; interbedded, laminated; intraclasts, quartz silt, pyrite; water escape structure.
10317-10329	Argillaceous Dolomicrite; grayish-green (5 G 5/2) and pale brown (5 YR 5/2); interbedded, cross-laminated, cryptalgal; quartz silt, intraclasts, pyritic; micro-faulted, water escape structures.	
	10319.6	Argillaceous Dolomicrite; pale brown; wavy laminations; intraclasts, dolomite, quartz silt, blocky anhydrite, pyrite, hematite; organic partings.
10329-10334	Argillaceous Micrite; dusky brown (5 YR 2/2) and light olive gray (5 Y 5/2); interbedded, mottled, finely laminated; intraclasts.	
10334-10338	As above; pyritic; micro-faulted.	
10338-10340	Dolomicrite; grayish-olive (10 Y 4/2) and dark yellowish-brown (10 YR 4/2); interbedded, finely laminated; pyritic; fractured.	

NDGS #4264

LEGAL: Texaco-Amerada/NCT-2 #3 NENW 3-153-95 KB: 2193

Core depth	Core description	
	Thin section depth	Thin section description
10033-10036	Dolomicrite; pale yellowish-brown (10 YR 6/2) and dusky brown (5 YR 2/2); interbedded, cross-laminated; quartz silt, light bluish-gray (5 B 7/1) distorted nodular mosaic anhydrite.	
10036-10039	Missing	
10039-10045	Argillaceous Dolomicrite; pale yellowish-brown (10 YR 6/2) and grayish-brown (5 YR 3/2); interbedded; micro-faulted, water escape structures.	
	10040	Argillaceous Dolomicrite; pale yellowish-brown; wispy laminations; dolomite, quartz silt, blocky anhydrite, pyrite.
10045-10050	As above; quartz silt, intraclasts.	
10050-10055	Argillaceous Dolomicrite; dusky brown (5 YR 2/2) and pale yellowish-brown (10 YR 6/2); interbedded, mottled; intraclasts, pyritic; micro-faulted.	
10055-10059	Missing	
10059-10061	Argillaceous Micrite; grayish-green (5 G 5/2) and moderate brown (5 YR 3/4); mottled, brecciated; micro-faulted.	
10061-10066	Argillaceous Dolomicrite; grayish-green (5 G 5/2) and moderate brown (5 YR 3/4); mottled, brecciated; pyritic; micro-faulted.	
10066-10069.5	Dolomicrite; dark yellowish-brown (10 YR 4/2) and light olive gray (5 Y 5/2); mottled; intraclasts, pyritic.	
10069.5-10071	Argillaceous Dolomicrite; grayish-brown (5 YR 3/2); finely laminated; very pale orange (10 YR 8/2) bedded nodular anhydrite.	

MOUNTRAIL COUNTY

NDGS #4113

LEGAL: Texaco-Skelly Oil/Ft. Berthold #1-A SENW 4-150-90 KB: 2198

Core depth	Core description	
	Thin section depth	Thin section description
10741-10745	Argillaceous Biomicrite; dark yellowish-brown (10 YR 4/2) and dark gray (N3); brachiopod; interbedded, mottled; quartz silt, intraclasts, pyritic; bioturbated.	
	10743.5	Argillaceous Biomicrite; dark yellowish-brown; brachiopod fragments; wispy laminations; microspar, dolomite, quartz silt, blocky anhydrite, pyrite; organic partings.
	10744.8	Argillaceous Micrite; dark yellowish-brown and moderate brown; interbedded, wavy laminations; microspar, dolomite, quartz silt, pyrite, hematite; organic partings; burrowed.
10745-10748	Argillaceous Micrite; grayish-green (5 G 5/2) and pale yellowish-brown (10 YR 6/2); interbedded, cross-laminated; quartz silt; bioturbated.	
	10745.7	Argillaceous Dolomicrite; yellowish-brown; mottled; intraclasts, dolomite, quartz silt, blocky anhydrite, pyrite, hematite; organic partings, burrowed.
10748-10752	As above; brecciated; intraclasts, pyritic; micro-faulted, water escape structures.	
10752-10756	Micrite; grayish-green (5 G 5/2) and pale yellowish-brown (10 YR 6/2); interbedded, brecciated, cross-laminated; quartz silt, intraclasts; micro-faulted.	
10756-10760	As above; white (N9) distorted nodular anhydrite, intraclasts.	

WARD COUNTY

NDGS #105

LEGAL: Stanolind Oil/Waswick #1 SWNE 2-153-85 KB: 2175

Core depth	Core description
	Thin section depth / Thin section description
7594-7597	Argillaceous Dolomicrite; grayish-green (5 G 5/2) and light olive gray (5 Y 5/2); mottled; intraclasts.
7597-7604	Micrite; yellowish-gray (5 Y 8/1) with few grayish-green (5 G 5/2) mudstone partings; massive bedded, mottled; quartz silt; stylolites.
7604-7612	Dolomicrite; dusky yellowish-green (10 GY 3/2) and grayish-green (5 G 5/2); mottled; quartz silt, large nodular pyrite.

WILLIAMS COUNTY

NDGS #2828

LEGAL: Texaco Inc./Hovde #1 NWNW 15-154-98 KB: 2233

Core depth	Core description	
	Thin section depth	Thin section description
11142-11152	Argillaceous Micrite; grayish-green (5 G 5/2) and pale yellowish-brown (10 YR 6/2); interbedded, cross-laminated; quartz silt, intraclasts, pyritic.	
	11142.6	Argillaceous Dolomicrite; grayish-green and dark yellowish-brown; mottled; intraclasts, dolomite, quartz silt, blocky anhydrite, pyrite, hematite.
11152-11156	Argillaceous Dolomicrite; grayish-green (5 G 5/2) and grayish-brown (5 YR 3/2); interbedded, wavy laminations.	
11156-11163	Micrite; grayish-green (5 G 5/2) and pale yellowish-brown (10 YR 6/2); interbedded, mottled, cross-laminated; quartz silt, intraclasts, pyritic; water escape structures.	
11163-11167	Argillaceous Micrite; pale yellowish-brown (10 YR 6/2) with dusky brown (5 YR 2/2) partings; cross-laminated; quartz silt, pyritic.	
	11163.4	Argillaceous Dolomicrite; dark yellowish-brown wavy laminations, intraclasts, dolomite, quartz silt, blocky anhydrite, pyrite, hematite.
	11161.1	Argillaceous Dolomicrite; pale yellowish-brown; wavy laminations; dolomite, quartz silt, blocky anhydrite, pyrite, hematite; organic partings.
11167-11175	Dolomicrite; moderate brown (5 YR 3/4), pale yellowish-brown (10 YR 6/2), and pale green (5 G 7/2); mottled.	
11175-11182	Argillaceous Dolomicrite; light olive gray (5 Y 5/2) to grayish-olive (10 Y 4/2); quartz silt, intraclasts.	
	11179.5	Argillaceous Dolomicrite; olive gray; mottled; dolomite, quartz silt, blocky anhydrite, pyrite.

11182-11186	Argillaceous Dolomicrite; dusky yellowish-brown (10 YR 2/2) and moderate yellowish-brown (10 YR 5/4); interbedded, finely laminated.
11186-11190	Argillaceous Dolomicrite; dusky yellowish-brown (10 YR 2/2) and olive gray (5 Y 3/2); interbedded, wavy laminations; intraclasts.

NDGS #4340

LEGAL: Pan American Petroleum/Marmon #1 SWSW 2-154-95 KB: 1972

Core depth	Core description	
	Thin section depth	Thin section description
10010-10012	Argillaceous Dolomicrite; olive gray (5 Y 3/2) and dusky brown (5 YR 2/2); mottled; pyritic.	
	10011.1	Argillaceous Dolomicrite; olive gray and dusky brown; slightly mottled; dolomite, quartz silt, blocky anhydrite, pyrite.
10012-10031	Micrite; grayish-olive (10 Y 4/2) and pale brown (5 YR 5/2); interbedded, cross-laminated; quartz silt, pyritic; water escape structure.	
10031-10034	Dolomicrite; grayish-olive (10 Y 4/2) and moderate brown (5 YR 3/4); mottled.	
10034-10041	Argillaceous Micrite; pale brown (5 YR 5/2) and grayish-olive (10 Y 4/2); interbedded, finely laminated, cross-laminated; quartz silt, intraclasts, pyritic; microfaulted, mudcracked.	
10041-10044	Argillaceous Micrite; grayish-green (5 G 5/2) and moderate brown (5 YR 3/4); interbedded, finely laminated, cross-laminated; quartz silt; water escape structure.	
10044-10046	Micrite; pale yellowish-brown (10 YR 6/2) and dusky yellowish-brown (10 YR 2/2); interbedded; quartz silt, light bluish-gray (5 B 7/1) nodular anhydrite, pyrite.	
10046-10049	As above; brecciated.	
10049-10052	Argillaceous Dolomicrite; grayish-brown (5 YR 3/2), light brown (5 YR 5/6), and grayish-green (5 G 5/2); mottled, brecciated; pyritic.	

10052- Argillaceous Micrite; olive gray (5 Y 3/2) and light
10060 olive gray (5 Y 5/2); interbedded, finely laminated; intraclasts.

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