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Zachary P. Alcorn  
*University of North Dakota*

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LITHOSTRATIGRAPHIC INVESTIGATION OF A LATE DEVONIAN  
CARBONATE-EVAPORITE SEQUENCE; THE DUPEROW  
FORMATION, WILLISTON BASIN, NORTH DAKOTA

by

Zachary P. Alcorn

Bachelor of Science in Geology, Marietta College, 2012

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

2014

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

---

Richard D. LeFever, Ph.D.,-Chairperson

---

Joseph Hartman, Ph.D.,-Committee Member

---

Nels Forsman, Ph.D.,-Committee Member

This thesis is being submitted by the appointed advisory committee as having met all of the requirements of the School of Graduate Studies at the University of North Dakota and is hereby approved.

---

Wayne Swisher  
Dean of the School of Graduate Studies

---

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## ABSTRACT

The Duperow Formation of northwestern North Dakota is a cyclical carbonate evaporite unit deposited on a shallow marine shelf during the early part of the Late Devonian (Frasnian). The formation forms the lower part of the Jefferson Group and lithostratigraphic review permits three informal members to be recognized: lower, middle, and upper. Petrographic, lithologic, and well log examination of drill cores and thin sections allows the identification of seven lithofacies within the three members. Lithofacies include; bioclastic wackestone/packstone (LF1), stromatoporoid boundstone/floatstone (LF2), Amphipora boundstone/floatstone (LF3), peloidal wackestone (LF4), dolomitic mudstone (LF5), microbially laminated dolowackestone (LF6), and anhydrite (Lf7). Lithofacies are further grouped into five lithofacies associations (LFA I to LFA V) which correspond to five depositional settings during accumulation of Duperow strata. Lithofacies were deposited within normal marine subtidal, stromatoporoid bank or mound, intertidal slightly restricted, intertidal more restricted, and supratidal conditions. Rocks of the Duperow were typically deposited in a transition from subtidal to supratidal environments, preserving several shallowing upward successions. Nine short term (1-2 million years) third order cycles are recorded by the rocks of the Duperow which represent two transgressive phases and one regressive phase.

Diagenetic features within the Duperow enhance porosity and establish units with appreciable amounts of reservoir characteristics. The main diagenetic features observed

are micrite enveloping and micritization, calcite cementation, dolomitization, compaction, dissolution, and anhydrite cementation. Only dolomitization and dissolution increase porosity in the rocks of the Duperow. Dolomitization is fabric selective, as only the stromatoporoid boundstone/floatstone and microbially laminated dolowackestone lithofacies contain large amounts of dolomite and well developed intercrystalline porosity. These lithofacies are traceable and correlated throughout the entire study area and extend away from the known producing regions along the Nesson and Billings anticlines. The high degrees of dolomitization observed are the result of active fracture and fault systems acting as conduits for dolomitizing fluids. Paleostructural highs and lows allow for the migration of fluids into the highly susceptible carbonates of the Duperow Formation.

## **CHAPTER 1**

### **INTRODUCTION**

The Duperow Formation is the most widespread Devonian rock unit in North Dakota and comprises a carbonate-evaporite sequence deposited within the Williston Basin of North Dakota, Montana, and Saskatchewan (Sandberg and Hammond, 1958; Rich and Pernichele, 1965; Wilson, 1967). Numerous investigations of ancient and analogous carbonates, deposited in low-energy tidal flat environments, have supplemented knowledge of the governing factors and resulting cyclical character of rocks associated with such environments. The importance of low-energy carbonates as potential hydrocarbon reservoirs is well established. Notable volumes of hydrocarbons have been recovered within the Duperow Formation along the Nesson and Billings anticlines in North Dakota, but knowledge regarding coeval strata away from these positive structural features remains relatively scarce. The Duperow Formation is correlative to the carbonate dominated reefal buildups of the Woodbend Group of the Alberta Basin which is known to have high hydrocarbon accumulations (Stoakes, 1992).

The study area occupies four counties in northwestern North Dakota and comprises a rectangular area bounded to the west by the Montana-North Dakota border; to the north by the US-Canada border; to the south by the 48<sup>0</sup>N latitude line; and to the east by the 102.5<sup>0</sup>W longitude line (Figure 1). The Duperow thickens to the northwest, reaching a maximum thickness of 423 feet in northwest Dunn County, North Dakota.

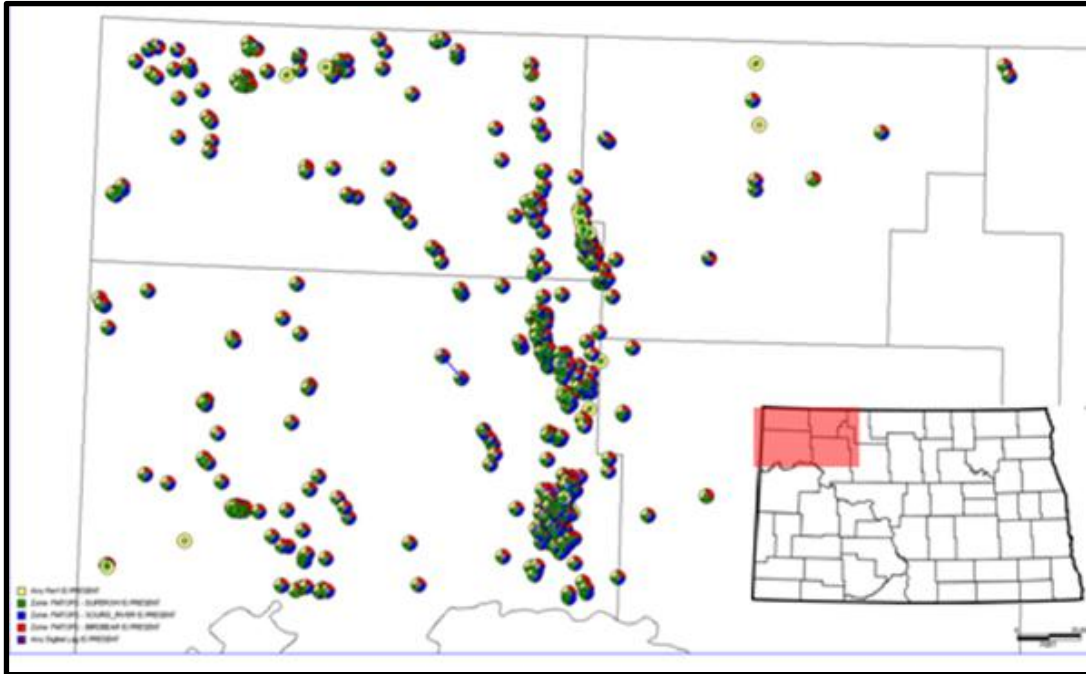


Figure 1. Map showing location of study area in northwestern North Dakota.

### Objectives

The objective of this study is threefold; identify informal members within the Duperow Formation; utilize a lithostratigraphic approach to correlate and map Duperow members within North Dakota; provide further insights into the depositional history and diagenesis of the Duperow Formation.

## Methodology

This study is based on analysis of drill cores from twenty-three wells, thin sections from thirty one wells, and wireline logs from eight-hundred and forty wells (Figure 2, Table 1, Appendix A). Drill cores were described, measured, and correlated throughout the study area. Samples were collected from twenty cores for geochemical analysis to determine amounts of total organic carbon.

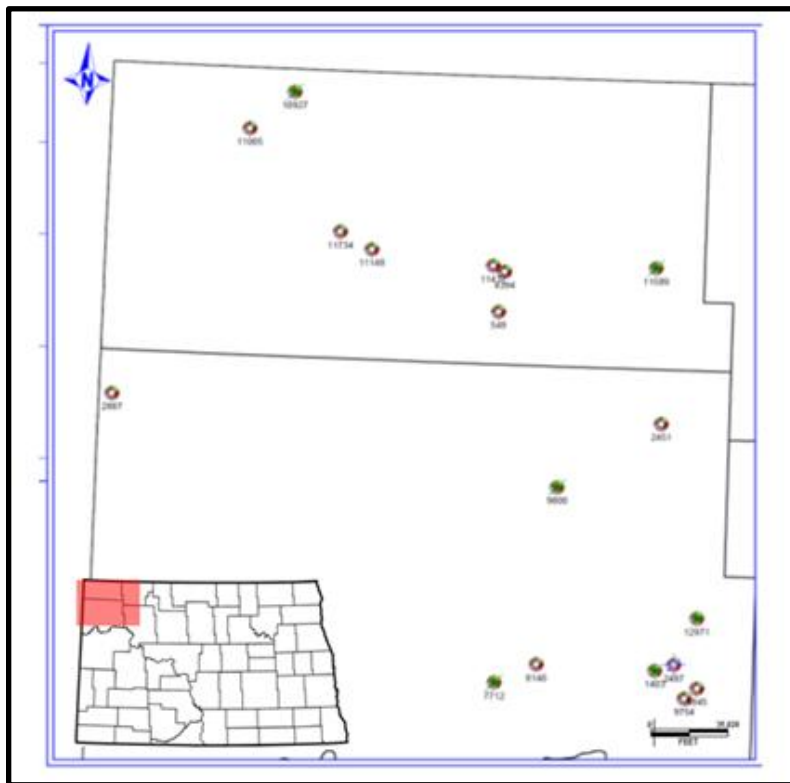


Figure 2. Map showing studied wells with core.

Cores were studied with a binocular microscope to ascertain rock names. Rock names were assigned using the classification scheme of Dunham (1962) with modifications from Embry and Klovan (1971). Thin sections to corresponding wells were



examined using a petrographic microscope. Half of each thin section was stained with Alizarin Red-S to differentiate dolomite from calcite.

Percentages and types of porosity were noted from thin section analysis. Wireline logs with gamma ray, resistivity, and density porosity curves were examined to determine lithology, porosity percentages, and for correlation purposes.

Table 1. Table Showing Studied Drill Cores, Thin Sections, and Lithostratigraphic Position of Cored Intervals.

Well Number NDIC #	Core			Thin Sections
	Lower Member	Middle Member	Upper Member	
32	x	x		
548	x			
1385				x
1403	x	x	x	
1636				
2009				x
2451		x		
2487	x	x	x	
2887	x	x	x	x
4323				x
4394	x	x		
7362				x
7631				x
7712	x			x
8140		x		
9033				x
9278				x
9754	x	x		
9800				x
9845				x
10137				x
10653	x	x		
10671				x
10787				x
10830				x
10869				x
10927		x	x	x
10928				x
11005		x	x	x
11102				x
11148		x	x	x
11173		x		x
11301				x
11437		x		x
11481				x
11567				x
11589	x	x		x
11734		x		x
11908		x		x
12119		x		x
12971				x

Maps were created using Surfer™ to display formation and member thickness and distribution. Cross sections were constructed in Petra™ to correlate rock units and identify individual members throughout the study area (Appendix B).

### **Geologic Setting**

The Duperow Formation is part of the lower Upper Devonian (Frasnian) rock units which extend beneath the Prairie Provinces southeastward from the Canadian Rockies and arctic Canada into the transcontinental arch of the United States. Predominantly a subsurface unit, the Duperow was deposited during a period of overall marine transgression as simultaneous sedimentation occurred in the Cordilleran geosyncline, Alberta, and Williston Basins (Wilson, 1967).

The Williston Basin is located on the western edge of the Canadian Shield and comprises an intracratonic, structural, and sedimentary basin (LeFever, 1991). The Canadian Shield extends under the Williston Basin to the Cordilleran geosyncline. This portion of the craton is bordered on the south by the Sioux arch, on the southwest by the Black Hills uplift and Miles City arch, and on the west by the Bowdoin dome (Gerhard et al., 1982). The basin spans North Dakota, South Dakota, Montana, Manitoba, and Saskatchewan (Figure 3). The formation of the basin is likely driven by structural controls which are associated with the Rocky Mountain belt. Positive structural elements include the Nesson, Cedar Creek, and Billings anticlines, which are all intermittently active throughout much of the basin's depositional history and affect the geometry of the strata deposited within the Williston Basin.

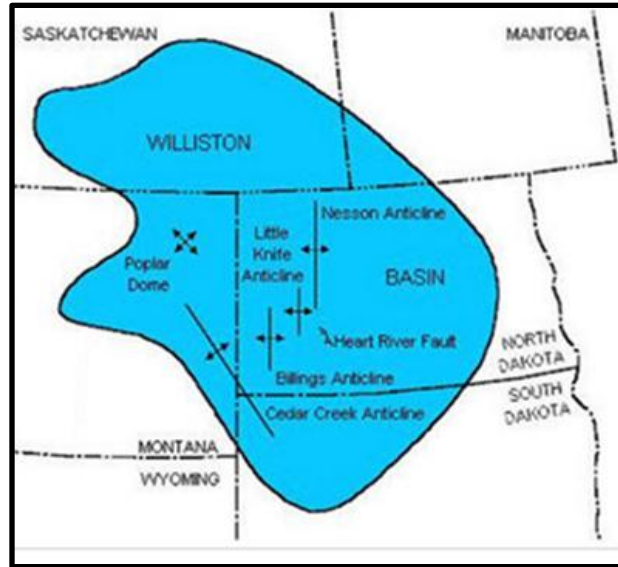


Figure 3. Map showing location of Williston Basin and major structural features (LeFever, 1991).

The Duperow Formation is primarily a mixed carbonate-evaporite unit that conformably overlies the Souris River Formation and is conformably overlain by the Birdbear Formation (Cen and Hersi, 2006). The Duperow was deposited during the Late Devonian in the southeastern Western Canada Sedimentary Basin. A back-reef inner platform setting, which lies southeast of the Leduc Reef Barrier of the Alberta Basin, is envisioned to be the environment of deposition. Preserved strata consist of thick, carbonate dominated rhythmic megasequences that indicate large scale, sea level fluctuations (Moore, 1989). Shallow marine limestones, dolostones, and evaporites form an overall shoaling upward pattern (Wilson, 1967; Dunn, 1975). Correlations with other Upper Devonian strata have been made (Stoakes, 1992), but more recent investigations have utilized conodonts to date the Duperow as Late Devonian (McCracken and Kreis, 2003).

## Previous Work

Work within the Duperow Formation largely began in the early 1950s. The first study to use the name Duperow was that of Powley (1951). Baillie (1953) and Sandberg and Hammond (1958) recognized cyclical limestone, dolomite, and anhydrite and divided and correlated the Duperow within Saskatchewan and North Dakota. Baillie (1953) divided the Devonian system of the Williston Basin into four subdivisions, his “unnamed” unit corresponding to Sandberg and Hammond’s (1958) Duperow reference section (Figure 4). Sandberg and Hammond’s (1958) reference section included marker beds which consist of dolomudstone with high gamma ray kicks. Six dolomudstone marker beds were identified and subsequently used by Wilson (1967), Kent (1968), and Dunn (1975) to aid in correlation (Figure 5).

	Andrichuk (1951) Southeast Sask.	Powley (1951) Central Sask.	Baillie (1953) Williston Basin	Sandberg and Hammond (1958) Williston Basin		
<b>Devonian</b>	Post-Evaporite Unit	<b>Moose Jaw Group</b>	M1	<b>Qu'Appelle Group</b>	<b>Three Forks Formation</b>	
	Dolomite-Evaporite Unit		M2			
	<b>Lower-Limestone Unit</b>		M3	<b>Saskatchewan Group</b>	<b>Unnamed Unit</b>	<b>Nisku Fm.</b>
		M4	<b>Duperow Formation</b>			
		M5 M6				
	Basal Devonian Unit	<b>Duperow Formation</b>	<b>Manitoba Group</b>		<b>Souris River Formation</b>	
	<b>Hudson Bay Formation</b>					

Figure 4. Lithostratigraphic divisions and nomenclature applied to the Duperow Formation of the Williston Basin and Saskatchewan (Cen, 2010).

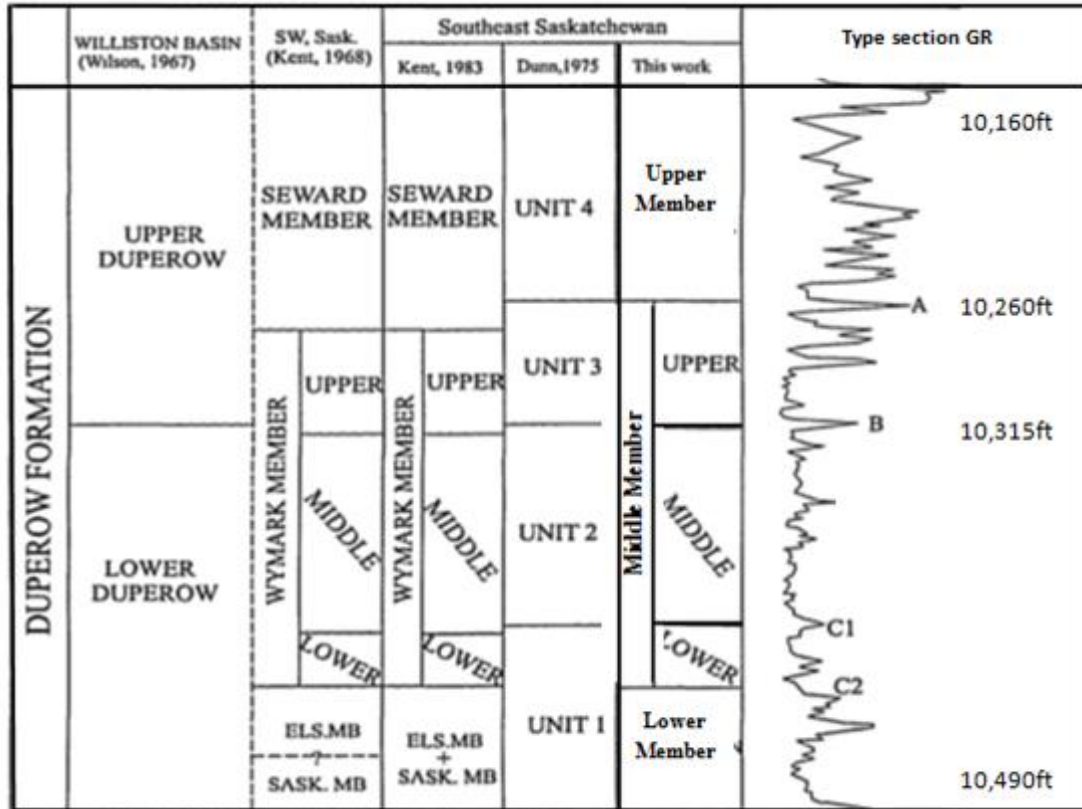


Figure 5. Stratigraphic nomenclature applied to the Duperow Formation in North Dakota, southern Saskatchewan. Sandberg and Hammond's (1958) marker beds are shown on gamma ray log (Modified from Cen, 2010)

Wilson (1967) divided the Duperow, in North Dakota, into lower and upper members. Studies by Cen (2010) and Kent (1968) divided the Duperow into three and four members, respectively, in southern Saskatchewan. The Duperow Formation of southern Saskatchewan was studied extensively by Kent (1968). He identified four stratigraphic units, in ascending order, the Saskatoon, Elstow, Wymark, and Seward members. Argillaceous carbonates compose the Elstow and Seward members whereas the Saskatoon and Wymark members are mostly clean carbonates. Dunn (1975) also studied and identified informal members within the Duperow Formation of southeastern Saskatchewan. His informal units (1-4) were in opposition to Kent's terminology, as

Dunn stated that the Elstow Member could not be traced and mapped into southeastern Saskatchewan due to facies change and that the Seward-Wymark contact is irregularly distributed. Kent later revised his nomenclature (1983) and combined the Saskatoon and Elstow members (Figure 5).

Two widely used models have been proposed to explain the cyclical sedimentation observed within Duperow strata. Sandberg and Hammond (1958) proposed that the cyclical character was a result of deposition in a transition from subtidal to supratidal environments, recording an overall shallowing upward succession. Kissling and Ehrets (1984) called upon laterally persistent time marker beds, which were controlled by salinity fluctuations, to explain the Duperow's cyclical rock units. Kissling (1985) recognized seventeen carbonate-evaporite cycles within the Duperow Formation and stated that these cycles are predictable both regionally and vertically. He also discusses the presence of stratigraphic traps within the Duperow and attributes their occurrence to the unique paleogeography during deposition of the Duperow.

Facies analysis and depositional model studies have been carried out by Hoganson (1978) and Rich and Pernichele (1965). Hoganson identified four distinct environments within the Duperow: supratidal, intertidal, stromatoporoid bank, and subtidal. Duperow sediments were deposited in a broad shallow shelf extending for approximately 1000 miles southeast of the south Alberta reef barrier. He concluded that repetitious sedimentation was the result of episodic inundation and restriction of the shelf allowing for identification of nine carbonate-evaporite repetitions. Rich and Pernichele (1965) recognized six lithofacies of the Duperow through thin section analysis. Of these six, most were fine grained limestones and dolostones all containing anhydrite.

More recently, reservoir characteristics have been of interest. Cen and Hersi (2006) addressed sedimentologic and petrographic aspects to identify reservoir characteristics within the Duperow. Petrographic analysis showed that only facies comprised of stromatoporoids and dolostone contain appreciable amounts of porosity that lead to good reservoir qualities. Work by Altschuld and Kerr (1982) identified several shoaling upward cycles, each with a sealing anhydrite underlain by porous stromatoporoid rich sucrosic dolomite reservoir. Facies were extrapolated over a large area in northwestern North Dakota and lithofacies and reservoir characteristics were determined.



**CHAPTER II**  
**STRATIGRAPHY OF THE DUPEROW FORMATION**

**Stratigraphic Context**

Peale (1893) termed the brown and black crystalline “limestones” (dolostone) that underlie the Three Forks Formation as the Jefferson group. The Jefferson Group consists of the Duperow and overlying Birdbear Formations (Figure 6). Equivalents of the Duperow and Birdbear are found in the Jefferson Formation of the Little Rocky, Little Belt, Beartooth Mountains, and the Bridger Range in Montana (Sandberg and Hammond, 1958).

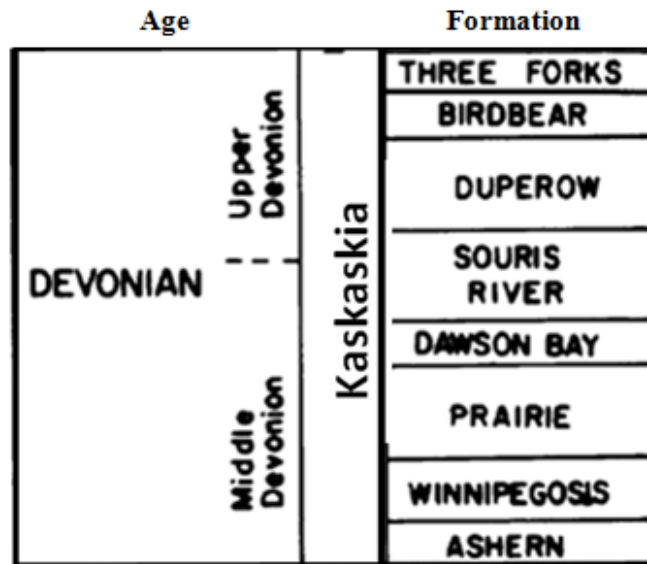


Figure 6. Generalized stratigraphic column of the Devonian system of North Dakota (Modified from Hoganson, 1978).

Sandberg and Hammond (1958) define the Jefferson group to include all beds overlying the Souris River Formation and underlying the Three Forks Formation. The Duperow and Birdbear are lithologically distinct so are considered separate formations rather than members of the Jefferson group, even though they are stratigraphically equivalent to the type Jefferson.

The Duperow Formation was first named by Powley (1951) for a section in the Tidewater Duperow-Crown well No. 1 in southwestern Saskatchewan, from a depth of 3,310 to 4,150 feet. Here, the formation reached a thickness of 849 feet (Rich and Pernichele, 1965). Powley considered the Duperow Formation to be equivalent to all but the lower section of the Beaverhill Lake Formation of Upper Devonian age in Alberta (Ballard, 1963). This initial definition of the Duperow was abandoned by the Williston Basin Nomenclature Committee of the American Association of Petroleum Geologists due to confusion of Powley's definition in regards to the position and extent of the Duperow Formation. This designation was subsequently assigned to an overlying rock unit equivalent to the Woodbend Formation in Alberta.

The standard reference section, suggested by Sandberg and Hammond (1958), was designated in the Mobile Producing Company's Well No. 1 Solomon- Birdbear in Sec. 22, T. 149N., R. 91W., Dunn County, North Dakota, from a depth of 10,400 to 10,743 feet. Use of this location as the reference section was recommended by the North Dakota Geological Society in 1961. The reference section consists of carbonate-evaporite sequences deposited during the Upper Devonian (Sandberg and Hammond, 1958). Lithology is predominantly carbonate with lesser anhydrite, shale, and siltstone (Rich and Pernichele, 1965).

Isopach maps of the Duperow Formation reveal that the unit thickens to the northwest where it obtains a maximum thickness of more than 550 feet in northern Divide and Burke counties (Figure 7). Western Saskatchewan records a thickness of over 700 feet, as a uniform increase in thickness continues northwestward. This uniform increase in thickness suggests a general northwestward subsidence of the North Dakota part of the Williston Basin during deposition.

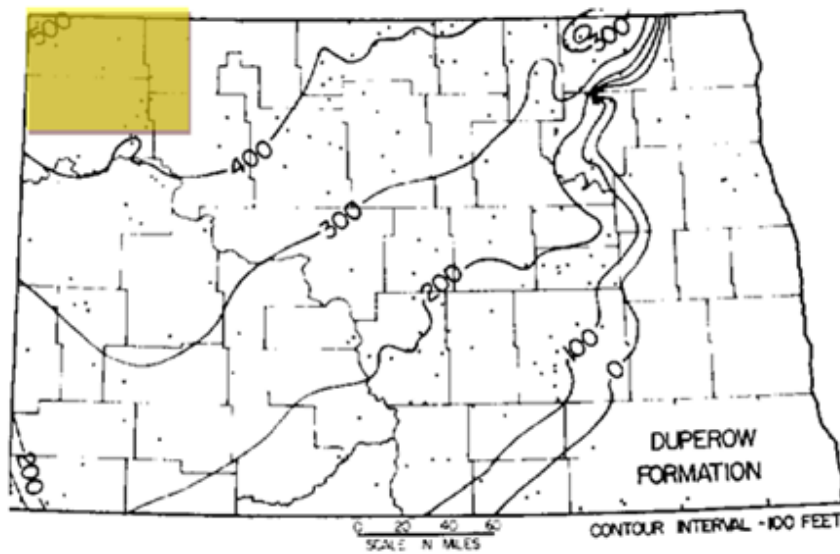


Figure 7. Isopach map of the Duperow Formation in North Dakota (modified from Carlson and Anderson, 1965). Location of study area is shown in northwestern corner.

## CHAPTER III

### LITHOFACIES AND LITHOFACIES ASSOCIATIONS

This study is largely based on recognizing lithofacies through petrographic observation of drill core and thin sections. Determination of lithofacies is regarded as the total amount of sedimentologic and paleontologic data which can be obtained from describing and classifying rock samples, thin section, slabs, or peels (Flügel, 2004). This approach is adopted here and implemented to recognize seven lithofacies (LF1 to LF7). Additionally, rock names were assigned following the carbonate classification of Dunham (1962) with modifications from Embry and Klovan (1971). Seven lithofacies (LF 1 to LF7) are recognized from the Duperow Formation through core, thin section, and well log analysis. Summaries of lithofacies characteristics are given in Table 2 which includes general rock descriptions, fossil content, interpreted depositional environment and location within the formation. Lithology and interpreted environments of deposition were used to group the seven lithofacies into five lithofacies associations (LFA-I to LFA-V).

#### **Lithofacies Association I (LFA-I)**

One lithofacies, bioclastic wackestone/packstone (LF1), comprises lithofacies association I (LFA-I). Macroscopically, rocks of lithofacies one consist of dark to light brown, gray, medium bedded, fine to medium grained, crystalline, bioclastic wackestones and packstones. Allochems include corals, sponges,

Table 2. Summary of Lithofacies Characteristics for the Duperow Formation.

LFA	LF#	Rock Name	General Descriptions	Fossils	Occurrence	Depositional Environment
LFA-I	LF1	Bioclastic wackestone/packstone	In hand specimen, dark brown, brown, gray, very fine to fine grained, crystalline, medium beds, stylolites, burrows, solution seams, occasional soft sediment deformation	Corals, sponges, crinoids, bivalve shell fragments, gastropods	Lower member and lower/middle units of the middle member	Subtidal, normal marine
LFA-II	LF2	Stromatoporoid boundstone/floatstone	In hand specimen, light to dark brown, gray, very fine to fine grained, crystalline, argillaceous seams and stylolites, large knob stromatoporoids, occasional compaction features, dolomitic in part	Bulbous and tabular stromatoporoids, corals, crinoids	Lower member and lower/middle units of the middle member	Bank or mound
LFA-III	LF3	Amphipora boundstone/floatstone	In hand specimen, light to dark brown, gray, very fine grained, crystalline, white circular dot and line Amphipora	Amphipora, brachiopods, corals, crinoids	Middle and upper units of the middle member	Intertidal, slightly restricted
	LF4	Peloidal wackestone	In hand specimen, light brown to dark brown, gray, very fine grained, crystalline, abundant peloids, argillaceous seams, soft sediment deformation,	Corals, crinoids, bivalve shell fragments, sponges, brachiopods	Lower, middle, and upper members	
LFA-IV	LF5	Dolomitic mudstone	In hand specimen, dark to light brown, thickly to nonlaminated, very fine grained, crystalline, flaser bedding, burrows, soft sediment deformation, occasional anhydrite crystals, varying dolomitization, rare stylolites	Rare crinoids	Lower, middle, and upper members	Intertidal, more restricted
	LF6	Microbially laminated dolowackestone	In hand specimen, light to dark brown, fine grained, wavy to planar laminations, hemispheroidal stromatolites, soft sediment deformation, anhydrite cement, dolomitic	Stromatolites, corals, crinoids	Lower, middle, and upper members	Intertidal, more restricted
LFA-V	LF7	Anhydrite	In hand specimen, brown, gray to white, nodular anhydrite interbedded with dolomite, mottled texture, occasionally horizontally laminated	None	Middle and upper members	Supratidal

brachiopods, crinoids, bivalve shell fragments, ostracods, and gastropods (Figure 8A and 8B). Horizontal burrows are present and solution seams and stylolites are common. Solution seams largely appear as irregular anastomosing sets while stylolites most commonly are characterized by peaks of high amplitude. Occasional soft sediment deformation occurs in finer grained beds.

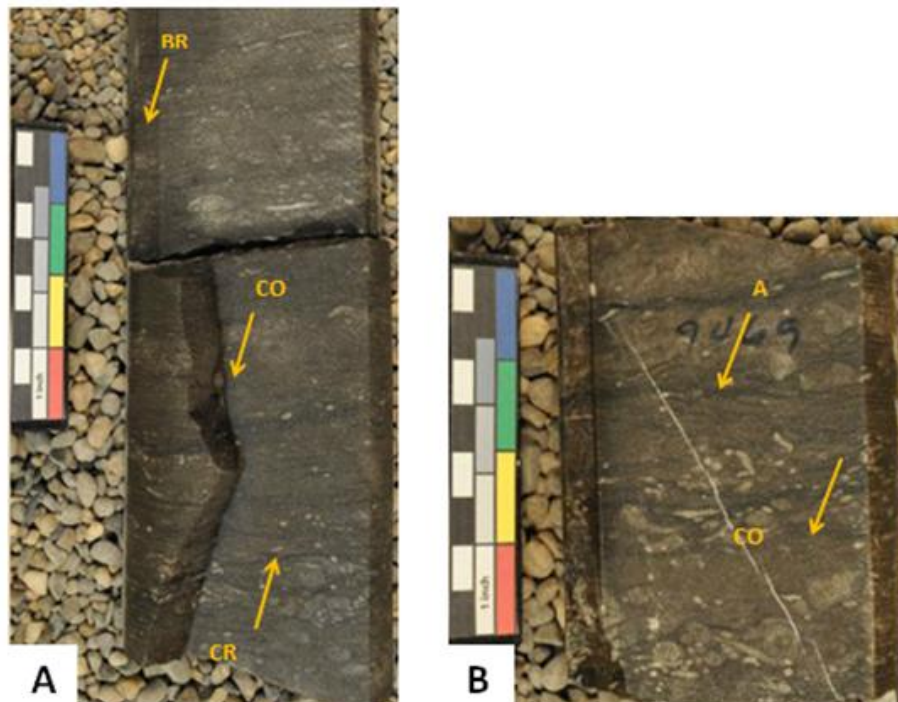


Figure 8. Bioclastic wackestone/packstone (LFI) core photographs. A) dark brown to dark gray, solution seams, and fossils including corals (CO), brachiopods (BR), crinoids (CR), NDIC #2887,9,468ft. B) light to dark brown, solution seams, compaction features, fractures, and fossils including corals (CO) and *Amphipora* branching stromatoporoid (A), NDIC #2887,9,469ft.

Microscopically, this lithofacies is typically microcrystalline, dark to light brown, with a fine carbonate mud dominated matrix. Fossils are poorly sorted and are both mud and framework supported. Fine carbonate mud matrix is often partly dolomitized with the presence of euhedral to subhedral dolomite rhombs. Crinoids, corals, and brachiopods constitute the majority of allochems with lesser amounts of bivalve shell fragments and

gastropods. Elongate anhydrite crystals often fill pore space and encrust some shell fragments. Stylolites and minor burrows are also observed.

### **Lithofacies Association II (LFA-II)**

Lithofacies association II is characterized by the stromatoporoid boundstone/floatstone (LF2) lithofacies. In hand specimen, LF2 consists of light to dark brown, gray, bulbous and tabular stromatoporoids and rugose corals within a mudstone matrix (Figures 9A and 9B). Argillaceous seams are common and typically surround sponge and coral fragments. Stromatoporoids and corals are often suspended with brachiopods, crinoids, and bivalve shell fragments. Matrix is usually fine to medium grained and rarely sucrosic. Stylolites are common with anhydrite occurring lesser amounts.

Microscopically, stromatoporoid boundstone/floatstone is comprised of dark to light brown, gray, crystalline, stromatoporoid wall structure within a wackestone matrix. Stromatoporoids are bulbous knobs with wall structures that are thick skeletal fragments suspended in a carbonate mud matrix. Other bioclasts include rugose corals, brachiopods, and crinoids. The mud matrix is partially dolomitized as dolomite rhombs often replace matrix and fossils. Argillaceous seams are common as well as bladed anhydrite grains within pore space. Intraparticle porosity is present within stromatoporoid wall structure and within corals.

### **Lithofacies Association III (LFA-III)**

Amphipora boundstone/floatstone (LF3) and Peloidal wackestone (LF4) comprise lithofacies association III (LFA-III). Distribution of these two lithofacies is not

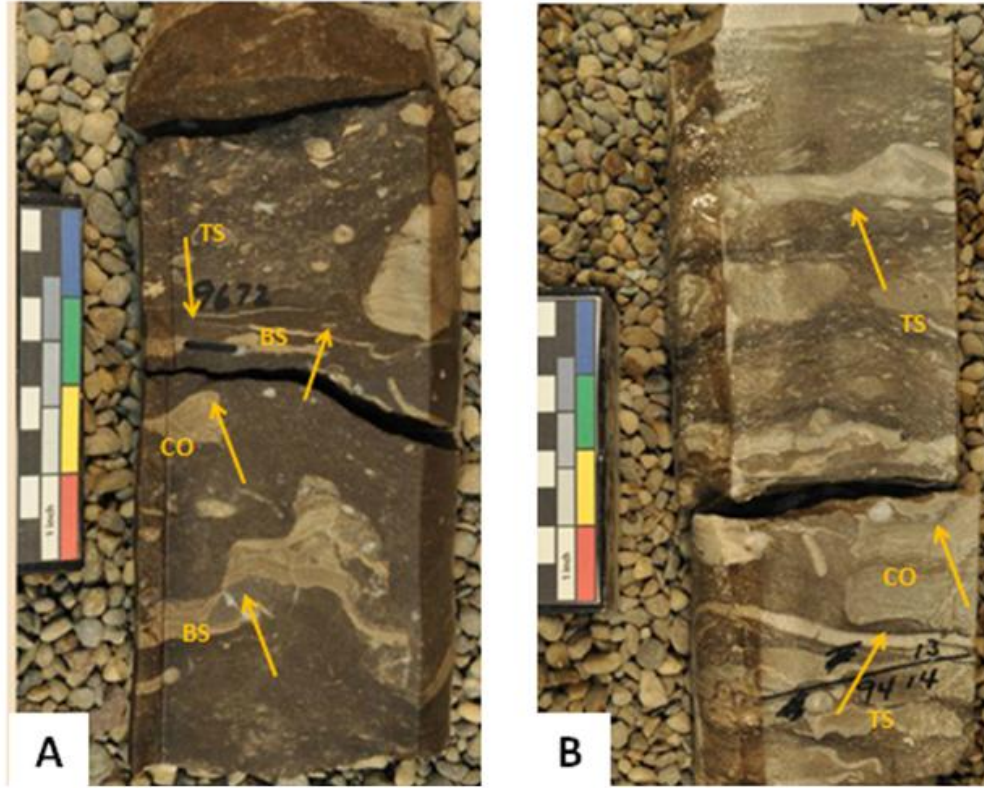


Figure 9. Stromatoporoid boundstone/floatstone (LF2) core photograph. A) dark brown, tabular (TS) and bulbous (BS) stromatoporoids and corals (CO) in a fine mud matrix, NDIC #2887,9,672ft. B) light brown to brown, tabular (TS) stromatoporoids, solution seams, and corals (CO) in a fine mud matrix, NDIC #2887,9,413ft.

necessarily consistent so environment of deposition and lithofacies proximity was used as the main criteria for grouping them into the same lithofacies association.

Macroscopically, *Amphipora* boundstone/floatstone consists of gray to brown, very fine grained wackestone matrix with framework allochems of white circular dot and line *Amphipora* sponge walls (Figure 10). Other fossils contents are comprised of brachiopods and crinoids. Solution seams and compaction features are present and commonly diverge around allochems.

In thin section, LF3 is light to dark brown, crystalline, with typical *Amphipora* wall structure suspended in a wackestone matrix. The carbonate mud matrix also contains



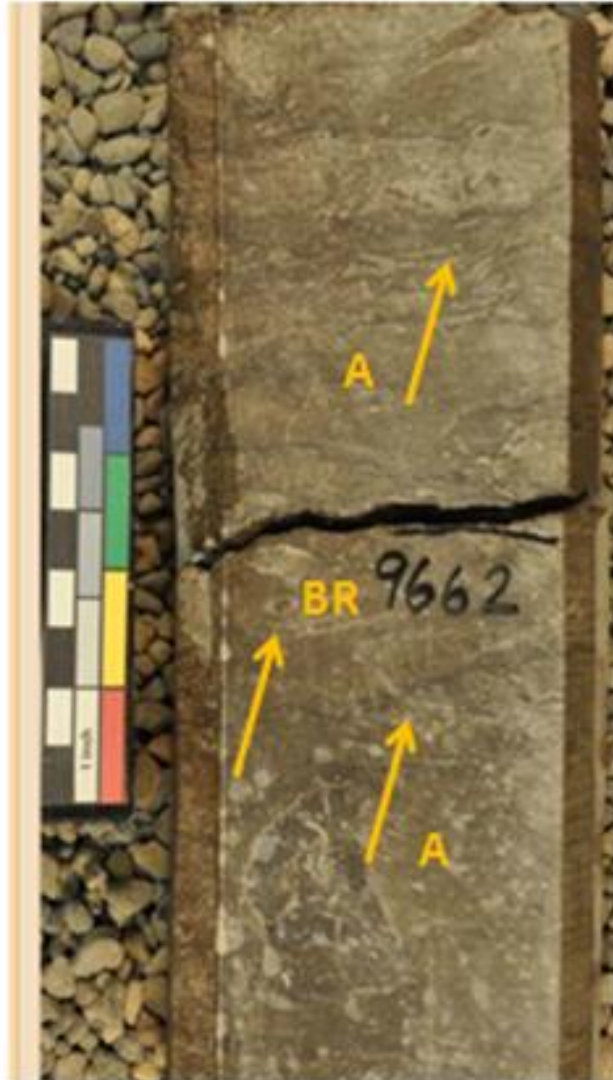


Figure 10. Amphipora boundstone/floatstone (LF3) core photograph. Light brown, white line and dot *Amphipora* (A) and brachiopods (BR), NDIC #2887,9,662ft.

allochems of brachiopods, corals, and crinoids. Sparry calcite replaces some fossils and degree of dolomitization is highly variable.

Peloidal wackestone lithofacies (LF4) is also included within LFA-III. Light to dark brown, thickly to nonlaminated, peloidal wackestones characterize LF4 (Figure 11). Matrix is very fine to fine grained with argillaceous seams and soft sediment deformation. Fossils are usually fragmented and consist of corals, crinoids, bivalves,

brachiopods, and sponges. Anhydrite replaces some allochems and dolomitization is common. Light brown intraclasts are found within the finer grained parts of LF4.

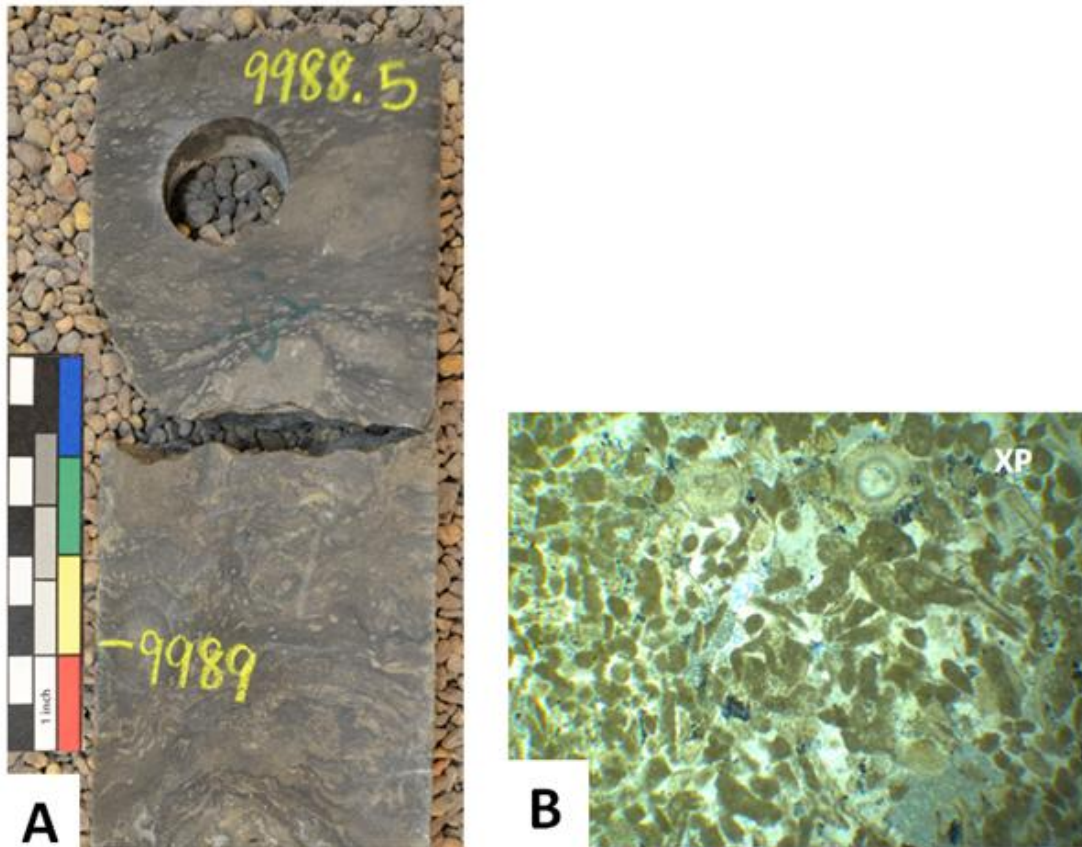


Figure 11. Peloidal wackestone (LF4). A) Core photograph. Brown peloids in a carbonate mud matrix with solution seams, NDIC #12119,9,989ft. B) Photomicrograph of micritic peloids with well developed interparticle porosity. Crinoid in upper part of section, NDIC #1385,10,223 ft. XP (cross polarized light).

Microscopically, the peloidal wackestone facies is comprised of light brown to gray, crystalline, small structureless peloids composed of very fine carbonate mud. Peloids are often clumped together and form masses of fine carbonate material. Intraclasts and bioclasts form a thick organic layer in many sections with solution seams diverging around darker organic material. Other allochems include corals, crinoids, bivalve shell fragments, sponges and brachiopods.

### **Lithofacies Association IV (LFA-IV)**

Two lithofacies are included within LFA-IV: dolomitic mudstone (LF5) and microbially laminated dolowackestone (LF6). Dolomitic mudstone facies consist of dark to light brown, dark gray, thickly laminated to nonlaminated very fine grained dolomitic mudstone (Figure 12). Thin organic laminae and solution seams are abundant and give the appearance of flaser bedding. Fossils are rare with a small occurrence of crinoids. Horizontal and vertical fractures are observed with some filled with crystalline anhydrite.

Stylolites and burrows are also observed. Most observation of fossils is in thin section. Thin sections reveal a dark to light brown, fine carbonate mud matrix with abundant solution seams and variable degrees of dolomitization. Dolomite rhombs are euhedral to subhedral and are contained within the fine grained carbonate mud matrix. Bladed anhydrite occurs with fossil fragments and matrix.

Light to dark brown, wavy to planar stromatolites characterize the microbially laminated dolowackestone lithofacies (Figure 13). This lithofacies is most commonly fine grained with anhydrite crystals and cement. Stromatolites are hemispheroidal in nature and often contain interparticle porosity. Thin section examination reveals variable degrees of dolomitization and abundant microbial skeleton and peloidal grains. Other allochems include corals and crinoids. Bladed to blocky anhydrite is present within desiccation cracks.

### **Lithofacies Association V (LFA-V)**

Anhydrite (LF7) comprises lithofacies association five. LF7 consists of brown, gray to white, nodular to horizontally bedded crystalline anhydrite interbedded with



Figure 12. Dolomitic mudstone (LF5) core photograph. Dark brown to brown to stylolites (St), NDIC # 11005,9,374ft.



Figure 13. Microbially laminated dolowackestone (LF6) core photograph. Light to dark brown wavy to planar stromatolites, NDIC #2754,9,539ft.

variable amounts of dolomite (Figure 14). Mottled textures are common as units become more dolomitized. In thin section, bladed, blocky, and felty anhydrite occurs with euhedral dolomite rhombs. Argillaceous seams are common and often diverge around anhydrite crystals.



Figure 14. Anhydrite mottled with dolomite (LF7) core photograph. Gray to white crystalline anhydrite with variable amounts of dolomite, NDIC #2887,9,504ft.

**CHAPTER IV**  
**LITHOSTRATIGRAPHY**  
**Lithostratigraphic Revision**

The lithostratigraphic study is based on examination of twenty five cores, correlation of well log curves, and petrographic study of 213 thin sections from 31 wells (Table 1, Appendix A). The collected and interpreted data was then compared and correlated to previous studies by Sandberg and Hammond (1958), Rich and Pernichele (1965), Wilson (1967), and Cen (2010).

The Duperow Formation in North Dakota has not yet been assigned formal member names. Wilson (1967) has divided the formation into lower and upper units which will be used as the basis for correlation in this study. Sandberg and Hammond's (1958) marker beds will also be utilized to correlate and map members throughout the study area. Three formal members, the Saskatoon, Wymark and Seward, have been named in Saskatchewan and can be lithostratigraphically correlated with coeval strata in North Dakota and Manitoba.

Wilson (1967) identified five informal cycles within the Duperow of North Dakota which correlate with the three members of southern Saskatchewan. Cycle one corresponds to the Saskatoon Member, cycles two through the lower part of cycle five correlate with the Wymark Member, and the upper part of cycle five correlates to the Seward Member (Figure 15).

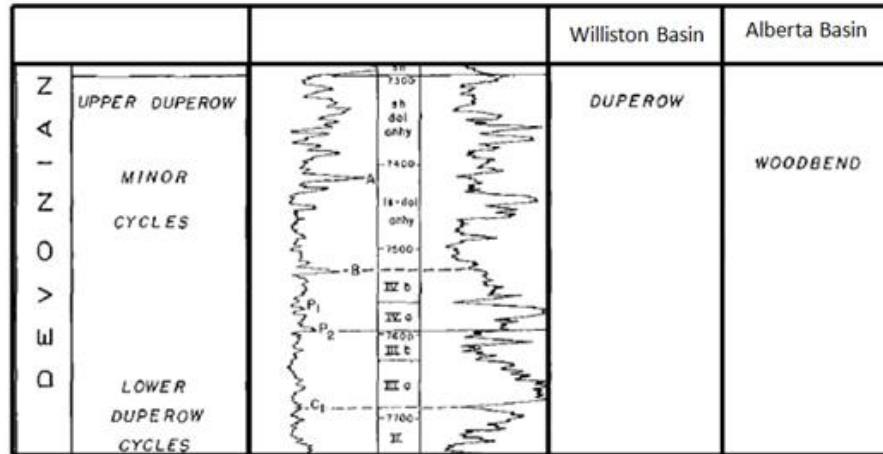


Figure 15. Wilson's interpreted Duperow cycles and correlation to strata in Alberta (modified from Wilson, 1967)

Subsurface mapping of lithostratigraphic units through well log and core correlation permitted the recognition of three informal members within the Duperow Formation of North Dakota. Members can be traced throughout the study area and correlate to the three recognized members in southeastern Saskatchewan (Kent, 1968 and Cen, 2010).

### Lithostratigraphic Descriptions

#### The Lower Member

The lowermost member of the Duperow Formation conformably overlies the Souris River Formation of the Manitoba Group. Fourteen cores of the lower member were examined with only three (NDIC #2487, #9754, #2887) containing the contact with the underlying Souris River Formation. The lower boundary is placed at the contact of bioclastic wackestone/packstone of the Souris River and the overlying dolomitic mudstone of the lower member of the Duperow Formation (Figure 16). A reference core, NDIC #2487, was chosen which contains the largest interval of the Duperow Formation and has traceable log characteristics.



Figure 16. Contact of the Duperow and Souris River Formations, NDIC #9800, 10,955 ft.

Lithofacies of the lower member includes limestones, dolostones, and anhydrites. The limestone lithofacies is comprised of bioclastic wackestone/packstone (LF1), stromatoporoid boundstone/floatstone (LF2), and dolomitic mudstone (LF5). The lower member ranges from an absence of bedding to being medium bedded with dark argillaceous seams. The member is typically horizontally laminated but lack of laminations is common. Fossil contents include tabular and bulbous stromatoporoids, corals, crinoids, brachiopods, and bivalves. The mudstone lithofacies contains occasional flaser bedding and variable degrees of dolomitization. A high gamma kick is readily identifiable for the dolomitic mudstone facies where clay content increases. Notable



diagenetic features in the limestone lithofacies are stylolites and secondary anhydrite crystals.

The dolostone lithofacies is characterized by microbially laminated dolowackestone (LF6). Wavy to planar microbial laminations occur with hemispheroidal stromatolites and varying degrees of dolomitization. The Anhydrite lithofacies is comprised of nodular to mottled, grayish white anhydrite interbedded with dolomite. Lithofacies are arranged in a cyclical pattern which consists of limestone, dolostone, and anhydrite, in ascending order. The dolomitic mudstone facies, with its high gamma kick, lies either at the top of the anhydrite lithofacies or between limestone beds. Cen and Hersi (2006) interpreted the more argillaceous dolomitic mudstone lithofacies to represent a marine flooding surface that marks the initiation of marine transgression.

The upper boundary of the lower member is at the base of a dolomitic mudstone which is correlated to Sandberg and Hammond's (1958) C2 marker bed. This dolomitic mudstone shows a high gamma kick and is often overlain by cleaner dolostones and mudstones. The thickness of the lower member ranges from 30 feet to 93 feet within the study area (Figure 17).

Two third-order cycles (L1 and L2) have been recognized within the lower member of the Duperow Formation through examination of four cores. The tops of these third-order cycles are marked by argillaceous dolomitic mudstone which yields a high gamma ray kick and are traceable throughout much of the study area. L1 consists predominantly of non argillaceous, fine grained carbonates whereas L2 is comprised of more argillaceous carbonate facies.

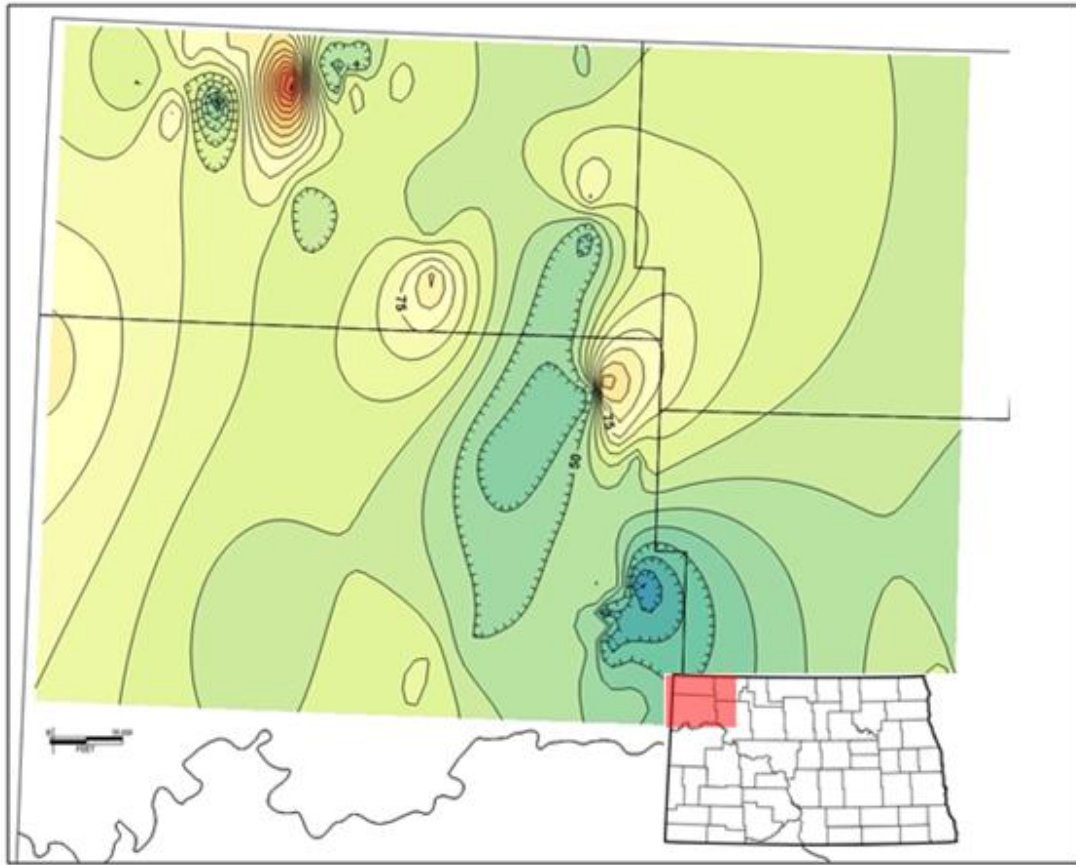


Figure 17. Isopach map of the lower member of the Duperow Formation.

Figure 18 displays two third-order cycles from three widely spaced wells. Cycles are not necessarily complete and often vary between localities. However, the presence of the dolomitic mudstone marker beds separating argillaceous carbonates from cleaner carbonates, allow recognition of both third-order cycles.

The reference well (NDIC #2487) contains both complete and incomplete cycles. L1 contains bioclastic wackestones/packstones with brachiopods, crinoids, corals, and bivalves which are interbedded with stromatoporoid boundstones/floatstones and are overlain by argillaceous dolomitic mudstone which often contains anhydrite cement.

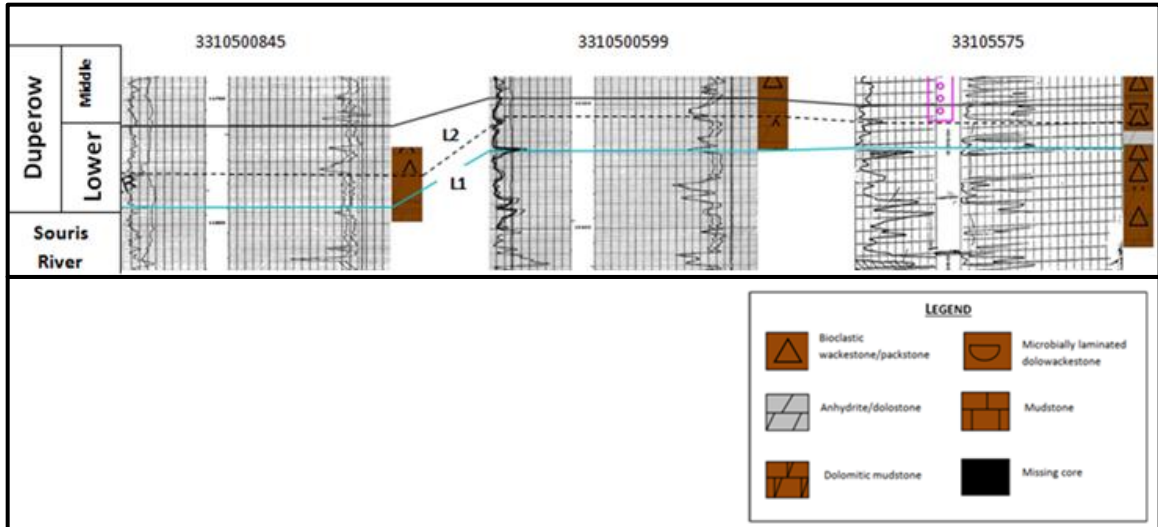


Figure 18. Cycles of the lower member of the Duperow Formation. Dashed line represents interpreted cycles. L1 (lower member cycle 1), L2 (lower member cycle 2).

Argillaceous dolomitic mudstone is the demarcation between L1 and L2. L2 is an incomplete cycle comprised of more argillaceous carbonates which consist of bioclastic wackestones/packstones interbedded with fine mudstone and capped by microbially laminated dolowackestone. Thin beds of argillaceous dolomitic mudstone occur at the top of the lower member and constitute the boundary with the middle member.

### The Middle Member

The middle member is the thickest of all members in the study area. Thickness ranges from 180 feet to 220 feet (Figure 19). The upper contact of the middle member is at the top of the dolomitic mudstone facies of the overlying upper member. A high gamma kick is observed which correlates to Sandberg and Hammond's (1958) marker bed "A." This dolomitic mudstone marker also corresponds to Cen's (2010) argillaceous dolomudstone.

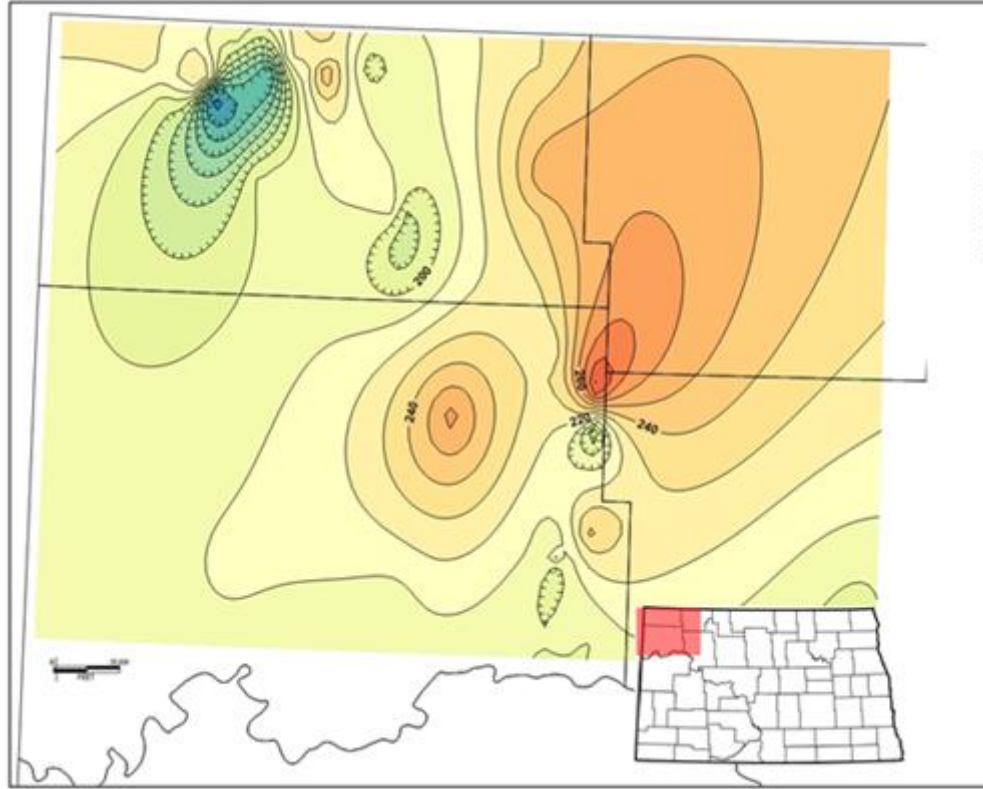


Figure 19. Isopach map of the middle member of the Duperow Formation.

Lithofacies of the middle member are characterized by limestones with lesser amounts of dolostones and anhydrite. Limestones are dark to light brown bioclastic wackestone/packstone (LF1), stromatoporoid boundstone/floatstone (LF2), dolomitic mudstone (LF5), peloidal wackestone (LF4), and *Amphipora* boundstone/floatstone (LF3). Allochems in the limestones consist of tabular, bulbous, and branching stromatoporoids, corals, crinoids, brachiopods, bivalves, and gastropods. Argillaceous seams and compaction features are common. Vugs filled with anhydrite cement occasionally occur and are the only diagenetic features observed.

Informal units can be discerned within the middle member, which correspond to individual sea level cycles. Three informal units are recognized and are easily traceable throughout the study area. Each unit is discussed below.

**The lower unit of the middle member.** The lower unit of the middle member lies between 10,470 feet and 10,440 feet in reference well NDIC #2487. The upper boundary is placed at the base of an argillaceous dolomitic mudstone which correlates with Sandberg and Hammond's (1958) C1 marker bed. Nine well cores were studied which contain the lower middle member interval (Table 1).

The lower unit is characterized by mostly limestone lithofacies which include bioclastic wackestone/packstone (LF1), stromatoporoid boundstone/floatstone (LF2), and dolomitic mudstone. Lesser amounts of dolostone facies occur and include microbially laminated dolowackestone (LF6) and dolostones interbedded with anhydrite. Fossils in the limestone lithofacies include corals, crinoids, brachiopods, branching and bulbous stromatoporoids, bivalves, and few gastropods. The unit contained nodular bedding from abundant argillaceous seams. Stylolites are common in the finer grained facies and anhydrite cements often fills in vugs.

One third-order cycle is interpreted from the lower unit of the middle member. This cycle is shorter in duration than the third-order cycles discussed for the lower member. The base of the lower unit, in the reference well, is comprised of fine carbonate mudstone overlain by bioclastic wackestone/packstone which is capped by argillaceous dolomitic mudstone (Figure 20). These facies are thought to represent a transition from a deeper subtidal environment to a normal subtidal environment. This vertical succession is

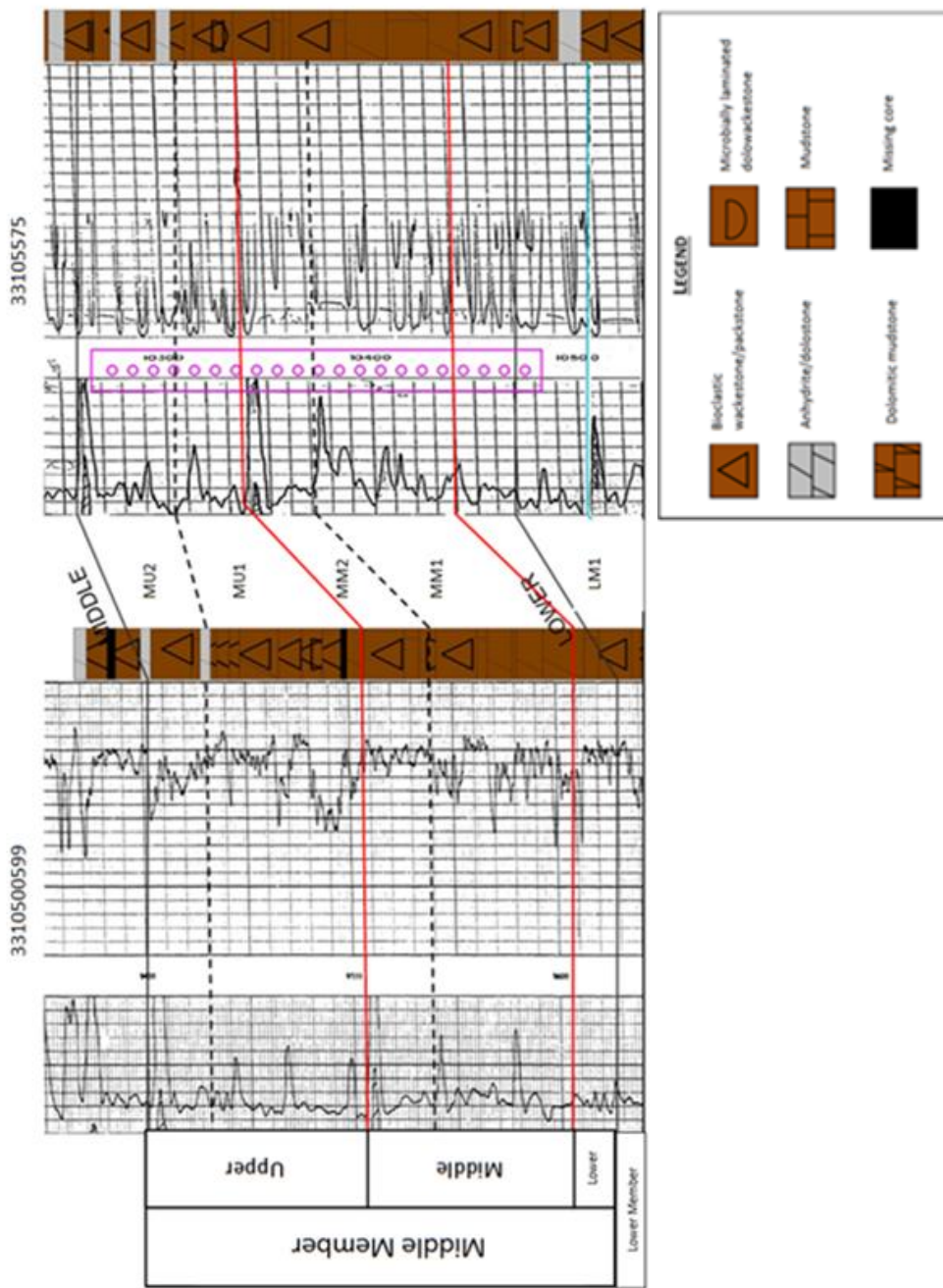


Figure 20. Cycles of the middle member of the Duperow Formation. Red lines correspond to units within the middle member, dashed lines represent interpreted cycles. LMI (lower middle cycle 1), MM1/2 (middle middle member cycles 1 and 2), MU1/2 (middle upper member cycles 1 and 2).

also observed in wells NDIC #2887, #9745, and #1403. Argillaceous dolomitic mudstone provides the boundary between the lower unit and middle unit of the middle member.

**The middle unit of the middle member.** The middle unit lies between 10,440 feet and 10,340 feet in the reference well. The upper boundary of this unit is easily recognizable and traceable throughout the study area. A high gamma ray kick which corresponds to argillaceous dolomitic mudstone caps the unit and correlates to Sandberg and Hammond's (1958) marker bed "B."

Well cores from sixteen wells contain the middle unit of the middle member (Table 1). Core analysis reveals that the middle unit is characterized by rhythmic successions of bioclastic wackestone/packstone, stromatoporoid boundstone/floatstone, and fine carbonate mudstone. Dolomitic mudstone is common in the lower parts of the unit and often interbeds bioclastic wackestone/packstone lithofacies. Fossil contents increase upsection and include corals, crinoids, bulbous, tabular and branching stromatoporoids, brachiopods, and bivalves. Argillaceous seams are common in the wackestone and mudstone facies and give a nodular appearance. Dolostone lithofacies occurs in the upper part of the middle unit and consists of microbially laminated dolowackestone and dolostone interbedded with anhydrite. Crystalline anhydrite is also observed which often occurs within vugs and fractures.

Two third-order cycles can be discerned within the middle unit of middle member. The lower third-order cycle is characterized by argillaceous dolomitic mudstone overlain by bioclastic wackestone/packstone which is capped by dolomitic wackestones and mudstones (Figure 20). Mudstones and wackestones are more clay rich than the overlying cycle and become more dolomitic near the top of the cycle. The upper third-

order cycle consists of cleaner mudstones, wackestones, and stromatoporoid boundstones/floatstones which are interbedded with dolostone lithofacies at the top of the cycle. Anhydrite often interbeds dolostone and these beds cap the second third order cycle. The presence of branching stromatoporoids (Amphipora) at the tops of these cycles in some well cores also provides caps as Amphipora represents lower energy environments. The decrease in bulbous and tabular stromatoporoids represents a transition into lower energy conditions throughout the middle unit. These cycles are therefore interpreted to represent a restricting upward succession.

**The upper unit of the middle member.** The upper unit of the middle member lies between 10,340 feet and 10,260 feet in the reference core. The upper boundary, also the upper boundary of the middle member, is placed at the top of an argillaceous dolomitic mudstone which correlates to Sandberg and Hammond's (1958) marker bed "A." The upper unit is predominantly bioclastic wackestone/packstone and fine carbonate mudstone. Brachiopods, corals, crinoids, and bivalves constitute the majority of bioclasts. Stylolites are common in the mudstone facies. Stromatoporoid boundstones/floatstones occur sparingly and are often sandwiched between bioclastic wackestones/packstones. Dolostone lithofacies also occurs in minor amounts and is comprised of microbially laminated dolowackestone and dolostone interbedded with anhydrite. Anhydrite increases in the upper part of this unit and is readily traced throughout the study area.

Examination of fifteen well cores with intervals within the upper unit of middle member allows recognition of two third-order cycles. Each cycle is identified by argillaceous dolomitic mudstone which yields a high gamma kick and is easily recognizable on logs (Figure 20). Thin dolostone beds interbedded with anhydrite cap



limestone facies of the upper unit. The lower parts of each cycle are composed of bioclastic wackestone/packstones with lesser amounts of microbially laminated dolowackestone. These facies are often overlain by fine carbonate mudstone and are capped by dolostone interbedded with anhydrite suggesting restricted depositional environments.

### **The Upper Member**

The upper Member ranges in thickness from 82 feet to 124 feet (Figure 21) and is located at depths between 10,260 feet and 10,160 feet in the reference core. The upper contact, also the upper contact of the Duperow Formation, is conformable with the overlying Birdbear Formation. Dolomitic mudstone with a high gamma kick bound the basal contact of the upper member with the underlying middle member. Limestone lithofacies predominantly occur with lesser amounts of dolostone and anhydrite

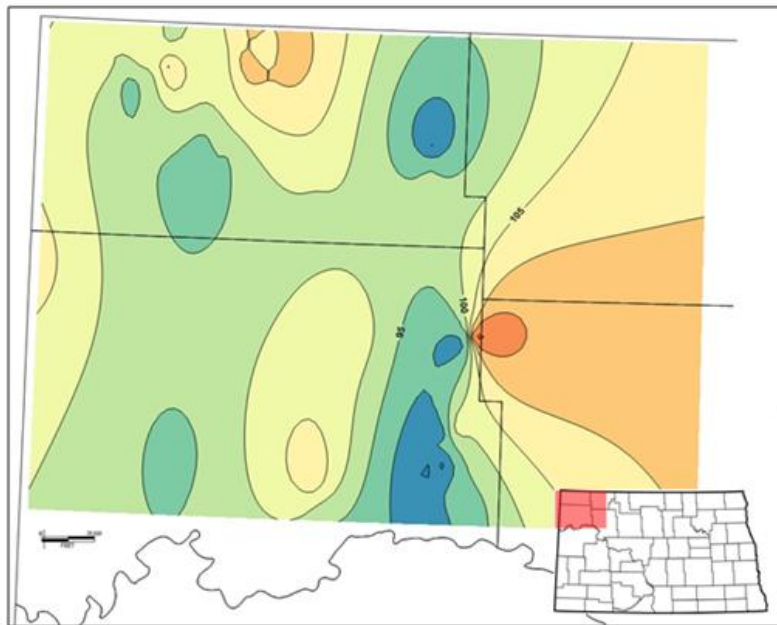


Figure 21. Isopach map of the upper member of the Duperow Formation.

lithofacies. The upper member is more argillaceous than the other two members. The limestone lithofacies includes fine to medium bedded, light brown bioclastic wackestone/packstone and fine bedded, dark brown to brown mudstone. Fossils contents include corals, sponges, crinoids, brachiopods, bivalves, and gastropods. Stylolites and intraclasts occur in the mudstone lithofacies. Dolostone lithofacies includes microbially laminated dolowackestone and dolostone interbedded with anhydrite. Vugs are observed in both lithofacies and are typically filled with evaporite minerals, calcite, or anhydrite.

Examination of core reveals that the upper member also has apparent cyclicity. Cycles are similar to those seen in the middle member but with less pronounced anhydrite accumulations. Cores from six wells span into the lower and middle parts of the upper member, while no wells contain core from the upper parts of the member. Gamma ray signatures and coeval strata within the middle member will be used to supplement knowledge of cycles within the upper part of the upper member where no core is available.

Two third-order cycles have been recognized within the upper member (Figure 22). Each cycle starts with a bioclastic wackestone/packstone that is capped by a fine, argillaceous dolomitic mudstone. A high gamma kick is used to recognize cycles on logs and correspond to the more clay rich caps to each cycle. Abundant corals, crinoids, brachiopods occur with lesser amounts of bivalves and gastropods. High amounts of argillaceous dolomitic mudstone, lacking anhydrite, in the upper part of the uppermost member could represent the initiation of sea level rise as these facies typically represent flooding surfaces in other Devonian strata (Cen, 2010). The absence of evaporite units in the upper part of the cycle also suggests a shift into deeper water facies.

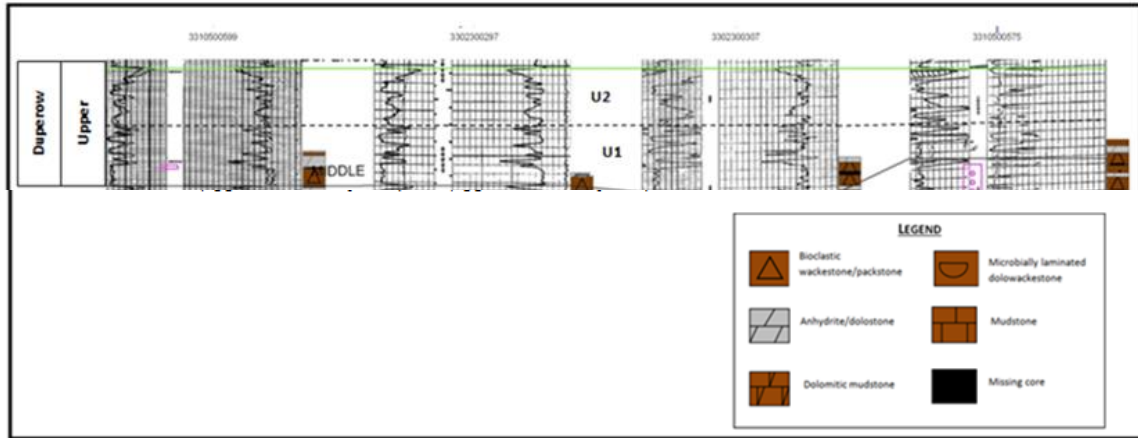


Figure 22. Cycles of the upper member of the Duperow Formation. Dashed lines represent interpreted cycles. U1 (upper member cycle 1), U2 (upper member cycle 2).

### Cyclical Sedimentation

Widespread carbonate units are predominantly governed by basin geometry, water level, and water energy level. These parameters are responsible for creating the cyclical successions recorded within the Duperow Formation of North Dakota. Accumulation rates of carbonates are often greater than subsidence and sea level rates combined, allowing for thick packages of sediment which shallow upward. The tops of many cycles are therefore capped with intertidal and supratidal deposits which represent periods of subaerial exposure. Fine grained carbonates at the tops of cycles may also represent a shift to deeper water environments. These small cycles can form vertical successions which allow interpretations to be made regarding times of transgression and regression. The interpreted third-order cycles represent sedimentation with duration of one to two million years. Individual cycles vary and are often incomplete so the presence of widely traced marker beds allows cyclicity conclusions to be drawn.

Two types of cycles are recognized within the Duperow Formation. Both cycles are comprised of restricting upward successions which are mostly composed of limestone

lithofacies. Type-1 cycles are common in the lower parts of the Duperow Formation and occur within the lower member up to the middle units of the middle member. Typically, these cycles contain a basal fine grained dolomitic mudstone overlain by bioclastic wackestone/packstone. Normal marine fauna dominates the allochems of the wackestones and packstones. Stromatoporoid boundstone/floatstone is commonly sandwiched between bioclastic wackestones/packstones. Tabulate and bulbous stromatoporoids occur with brachiopods and rugose corals in fine grained mud matrix. In some well localities, Amphipora boundstone/floatstone is more developed representing further restricted facies. The upper parts of Type-1 cycles are capped by evaporite facies of mottled anhydrite interbedded with dolostone (Figure 23). Type-2 cycles are mostly the same with the only difference being the absence of stromatoporoid boundstone/floatstone lithofacies. The upper portions of the Duperow Formation are characterized by Type-2 cycles.

Nine third-order cycles have been recognized within the Duperow formation of North Dakota (Figure 24). The duration of these cycles is likely on the low end of the one to ten million year interval as exact accumulation rates are difficult to determine due to high degrees of diagenesis and compaction. Two cycles occur in the lower member, five in the middle member, and two in the upper member. It is possible that these third-order cycles could be broken into fourth order cycles but attempts to do so are inhibited by the lack of complete and widespread vertical successions.

Lithofacies	Type-1 Cyclicity	Depositional Environment
Dolostone/ anhydrite		Supratidal
Amphipora bdst/fltst		Intertidal, slightly restricted
Stromatoporoid bdst/fltst		Subtidal/bank
Bioclastic wkst/pkst		Subtidal
Dolomitic mudstone		Intertidal

**Legend**

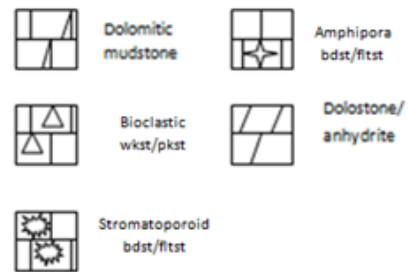


Figure 23. Idealized lithologic column of Type-1 cyclicity within the lower and middle members of the Duperow Formation.

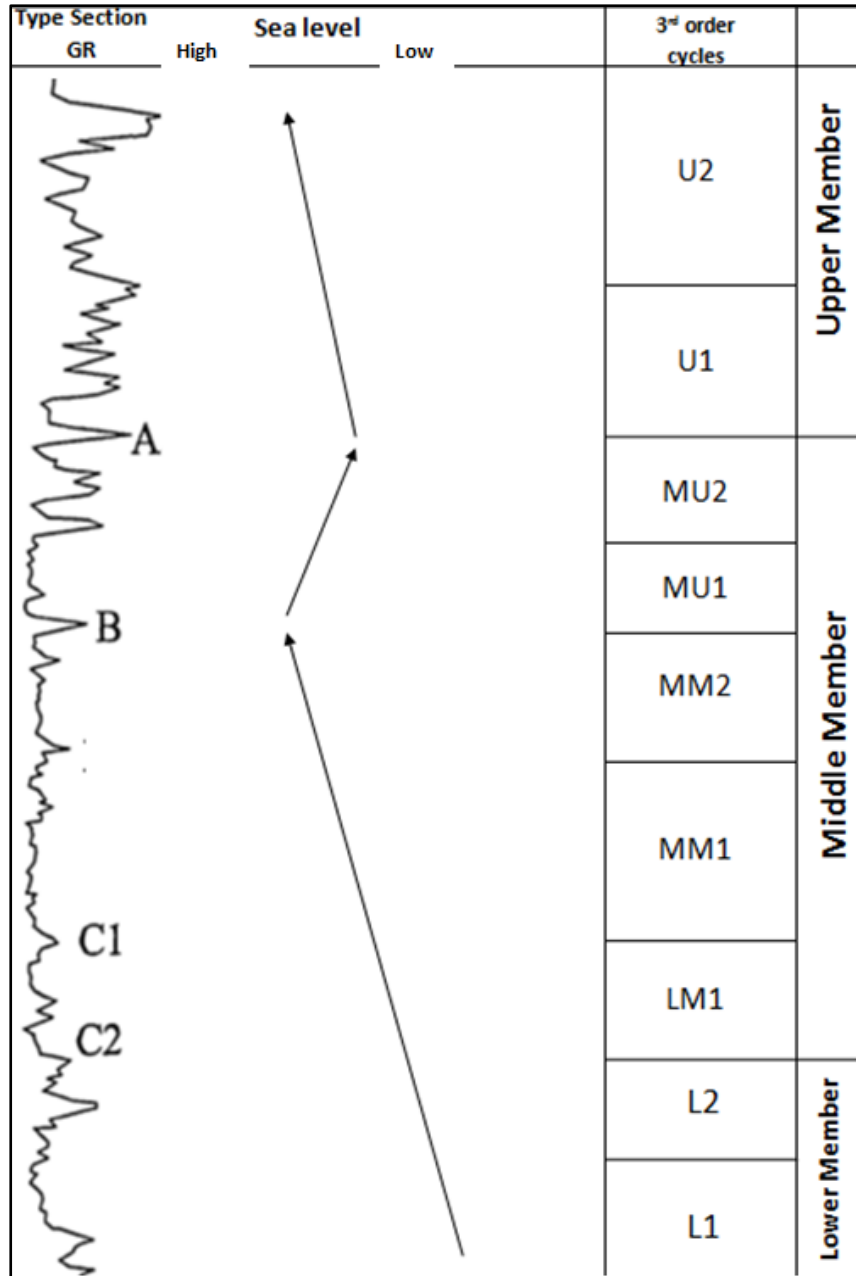


Figure 24. Cyclical sedimentation of the Duperow Formation. Nine 3<sup>rd</sup> order cycles, two transgressive cycles, and one regressive cycle is interpreted.

## **CHAPTER V**

### **DEPOSITIONAL ENVIRONMENTS**

The extensive subsurface distribution of Duperow strata permits detailed environmental interpretations and generation of depositional models. The Duperow Formation accumulated in the Duperow Embayment lying on the leeward southeastern side of the Leduc Reefs of Alberta (Cen and Salad Hersi, 2006). Deposition occurred in a wide epicontinental platform, sheltered by barrier reefs. The Leduc Reefs were likely responsible for restricting water circulation within the platform interior. The depositional setting includes transitions from shallow subtidal to supratidal conditions.

Cyclicality and lithofacies distribution within the Duperow Formation allows five lithofacies associations to be made, which correspond to five depositional settings. The five depositional settings include: 1) subtidal, normal marine, 2) stromatoporoid bank/mound, 3) intertidal, slightly restricted, 4) intertidal, more restricted, and 5) supratidal environments. Individual depositional environments are discussed below.

#### **Subtidal, Normal Marine**

Depositional setting one represents a subtidal normal marine environment which contains lithofacies association one (LFA-I), bioclastic wackestone/packstone. It most commonly occurs in the lower parts of the Duperow Formation within the lower and lower middle members. A wide range of diverse fauna suggests deposition under normal marine conditions with normal salinity and shallow water depth (Figure 25). Corals,

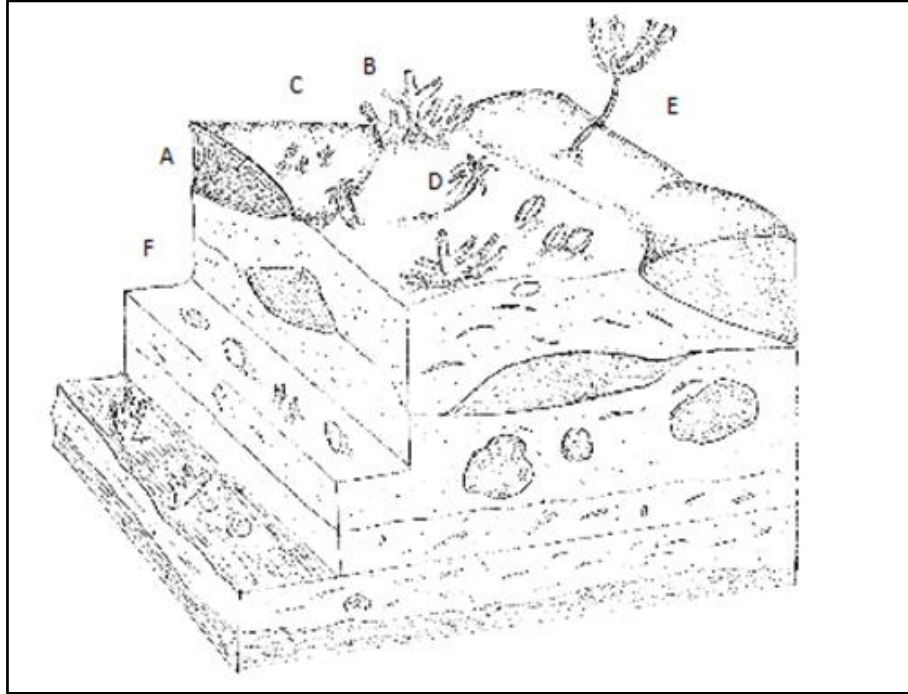


Figure 25. Block diagram of the Duperow Formation's normal marine fauna. A) Stromatoporoid B) *Thamnopora* C) *Syringopora* polyps D) Corals E) Crinoid F) Ostracods (Modified from McKerrow, 1982).

sponges, brachiopods, crinoids, bivalves, and gastropods suggest deposition in water that was well circulated and open (Wilson, 1967). Shinn (1983) reports that horizontal burrows and high amounts of fine grained mud matrix with few evaporites indicates deposition within a low energy, subtidal environment.

### **Stromatoporoid Bank or Mound**

Stromatoporoid bank or mound environments characterize depositional setting two. Stromatoporoids often build a rigid framework which form bank and/or mound structures. Lithofacies association two (LFA-II) predominantly comprises this environment with tabular and bulbous stromatoporoids accumulating in front of a tidal flat and lagoon. Bioclastic wackestone/packstone (LF1) is also associated with this environment as corals, crinoids, and brachiopods are present. The diverse fossil



assemblage within this environment suggests deposition within a high energy environment, possibly a shoal (Shinn, 1983).

### **Intertidal, Slightly Restricted**

Lithofacies association three (LFA-III) comprises depositional setting 3 which represents intertidal, slightly restricted environments of deposition. This environment had less water circulation and lower energy conditions than seen in depositional setting two. Amphipora boundstone/floatstone (LF3) and peloidal wackestone (LF4) characterize lithofacies observed in this environment. Flugel (2004) interpreted the occurrence of branching stromatoporoids (Amphipora) as being deposited within a quiet, back reef environment with slightly restricted waters. Observation of peloids, soft sediment deformation, compaction features, high amounts of mud matrix, diverse fossil assemblage, and nodules further point to deposition within quiet, slightly restricted waters with periods of poor circulation. These deposits likely accumulated behind the stromatoporoid banks and mounds as they provided shelter for the more restricted facies.

### **Intertidal, More Restricted**

Depositional setting four is composed of dolomitic mudstone (LF5) and microbially laminated dolowackestone (LF6). Together these lithofacies comprise lithofacies association 4 (LFA-IV). This association represents deposition in an intertidal, more restricted environment. Dolomitic mudstone lithofacies (LF5) contains thin to thick laminations with flaser bedding and soft sediment deformation which suggests an intertidal mudflat depositional setting. Ginsburg (1977) and Shinn (1983) reported that the low amounts of fossil contents and sedimentary structures allowed for accumulation of sediments in a more restricted environment than depositional setting three. Rare fossils

and the occurrence of algal laminations suggest deposition within water above normal salinities. The microbially laminated dolowackestone facies (LF6) with abundant algal laminations, lesser amounts of peloids, and soft sediment deformation likely formed in an intertidal mudflat environment. Work by Wilson (1967) also concludes that the lithofacies association four (LFA-IV) accumulated in calm, high salinity water within an intertidal mudflat environment.

### **Supratidal**

Anhydrite lithofacies (LF7) comprises lithofacies association five (LFA-V) and depositional setting five. Gray to white, nodular and mottled anhydrite represents deposition within supratidal conditions. High salinity supratidal or sabkha conditions have been interpreted by Cen and Hersi (2006) and Wilson (1967). Anhydrite was initially gypsum crystals which were altered within soft sediment to create the nodular and mottled appearance of the observed anhydrite facies. Horizontal beds of dolostone interbed anhydrite in many locations representing deposition within shallow, calm lagoons (Wilson, 1967). Lack of fossil contents and the occurrence of halite suggest super high salinities within an evaporite environment.

### **Depositional Model**

Recognition of five depositional settings permits a discussion of a hypothetical depositional model for the Duperow Formation. The Duperow Formation of the Williston Basin comprises the largest carbonate facies development during a major transgression (Dunn, 1975 and Kent, 1983). The Late Devonian Duperow Sea stretched southeastward from the Alberta reef to Saskatchewan, North Dakota, most of Montana, and central South Dakota. Two transgressive-regressive periods are recognized within the Duperow

Formation which are interpreted as 3<sup>rd</sup> order cycles during deposition of the Duperow. Wilson's (1967) marker bed "A" is interpreted to represent a maximum flooding surface during the maximum marine transgression of the Duperow Sea. The initial transgressive phase is represented within lower member and lower middle member facies while the regressive phase is interpreted from the upper middle member. The last transgressive phase of Duperow deposition is represented within the upper member.

The first transgression of the Duperow Sea resulted in rising sea level which allowed normal marine fauna to become diverse and widespread. Brachiopods, corals, crinoids, sponges, bivalves, and gastropods all flourished in waters of normal salinity with shallow depth. Stromatoporoid banks/mounds and corals accumulated mostly upon paleotopographic highs, including the Nesson and Billings anticlines, where water depth was relatively shallower. Here, they restricted water circulation and caused an increase in water salinity and a decrease in water energy. The increased salinities and poor circulation eventually caused the demise of stromatoporoid banks/mounds as these organisms cannot inhabit such saline environments. Their role is of much importance in determining and interpreting the type of cyclicity seen within the lower Duperow.

Cycles recognized within the lower Duperow are characterized by subtidal stromatoporoid bank/mound deposits being overlain by intertidal to supratidal limestones, dolostones, and anhydrite. Bioclastic wackestone/packstone lithofacies also occurs within the subtidal environment and is often bound above and below by stromatoporoid boundstone/floatstone. An overall shallowing upward succession is recognized as a regressive phase was initiated during deposition of the upper Duperow.

The absence of normal marine fauna and presence of stromatolites in the upper middle member of the Duperow suggest a fall in sea level and increase in salinity. The regressive phase caused sea levels to drop, limiting circulation, and may have resulted in progradation of a shallowing upward succession. Thick accumulations of anhydrite in the uppermost middle member represent the lowest point of sea level and the final stage of the regressive third-order cycle.

The upper member of the Duperow contains more argillaceous limestone lithofacies suggesting a shift in sea level. Here, third order cycles are interpreted as a transgressive phase. The transgressive phase resulted in an increase in water depth, circulation, and a return to normal salinities. Normal marine faunas again flourished with abundant brachiopods, crinoids, corals, sponges, and bivalves. A vertical succession of clay rich dolomitic mudstone overlain by bioclastic wackestone/packstone characterizes the uppermost part of the Duperow Formation as transgression likely continued into the overlying Birdbear Formation.

## **CHAPTER VI**

### **DIAGENESIS AND POROSITY**

Well core and thin section examination allows recognition of diagenetic fabrics within the Duperow Formation. Identifying these variable diagenetic features permits a paragenetic sequence to be constructed. Dolomitization, micritization, dissolution, calcite cement, and compaction are all observed within the Duperow and represent differing diagenetic environments. Varying degrees of diagenetic processes influence porosity within the sediments of the Duperow Formation. High amounts of post burial alteration results in some lithofacies achieving greater reservoir characteristics than others. A discussion of diagenetic features, associated environments, and porosity is given below.

#### **Diagenetic Features**

The examined rocks of the Duperow contain a number of diagenetic features. Micritization, dolomitization, cementation, dissolution, compaction and fractures are found in variable amounts throughout the formation. Micritization, dolomitization, and cementation are easily recognized in thin section whereas dissolution, compaction and fractures are readily identifiable in core study. The most common diagenetic features are calcite cementation and dolomitization. Each of these features is associated with porosity evolution and reservoir qualities within the Duperow Formation. Marine, meteoric, and burial diagenetic environments are the attributing factor for the observed diagenetic

features. Micritization, calcite cement, dolomitization, and compaction are the most common diagenetic features thus are the focus of the following discussion.

### **Marine Stage Diagenesis**

#### **Micrite Enveloping and Micritization**

Micrite enveloping and micritization were observed in several thin sections which are distributed throughout the entire Duperow Formation. These features are likely the earliest diagenetic fabrics to occur and often are characterized by finely crystalline micritic rims around bioclasts (Figure 26A). Rims are usually dark to light brown and most commonly coat brachiopod and bivalve shell fragments. Complete micritization is also observed and is characterized by crystalline micrite completely replacing the internal structure brachiopod shells.

#### **Calcite Cement**

Bladed calcite cement is the predominant type of calcite cement to occur within the Duperow. It likely represents the initial phase of pore filling cement and often occurs in the interparticle space of stromatoporoids, corals, and crinoids (Figure 26B). The lower member and the lower part of the middle member both contain appreciable amounts of bladed calcite cement. Cement occurs in voids and is often a columnar mosaic of calcite grains.

#### **Fine Crystalline Dolomite**

Fine crystalline dolomite is one of the most abundant and widespread diagenetic features observed within the Duperow. Subhedral to euhedral crystals occur often with fine carbonate mud matrix and along the edges of bioclasts (Figure 26C). Complete dolomitization does occur and often preserves good intercrystalline porosity (Figure 27).



Figure 26. Marine stage diagenetic features. A) Micritization and micrite enveloping (dark brown areas), NDIC #10671,8,536ft. B) Bladed calcite cement within internal bioclast structure NDIC #11301,8,574ft. C) Fine crystalline dolomite rhombs around edges of sponge fragment, NDIC #11148,9,193ft. PP (plane polarized light. Scale bar: 500um.

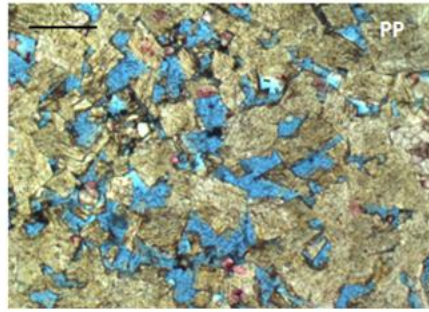


Figure 27. Photomicrograph of fine crystalline dolomite rhombs with well developed intercrystalline porosity (blue areas), NDIC #2887,9,473ft. PP (plane polarized light). Scale bar: 500um.

The more dolomitized facies typically exhibit larger amounts of porosity. Porosity ranges from 5% to 20% in the dolomitized facies. Dolomitization appears to be fabric selective as only two lithofacies contain fine crystalline dolomite. Stromatoporoid boundstone/floatstone and microbially laminated dolowackestone both have varying degrees of dolomitization and intercrystalline porosity.

## Meteoric Stage Diagenesis

### Dissolution

Dissolution of skeletal fragments only occurs in the upper unit of the middle member of the Duperow. Brachiopod and bivalve shells are often dissolved and replaced with calcite cements (Figure 28A). In both hand specimen and thin section, bioclasts are typically dissolved which gives way to moldic and vuggy porosity (Figure 28B). Many moldic pore spaces are destroyed due to later compaction.

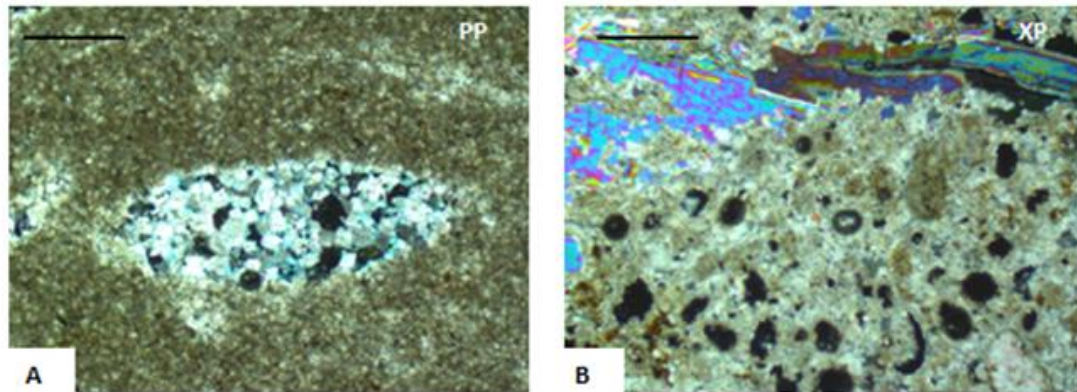


Figure 28. Meteoric stage diagenetic features. A) Dissolved shell replaced by calcite crystals, NDIC #11301, 8,580ft. B) Dissolved bioclasts (black voids), NDIC #11567, 8,524ft. PP (plane polarized light), XP (cross polarized light). Scale bar: 500  $\mu$ m.

## Burial Stage Diagenesis

### Physical and Chemical Compaction

Physical and chemical compaction diagenetic features are recognized in thin section and hand specimen. Physical compaction is the result of overburden pressure during burial. Breakage of bioclasts and molds are common within the bioclastic wackestone/packstone and peloidal wackestone lithofacies. Reduction of porosity is



observed as voids are reduced due to the overlying weight of the sediment being deposited.

Chemical compaction is often associated with the later stages of physical compaction. Dissolution seams and stylolites characterize chemical compaction fabrics and occur throughout the entire Duperow Formation (Figure 29A and B). Stylolites are the most important feature as they represent a transition from marine and meteoric stage to burial stage diagenesis. The geometry of observed stylolites varies from smooth anastomosing sets to individual seams with sharp peaks with high amplitude. The concentrations of minerals within the solution likely controlled their geometry and response to burial.

### **Blocky Calcite Cement**

Subhedral to euhedral blocky calcite cement is the most common and significant burial diagenetic feature. It is found throughout the entire formation and occurs in bioclastic wackestone/packstone, stromatoporoid boundstone/floatstone, and *Amphipora* boundstone/floatstone lithofacies. This cement typically fills pores and voids and is

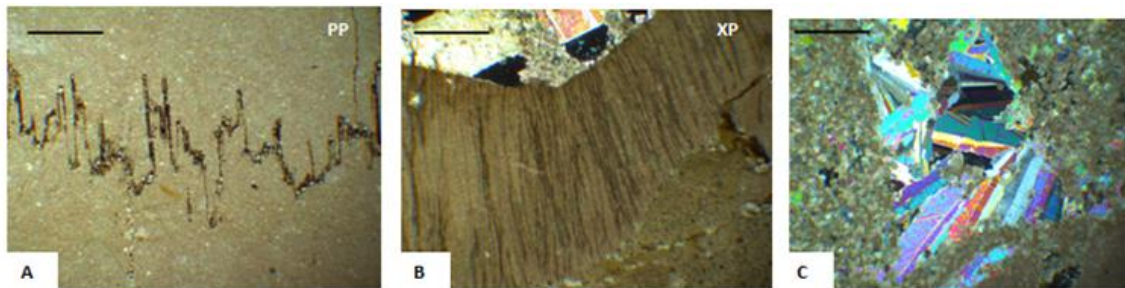


Figure 29. Burial stage diagenetic features. A) Stylolites in a mudstone matrix, NDIC #11567,8,454ft. B) Solution seams in a mudstone matrix, NDIC #10830,8,349ft. C) Anhydrite cement in void, NDIC #11148,9,412ft. PP (plane polarized light, XP (cross polarized light).

equant to elongate in shape. Bladed calcite cement is replaced by blocky calcite cement as the latter represents secondary pore filling (Cen, 2010). Internal molds of stromatoporoids and coals are often filled with blocky cement crystals that grow inward from the void. Often blocky calcite is found with and replaced by dolomite rhombs suggesting that the calcite cement was present before the dolomite.

### **Dissolution**

Burial dissolution of vugs is also observed in the Duperow Formation. It occurs less frequently than the other burial diagenetic features and is found only in the microbially laminated dolowackestone lithofacies. Dissolution vugs often cut across preexisting grains or appear as etching on dolomite rhombs. Etched dolomite rhombs suggest an older age for dissolution vugs. Vugs created by dissolution enhance porosity and permeability within the thin sections examined.

### **Fractures**

Fractures occur throughout the Duperow Formation and are found within the bioclastic wackestone/packstone and dolomitic mudstone lithofacies. Fractures are observed in hand specimen and thin section. Vertical fractures dominate while lesser amounts of horizontal fractures occur. Anhydrite typically fills in fractures implying anhydrite cementation post fracture.

### **Anhydrite Cement**

Anhydrite cement can also be observed in hand specimen and thin section. It is found predominantly in the upper middle unit of the middle member. In core, it is typically white to bluish gray whereas white bladed elongate crystals characterize it in thin section. Anhydrite crystals often occur as clusters of medium to coarse elongate

crystals within voids (Figure 29C). Void filling anhydrite reduces porosity and permeability and replaces most of the earlier diagenetic features.

### **Diagenetic Environment**

Marine, meteoric, and burial diagenesis characterize the diagenetic influence of the rocks studied in the Duperow Formation. Marine diagenesis includes micrite enveloping and micritization, bladed calcite cement, and fine crystalline dolomite. Dissolution of skeletal fragments characterizes meteoric stage diagenesis whereas compaction, blocky calcite cement, dissolution of vugs, fractures, and anhydrite cement occur during burial stage diagenesis (Tucker and Wright, 1992, Wanless, 1975 and Moore, 1989). A hypothetical diagenetic environment model is discussed below, which is based upon the spatial relationship between the diagenetic features. Rocks in the Duperow that underwent diagenesis did so from being influenced by marine, meteoric, and burial stage diagenetic events.

Micritization, micrite enveloping, bladed calcite cement, and fine crystalline dolomite are associated with marine environments and represent the earliest diagenetic stage of the Duperow Formation. The depositional settings of the Duperow Formation occur across transitions from subtidal to supratidal environments. Within shallow marine environments, amounts and degrees of diagenesis depend on water energy level (Tucker, 1990). More restricted areas, such as upper intertidal and supratidal environments, allow deposition of fine carbonate mudstone. Here, water energy is low so the main catalyst to diagenesis is micritization by algae and bacteria (Tucker, 1990).

More restricted intertidal areas permit fine crystalline dolomite to accumulate. The microbially laminated dolowackestone lithofacies contains the greatest amount of

fine crystalline dolomite. The occurrence of stromatolites within a restricted environment suggests that magnesium rich fluids passed through these rocks, resulting in fine crystalline dolomite. The anhydrite lithofacies also contains fine crystalline dolomite. Anhydrite is thought to represent the most shoreward supratidal facies where the evaporation of seawater is a likely mechanism to explain the degrees of dolomitization.

Subtidal environments experience much more water energy, therefore are more susceptible to cementation through sea water passing through porous carbonates. Bioclastic wackestone/packstone and stromatoporoid boundstone/floatstone lithofacies both contain appreciable amounts of bladed calcite cement which is indicative of a higher energy environment (Tucker, 1990).

Only dissolution of skeletal fragments has been observed within the meteoric realm of diagenesis. The meteoric environment is subjected upon Duperow rocks during periods of sea level fall or shoreline progradation. Dissolution mainly occurs in the bioclastic wackestone/packstone lithofacies as bivalves and brachiopods are dissolved to form moldic pores. Moore (1989) suggests that this type of fabric selective dissolution occurred early in the meteoric diagenetic stage. Skeletal fragments are highly susceptible to dissolution and solvents likely passed through bioclastic rich rocks soon after deposition.

The latest diagenetic stage to occur within the Duperow Formation is burial stage diagenesis. The burial stage is characterized by compaction, blocky calcite cement, dissolution of vugs, fractures, and anhydrite cement. Overburden pressure during burial is responsible for physical and chemical compaction. The presence of stylolites suggests later stages of burial diagenesis (Moore, 1984). Stylolites provide unique insights into

diagenetic history as they represent a transition from marine and meteoric diagenetic environment to burial environment. Stylolites often cut across other diagenetic features and have variably morphology. These presumed later diagenetic feature variations in morphology could be the result of concentrations of insoluble minerals, such as clays and pyrite, within solution seams. During burial, the solution seams individual response to overburden pressure and their interaction with surrounding sediment could be the result of morphology variations.

The process responsible for blocky calcite cement is still in much debate (Tucker, 1990 and James and Choquette, 1984). It has been included within the burial stage of this study due to its occurrence within the coarser grained facies of the Duperow and its association with dolomite. Blocky calcite cement most commonly occurs as white to clear calcite crystals which likely accumulated within voids of skeletal structures.

Dissolution vugs occur in grains, matrix, and cement suggesting one of the latest stages of burial diagenesis. Non fabric selective processes are important for establishing a spatial framework. Anhydrite cement often replaces grains, matrix, and other diagenetic features implying an even later diagenetic stage. The infill of anhydrite into fractures allows their sequential relationship to be determined. Anhydrite certainly occurred post fracture and likely accumulated during evaporation of seawater in an intertidal to supratidal environment.

## CHAPTER VII

### DISCUSSION AND CONCLUSIONS

The Late Devonian Duperow Formation of North Dakota is a cyclical carbonate-evaporite unit deposited in the southeastern Western Canada Sedimentary Basin. The depositional setting is a back-reef inner platform, which lies southeast of the Leduc Reef Barrier of the Alberta Basin. The lithostratigraphic approach used to identify informal members follows that by Sandberg and Hammond (1958), Wilson (1967), Dunn (1975), Kent (1983), and Cen (2010). Drill core and well log examination resulted in the identification of three informal members (i.e., lower middle, and upper), all of which can be readily traced throughout the study area.

The lower member of the Duperow Formation conformably overlies the Souris River Formation and is predominantly comprised of limestone and dolostone lithofacies. Bioclastic wackestone/packstone, stromatoporoid boundstone/floatstone, and dolomitic mudstone characterize the limestone lithofacies. Whereas microbially laminated dolowackestone constitutes the dolostone lithofacies. Normal marine fauna are abundant throughout the lower member. Lithofacies are arranged in a cyclical pattern of limestone, dolostone, and anhydrite, in ascending order.

The middle member of the Duperow Formation is the thickest and has been divided into three subunits; lower, middle, and upper. The lower unit is characterized by limestone lithofacies which include bioclastic wackestone/packstone, stromatoporoid

boundstone/floatstone, and dolomitic mudstone. Lesser amounts of dolostone facies occur and include microbially laminated dolowackestone and dolostones interbedded with anhydrite. The middle unit consists of rhythmic successions of bioclastic wackestone/packstone, stromatoporoid boundstone/floatstone, and fine carbonate mudstone. Dolomitic mudstone is common in the lower parts of the unit and often interbeds bioclastic wackestone/packstone lithofacies. The upper unit of the middle member is mostly comprised of bioclastic wackestone/packstone and fine carbonate mudstone. Brachiopods, corals, crinoids, and bivalves constitute the majority of bioclasts. Stylolites are common in the mudstone facies. Dolostone lithofacies occur in minor amounts which contain microbially laminated dolowackestone and dolostone interbedded with anhydrite. Increasing amounts of anhydrite are observed the upper part of the unit.

The upper member of the Duperow Formation conformably underlies the Birdbear Formation. The uppermost unit consists of limestone lithofacies with lesser amounts of dolostone and anhydrite. The upper member is more argillaceous than the other two members. Limestone lithofacies include bioclastic wackestone/packstone and carbonate mudstone. Dolostone lithofacies includes microbially laminated dolowackestone and dolostone interbedded with anhydrite.

Isopach mapping of the individual Duperow members exhibits that each member can be readily traced throughout the study area. Members achieve their maximum thickness along positive paleostructural trends near the Nesson and Billings anticlines. Consistent isopachs coupled with traceable log characteristics permits each member to be correlated throughout the study area. Therefore, Duperow strata which are known to

produce hydrocarbons along the Nesson and Billings anticlines can be extrapolated away from these features and still yield appreciable amounts of reservoir characteristics.

Petrographic examination of thin sections and drill core permitted recognition of seven lithofacies (LF1 to LF7) which can be grouped into five lithofacies associations (LFA-I to LFA-V). Lithofacies association one only contains one lithofacies, bioclastic wackestone/packstone (LF1) which was deposited within a subtidal normal marine environment. Lithofacies association two contains stromatoporoid boundstone/floatstone representing deposition within stromatoporoid banks or mounds. Two lithofacies, *Amphipora* boundstone/floatstone and peloidal wackestone, comprise lithofacies association three. These units were deposited within a slightly restricted intertidal setting. Lithofacies association four also contains two lithofacies. Dolomitic mudstone and microbially laminated dolowackestone comprise this association and were deposited under more restricted intertidal conditions. Anhydrite lithofacies characterizes lithofacies association five and represents deposition within supratidal conditions.

The Duperow Formation preserves large scale rhythmic sea level fluctuations which display shallowing upward sequences. Sequences consist of normal marine subtidal deposits grading upwards into intertidal and supratidal deposits. Preserved sedimentary cycles are the result of variations in sea level which govern sedimentation on shallow marine shelves. Two cycles, Type-1 and Type-2, are recognized and characterize the cyclical sedimentation of the Duperow Formation. The difference in cycles comes from the absence of stromatoporoid boundstone/floatstone in Type-2 cycles. Both cycles likely record fourth- order sea level fluctuations but are grouped into broader third-order



cycles on the basis of preserved sediment thickness and high amounts of post burial compaction.

Nine third-order cycles are interpreted from the studied rocks of the Duperow. These third-order cycles are shorter term events, representing depositional duration on the order of one to two million years. Cycles were chosen on the basis of shifts in environment, interpreted from facies, and coupled with traceable log characteristics. Sea level change was likely the result of small tectonic events which allowed seawater to rise and fall within the Duperow Sea. The high degree of compaction and fluid movement through porous Duperow carbonates makes it difficult to ascertain an approximate original sediment thickness and overall accumulation rates.

An overall transgressive sequence is recorded by rocks of the Duperow. Small regressive deposits at the top of the middle member are probably the result of sedimentation rate outpacing relative sea level rise. Transgression was initiated in the underlying Souris River Formation and continued into the overlying Birdbear Formation.

The predominant diagenetic processes affecting Duperow strata are calcite cementation, dolomitization, and compaction. These three diagenetic fabrics have the greatest influence on porosity and permeability. Calcite cement is the most common and typically occurs as isopachous cement which is altered to bladed and blocky cements. Compaction features include solution seams and stylolites. Stylolites are abundant in the finer grained facies of the Duperow and record sediment compaction along many horizons. The widespread distribution of stylolites suggests that preserved sediment thickness is much less than the original deposited succession. Degree of dolomitization is highly variable within the Duperow, with more dolomitized strata containing greater

amounts of porosity. Subhedral to euhedral dolomite rhombs provide an intercrystalline network of pores which have the ability to retain and transport possible fluids and hydrocarbons. Dolomitization does appear to be fabric selective as it mostly occurs within the stromatoporoid boundstone/floatstone and microbially laminated dolowackestone lithofacies.

The processes that govern dolomitization are still much in debate. Major differences in degrees of dolomitization are noted in Saskatchewan and North Dakota. Differences could be attributed to paleostructural highs and lows, in North Dakota, acting as conduits for dolomitizing fluids. The porous carbonates of the Duperow easily allow fluids to alter their original structure and usually enhance reservoir quality. Additional comprehension of the controls of fluid movement through the Devonian strata of the Williston Basin would permit more accurate conclusions to be drawn regarding the variability of diagenesis. Understanding these diagenetic parameters further advances the knowledge of subsurface strata within North Dakota.

## APPENDICES

## Appendix A Core and Thin Section Descriptions

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**Well #11908 (3302300359)**  
**T160N, R96W, sec. 35 Divide County**

**Texas Gas Exploration**

- 9,684'-9,685' Boundstone, light brown, gray, very fine grained, sucrosic, sponge fragments abundant, solution seams, soft sediment deformation.
- 9,685'-9,686' Packstone, gray, light brown, crystalline, corals, sponge spicules and fragments
- 9,686'-9,687' Wackestone, gray, brown, crystalline, solution seams
- 9,687'-9,690.5' Dolomite, gray, light brown, crystalline, solution seams, anhydrite in part.
- 9,689'-9,690.5' Stromatoporoid Boundstone-Floatstone, brown, gray, fine grained, crystalline, stromatoporoid framework.
- 9,690.5'-9,698' Wackestone, gray, brown, crystalline, solution seams, soft sediment deformation, corals, crinoids, sponge spicules and fragments, bivalve fragments, compaction features, sucrosic in part, stylolites common.
- 9,698'-9,703' Packstone, light brown, tan, gray, crystalline, solution seams, sucrosic, abundant sponge fragments, corals.
- 9,703'-9,708' Wackestone, gray, brown, light brown, crystalline, sucrosic, solution seams, compaction features, sponge fragments, corals, brachiopods, minor burrowing, stylolites rare.
- 9,708'-9,710' Mudstone-Wackestone, brown, dark gray, crystalline, anhydrite, sponge fragments.
- 9,710'-9,714' Dolomite, light gray to gray, crystalline, mottled with anhydrite in part.

**Well #12119 (3310501291)**  
**T158N, R95W, sec. 12 Williams County**

**Amerada Hess Corporation**

- 9,975'-9,976' Packstone, dark gray, brown, crystalline, sponge fragments, corals, dolomitic in part.
- 9,976'-9,982' Dolomite, brown, tan, dark. gray, crystalline, solution seams, compaction features, anhydrite in part.
- 9,982'-9,984.5' Wackestone-Packstone, dark gray, brown, gray, very fine grained, crystalline, soft sediment deformation, sponge fragments, corals, burrows.
- 9,984.5'-9,987' Packstone, dark brown, brown, gray, fine grained, corals and sponge fragments abundant, minor burrows
- 9,987'-9,988' Wackestone, brown, gray, crystalline, solution seams, compaction features, peloids.

- 9,988'-9,994' Boundstone, dark gray, brown, light brown, crystalline, sponge framework, solution seams, compaction features, corals.
- 9,994'-9,996.5' Packstone, dark brown, dark gray, tan, crystalline, solution seams, corals, sponge fragments, vugs in part.
- 9,996.5'-9,998.5' Wackestone, brown, gray, crystalline, soft sediment deformation, compaction features, mottled in part.
- 9,998.5'-10,000' Boundstone, gray, dark gray, brown, crystalline, sponge framework, anhydrite
- 10,000'-10,002' Wackestone-Packstone, dark gray, brown, crystalline, corals, sponge fragments, stylolites rare.
- 10,002'-10,004.5' Dolomite, dk. gray, light gray, patterned, crystalline, soft sediment intraclasts, dark gray interbeds, anhydrite in part.
- 10,004.5'-10,011' Mudstone, brown, gray, light brown, crystalline, solution seams, "pebbly" texture, compaction features, anhydrite. Solution seams create horizontal bedding in part, stylolites rare.
- 10,011'-10,017' Mudstone-Wackestone, dark brown, gray, crystalline, brachiopods, corals, anhydrite.
- 10,017'-10,018.5' Boundstone, brown, gray, crystalline, sponge framework, solution seams
- 10,018.5'-10,020' Wackestone-Packstone, dk. gray, brown, crystalline, corals, crinoids.
- 10,020'-10,023' Packstone, dk. brown, gray, brown, crystalline, sponge fragments, corals, crinoids, fractures common.
- 10,023'-10,025' Wackestone-Mudstone, dk. brown, gray, crystalline, solution seams, compaction features, sponge fragments, ostracods, corals, stylolites rare, fractures.
- 10,025'-10,030.5' Dolomite, lt. brown, tan, crystalline, soft sediment deformation, solution seams, anhydrite in part. Brown and dk. gray laminations in part.
- 10,030.5'-10,035' Wackestone, dk. gray, dk. brown, brown, crystalline, fine grained, solution seams. "Pebbly" texture and anhydrite in part.
- Missing 10,035'-10,123'
- 10,125'-10,127' Dolomite, brown, light brown, tan, dk. gray, crystalline, anhydrite, algal laminations, soft sediment deformation.
- 10,127'-10,129.5' Mudstone-Wackestone, brown, dk. gray, crystalline, solution seams, corals, ostracods, brachiopods.
- 10,129.5'-10,133' Dolomite, dk. gray, dk. brown, crystalline, solution seams, abundant anhydrite, soft sediment deformation
- 10,133'-10,136' Wackestone, dk. brown, dk. gray, very fine grained, crystalline, solution seams, anhydrite in part, dissolved fossils

- 10,136'-10,138.5' Dolomite, dk. gray, dk. brown, crystalline, solution seams. Becomes lt. brown, tan with algal laminations and anhydrite in part.
- 10,138.5'-10,139.5' Wackestone, dk. brown, dk. gray, crystalline, solution seams, corals, crinoids
- 10,139.5'-10,146.5' Dolomite, brown, gray, lt. brown, tan, crystalline, solution seams, anhydrite abundant, possible algal laminations.
- 10,146.5'-10,151' Mudstone-Wackestone, dk. brown, dk. gray, very fine grained, crystalline, solution seams, corals, few brachiopods.
- 10,151'-10,152' Dolomite, gray, tan, crystalline, abundant anhydrite, algal laminations, soft sediment deformation.
- 10,152'-10,156.5' Mudstone-Wackestone, dk. brown, dk. gray, crystalline, solution seams, dolomitic in part, minor burrowing, "pebbly" texture in part.
- 10,156.5'-10,157.5' Dolomite, lt. brown, tan, crystalline, solution seams, anhydrite.
- 10,157.5'-10,163' Mudstone, dk. brown, dk. gray, brown, crystalline, solution seams, fractures common.
- 10,163'-10,164' Boundstone, brown, gray, crystalline, sponge framework.
- 10,164'-10,165' Wackestone, dk. brown, dk. gray, crystalline, solution seams, brachiopods, corals
- 10,165'-10,171' Mudstone, dk. brown, dk. gray, brown, crystalline, soft sediment deformation, solution seams.
- 10,171'-10,172.5' Wackestone, dk. brown, dk. gray, brown, very fine grained, crystalline, solution seams, soft sediment deformation, compaction features, corals, crinoids.
- 10,172.5'-10,177' Packstone, brown, gray, tan, dk. gray, crystalline, abundant sponge fragments, corals, ostracods, brachiopods.
- 10,177'-10,180.5' Wackestone, brown, gray, dk. gray, fine grained, crystalline, solution seams, corals, sponge fragments.
- 10,180.5'-10,184' Mudstone, brown, dk. gray, very fine grained, crystalline, solution seams, soft sediment deformation.

**Well #32 (3310500005)**

**T157N, R95W, sec. 12 Williams County**

**Amerada Petroleum Corporation**

- 10,192'-10,201' Wackestone, dark brown to brown, dark gray, very fine grained, crystalline, solution seams, soft sediment deformation, crinoids, corals, bivalve shell fragments, sponges, dolomitic in part.

- 10,201'-10,206' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, dolomite in part, "pebbly" texture.
- TS: 10,202' Mudstone, dark brown to gray, very fine grained, fine carbonate mud matrix, calcite and anhydrite grains, microspar occurs around mineral grains, interparticle porosity (15%).
- 10,206'-10,221' Wackestone, dark brown to brown, gray, very fine grained, crystalline, solution seams, soft sediment deformation, dolomite in part, corals, crinoids, brachiopods, burrows, abundant sponge fragments.
- 10,221'-10,222.5' Dolomite, light gray to gray, crystalline, patterned.
- 10,222.5-10,224.5' Mudstone-Wackestone, dark brown to brown, dark gray, very fine grained, crystalline.
- 10,224.5'-10,227' Dolomite, light gray to light brown, tan, crystalline, solution seams, patterned in part.
- 10,227'-10,230' Wackestone, dark brown to brown, dark gray, very fine grained, crystalline, solution seams, corals, crinoids, gastropods
- 10,230'-10,233' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, soft sediment deformation, compaction features
- Missing 10,223-10,279'
- 10,279'-10,287' Mudstone, dark brown to dark gray, very fine grained crystalline, solution seams, soft sediment deformation, compaction features.
- 10,287'-10,288' Dolomite, light gray to brown, crystalline, solution seams, limestone in part.
- 10,288'-10,300' Mudstone, dark brown to brown, dark gray, very fine grained, crystalline, solution seams, sponge spicules, dolomite in part, minor burrows.
- 10,300'-10,307' Dolomite, dark gray to gray, light brown to brown, crystalline, solution seams, horizontal anhydrite laminations.
- 10,307'-10,308' Mudstone, dark gray to dark brown, crystalline, solution seams, burrows.
- TS: 10,307' Mudstone, gray to brown, very fine grained, fine carbonate mud matrix, peloids, calcispheres, calcite cement, vuggy porosity (15%), anhydrite present.
- 10,308'-10,310' Dolomite, gray, light brown to brown, crystalline, solution seams, anhydrite mottling.
- 10,310'-10,311' Mudstone, dark brown to brown, dark gray, very fine grained, crystalline, solution seams.
- 10,311'-10,317' Dolomite, light brown, tan, gray, crystalline, solutions seams, anhydrite mottling, algal laminations in part.



- 10,317'-10,318' Mudstone, dark brown to brown, dark gray, very fine grained, crystalline, solution seams, dolomitic.
- 10,318'-10,319' Dolomite, brown, gray, crystalline, solution seams.
- 10,319'-10,320' Wackestone, dark brown to brown, dark gray, fine grained, crystalline, solution seams, compaction features, corals.
- 10,320'-10,323' Dolomite, dark gray to gray, light brown to brown, crystalline, solution seams, horizontal anhydrite laminations.
- 10,323'-10,325' Mudstone-Wackestone, brown to dark gray, crystalline, solution seams, replaced corals, brachiopods.
- 10,325'-10,329' Dolomite, light brown to brown, gray, crystalline, solution seams, horizontal anhydrite laminations.
- 10,329'-10,330' Mudstone, dark brown, dark gray, to gray, very fine grained, crystalline, solution seams, burrows
- 10,330'-10,332' Dolomite, dark gray to gray, brown, crystalline, solution seams, horizontal anhydrite laminations, soft sediment deformation.
- 10,332'-10,334' Wackestone, dark brown to dark gray, very fine grained, crystalline, solution seams, corals, crinoids, sponge spicules
- 10,334'-10,342' Dolomite, light brown to brown, dark gray, crystalline, solution seams, anhydrite mottling in part, soft sediment deformation, sponge fragments
- 10,342'-10,345' Wackestone, dark brown to brown, dark gray, very fine grained, crystalline, solution seams, corals.
- TS: 10,336' Mudstone-Wackestone, brown to gray, fine grained, fine carbonate mud with minor amounts of peloid pellets and anhydrite.
- 10,345'-10,346.5' Dolomite, dark gray to gray, brown, crystalline, solutions seams, anhydrite.
- 10,346.5'-10,349' Mudstone, dark brown to brown, dark gray, fine grained, compaction features.
- 10,349'-10,355.5' Wackestone, brown to gray, fine grained, crystalline, solution seams, soft sediment deformation, corals, crinoids, dolomitic in part.
- 10,355.5'-10,360.5' Packstone, dark brown to brown, dark gray, crystalline, solution seams, soft sediment deformation, compaction features, sponge and sponge fragments abundant.
- 10,360.5-10,362' Wackestone, light brown, tan, fine grained, crystalline, vugs, sponge structure with vugs.

**Well #2451 (3310500572)**  
**T159N, R95W, sec. 30 Williams County**

**Dallea Petroleum Corporation**

- 9,972'-9,977.5' Wackestone-Packstone, dark brown to brown, gray, fine grained, crystalline, solution seams, corals, sponge fragments, crinoids, minor burrows.
- 9,977.5'-9,981' Amphipora Boundstone-Floatstone, dark brown to brown dark gray, crystalline, small circular line and dot *Amphipora* sponges, solution seams, compaction features.
- 9,981'-9,990' Wackestone, dark to light brown, dark gray to gray, very fine grained, crystalline, sponge fragments, crinoids, corals, brachiopods.
- 9,990'-9,996.5' Dolomite, light to dark gray, brown, crystalline, "pebbly" texture, solution seams, vugs.
- 9,996.5'-10,006' Mudstone, dark brown, gray, very fine grained, crystalline, horizontal solution laminations.
- 10,006'-10,014' Mudstone-Wackestone, dark to light brown, gray, crystalline, soft sediment deformation, sponge fragments, coral, crinoids.
- 10,014'-10,021' Stromatoporoid Boundstone-Floatstone, light brown to brown, gray, fine grained, crystalline, solution seams, stromatoporoid framework, corals, crinoids.
- 10,021'-10,022' Dolomite, light brown to brown, gray, crystalline, soft sediment deformation.
- 10,022'-10,023.5' Wackestone, light brown to brown, gray, crystalline, corals, sponges.
- 10,023.5'-10,028' dolomite, light gray to gray, crystalline, horizontal solution laminations.

**Well #12971 (3310501397)**  
**T156N, R95W, sec. 20 Williams County**

**Amerada Hess Corporation**

- 10,354'-10,359.5' Wackestone-Packstone, dark brown to brown, gray, fine grained, crystalline, stylolites common, solution seams, echinoderms, sponges, brachiopods.
- 10,359.5'-10,366' Dolomite, light brown to brown, gray, crystalline, solution seams, soft sediment deformation, anhydrite abundant, sucrosic.
- 10,366'-10,370' Mudstone, dark brown to gray, very fine grained, crystalline, solution seams, compaction features.
- 10,370'-10,372.5' Wackestone, dark brown to gray, very fine grained, crystalline, sponge fragments, echinoderms, stylolites, anhydrite in part, solution seams.

- 10,372.5'-10,376' Microbially laminated wackestone, light brown to gray, crystalline, stromatolite framework, gypsum pseudomorphs, anhydrite in part.
- 10,376'-10,380' Wackestone-Packstone, dark brown, dark gray to gray, fine grained, crystalline, solution seams, soft sediment deformation, compaction features, anhydrite in part, sponge fragments, echinoderms, ostracods, small circular white line and dot Amphipora.
- 10,380'-10,384' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, horizontal fractures, soft sediment deformation.
- 10,384'-10,390' Dolomite, gray to light brown, crystalline, anhydrite mottling, solution seams.
- 10,390'-10,398.5' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, soft sediment deformation, anhydrite in part, horizontal fractures, stylolites.
- 10,398.5-10,403' Stromatoporoid Boundstone-Floatstone, light to dark brown, dark gray, fine grained, crystalline, stromatoporoid framework, corals.
- 10,403'-10,405' Mudstone-Wackestone, dark to light brown, gray, very fine grained, crystalline, solution seams, corals.
- 10,405'-10,409' Dolomite, gray to light brown, crystalline, sucrosic, stylolite.
- 10,409'-10,413' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams.
- 10,413'-10,416' Wackestone, dark brown to dark gray, fine grained crystalline, anhydrite in part, compaction features, echinoderms, corals.
- Missing 10,416'-10,516'
- 10,516'-10,517' Wackestone, dark gray to gray, brown, very fine grained, crystalline, solution seams, corals, stylolites, sponge fragments.
- 10,517'-10,520.5' Dolomite, light gray to light brown, crystalline, sucrosic, solution seams.
- 10,520.5'-10,522' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams.
- 10,522'-10,523' Dolomite, gray to brown, crystalline, anhydrite mottling.
- 10,523'-10,528' Mudstone, dark brown to dark gray, very fine grained, crystalline, horizontal solution laminations, anhydrite in part.
- 10,528'-10,530.5' Dolomite, gray to light brown, crystalline, horizontal anhydrite laminations.
- 10,530.5'-10,534' Wackestone, dark gray to gray, brown, very fine grained, crystalline, solution seams, corals, sponge fragments, stylolites.
- 10,534'-10,543' Mudstone, dark brown to brown, gray, very fine grained, crystalline, horizontal solution seams, soft sediment deformation, anhydrite in part, dolomitic.

- 10,543'-10,545' Packstone-Wackestone, light brown to brown, gray, crystalline, solution seams, dissolved stromatoporoids, crinoids, corals.
- 10,545'-10,548.5' Wackestone, brown, gray, crystalline, coals, brachiopods, gray intraclasts (replaced fossils)
- 10,548.5'-10,550' Stromatoporoid Boundstone-Floatstone, brown, gray, crystalline, solution seams, soft sediment deformation, stromatoporoid framework, corals.
- 10,550'-10,554' Mudstone, dark gray to dark brown, very fine grained, crystalline, horizontal solution laminations, light gray silty intraclasts.
- 10,554'-10,556' Wackestone, brown, gray, crystalline, solution seams, corals, sponge fragments.
- 10,556'-10,562' Stromatoporoid Floatstone, gray, light brown to brown, fine grained, crystalline, solution seams, stromatoporoid framework, corals.
- 10,562'-10,564' Wackestone, dark brown to gray, fine grained, crystalline, solution seams, corals, intraclasts.
- 10,564'-10,566' Mudstone, dark brown to gray, very fine grained, crystalline, solution seams, soft sediment deformation, dolomitic.
- 10,566'-10,568.5' Dolomite, light gray to gray, crystalline, patterned, anhydrite in part, tan algal laminations.
- 10,568.5'-10,569.5' Mudstone, dark brown to gray, very fine grained, crystalline, solution seams.
- 10,569.5'-10,575' Dolomite, gray to brown, crystalline, horizontal anhydrite laminations.
- 10,575'-10,576' Mudstone, dark brown to brown, gray, very fine grained, crystalline, solution seams, soft sediment deformation.

**Well #9800 (3310501044)**

**T158N, R97W, sec. 27 Williams County**

**Atlantic Richfield Corporation**

- 10,736-10,740.5' Mudstone-Wackestone, dark brown to brown, dark gray, very fine grained, crystalline, solution seams, soft sediment deformation, corals, crinoids, brachiopods, solution seam separating mudstone from wackestone, rare ostracods, dolomitic in part.
- TS: 10,737' Dolomitic wackestone, dark brown to gray, fine grained, fine carbonate mud matrix, euhedral dolomite rhombs, anhydrite veins and grains present in minor amounts, brachiopod shell fragments.
- 10,740.5'-10,745' Dolomite, dark gray to gray, brown, crystalline, solution seams, compaction features, anhydrite, horizontal solution laminations.
- 10,745'-10,746.5' Wackestone, dark brown to brown, gray, very fine grained, crystalline, corals, crinoids,

10,746.5'-10,753.5' Dolomite, dark gray to gray, light brown to brown, crystalline, solution seams, anhydrite, soft sediment deformation, silty laminations, soft sediment clasts, limestone in part, stylolites.

TS: 10,753' Dolomitic mudstone, dark brown, very fine grained to crystalline, fine carbonate mud matrix, subhedral to euhedral dolomite rhombs, compaction features.

10,753.5'-10,758.5' Mudstone, dark gray to gray, dark brown, crystalline, solution seams, burrows in part

10,758.5'-10,762.5' Dolomite, gray, dark brown to brown, crystalline, solution seams, soft sediment deformation, anhydrite in part, horizontal solution laminations, algal lamination in part, silty in part, compaction features

10,762.5'-10,766.5' Wackestone, dark gray to dark brown, very fine grained, crystalline, solution seams, soft sediment deformation, sponge fragments, corals, crinoids.

10,766.5'-10,771.5' Dolomite, gray to light brown, tan in part, crystalline, solution seams, anhydrite, soft sediment deformation, limestone in part.

TS: 10,767' Anhydritic mudstone, gray to brown, fine grained, fine carbonate mud matrix occurs with anhydrite grains, dolomite rhombs occur in minor amounts, microspar in part, interparticle porosity (12%).

10,771.5'-10,775.5' Mudstone, dark brown, dark gray to gray, very fine grained, crystalline, solution seams, burrows in part, stylolites

10,775.5'-10,780.5' Dolomite, dark brown to brown, gray, crystalline, solution seams, anhydrite in part, soft sediment deformation, horizontal solution laminations.

10,780.5'-10,784.5' Mudstone-Wackestone, dk. brown, dk. gray, very fine grained, crystalline, solution seams, anhydrite with pyrite, gypsum pseudomorphs, brachiopods, corals, dolomitic in part

10,784.5'-10,786.5' Dolomite, dark gray to gray, brown, crystalline, solution seams, soft sediment deformation, anhydrite, algal laminations.

10,786.5'-10,791.5' Mudstone-Wackestone, dark brown to dark gray, very fine grained, crystalline, solution seams, corals, burrows, crinoids, dolomitic in part, anhydrite.

TS: 10,790' Dolomitized mudstone, dark brown, very fine grained, fine carbonate mud matrix, dolomite rhombs occur abundantly, solution seams, intercrystalline porosity (25%).

10,791.5'-10,793.5' Dolomite, light gray to gray, tan, crystalline, solution seams, soft sediment deformation.

10,793.5'-10,800' Mudstone, dark brown, dark gray to gray, very fine grained, crystalline, solution seams, burrows in part, dolomitic.

TS: 10,799' Peloidal wackstone brown to gray, very fine grained, abundant peloids occur composed of fine carbonate mud with minor amounts of calcite between grains, crinoids and ostracods replaced by calcite and carbonate mud present.

10,800'-10,804' Mudstone-Wackestone, dark brown to brown, gray, very fine grained, crystalline, solution seams, anhydrite, sponge fragments, corals.

10,804'-10,806' Packstone, dark brown to brown, gray, fine grained, crystalline, sponge fragments, corals abundant.

10,806'-10,816' Wackestone-Packstone, dark brown to gray, light brown, fine grained, crystalline, solution seams, sponges, corals, crinoids, sponge fragments.

TS: 10,810' Wackestone, dark brown to brown, fine grained, fine carbonate mud, dolomite rhombs, anhydrite, bulbous sponge structure replaced by fine carbonate mud.

10,816'-10,823' Wackestone, brown, gray, fine grained, sponge fragments, gypsum pseudomorphs, anhydrite in part, dolomite replaces fossils.

10,823'-10,826' Dolomite, dark gray to brown, crystalline, horizontal anhydrite laminations, compaction features, nodular anhydrite in part.

10,826'-10,827.5' Mudstone, brown to dark gray, very fine grained, crystalline, solution seams.

10,827.5'-10,831' Dolomite, dark gray to brown, crystalline, horizontal anhydrite laminations, compaction features.

### **Well #548 (3302300003)**

**T160N, R98W, sec. 11 Divide County**

#### **Pure Oil Company**

9,818'-9,822' Wackestone, light brown to brown, gray, crystalline, solution seams, soft sediment deformation, compaction features, anhydrite, bivalve fragments, ostracods, brachiopods.

9,822'-9,824' Stromatoporoid Boundstone, light brown to brown, gray, fine grained, sponge framework, soft sediment deformation, ostracods, anhydrite.

9,824'-9,831' Wackestone, brown, gray, fine grained, crystalline, anhydrite, ostracods, brachiopods

9,831'-9,832' Dolomite, lt. gray, gray, crystalline, patterned.

9,832'-9,834' Mudstone-Wackestone, dark gray to brown, fine grained, crystalline, solution seams, compaction features, burrows.

9,834'-9,836' Stromatoporoid Boundstone, light brown to brown, dark gray, fine grained, crystalline, solution seams, sponge framework.

- 9,836'-9,849' Wackestone, brown, gray, very fine grained, crystalline, crinoids, corals, brachiopods, algal laminations, dolomitic in part.
- 9,849'-9,850' Dolomite, light gray to tan, crystalline, anhydrite.
- 9,850'-9,854' Mudstone, dark brown to brown, very fine grained, crystalline, solution seams, compaction features, dolomitic.
- 9,854'-9,859' Dolomite, light gray to gray, crystalline, solution seams, brecciated zone at base.

**Well #4394 (3302300100)**  
**T161N, R97W, sec. 20 Divide County**  
**Texaco Incorporated**

**Well #11173 (3302300319)**  
**T164N, R99W, sec. 35 Divide County**  
**Louisiana Land and Exploration**

- 8,221'-8,224.5' Dolomite, gray, light brown to brown, crystalline, algal laminations, salt nodules, solution seams, anhydrite.
- 8,224.5'-8,233' Mudstone, dark brown to brown, very fine grained, crystalline, solution seams, anhydrite, vertical fractures, compaction features, dissolved corals replaced by anhydrite.
- 8,233'-8,237.5' Wackestone, dark brown to brown, fine grained, crystalline, solution seams, compaction features, corals, crinoids, brachiopods.
- 8,237.5'-8,240' Dolomite, gray to light brown, crystalline, anhydrite, solution seams, compaction features, soft sediment deformation, irregular mottling.
- 8,240'-8,246.5' Mudstone-Wackestone, dark brown to brown, very fine to fine grained, crystalline, solution seams, anhydrite, "pebbly" texture, stylolites, soft sediment deformation, c TS: 9,319' Boundstone, dark brown to dark gray, fine grained, fine carbonate mud sponge framework, dolomite rhombs (10%), calcite and anhydrite occur within sponge structure, solution seams.
- TS: 9,436' Mudstone, dark to light brown, very fine grained, fine carbonate mud matrix, euhedral dolomite rhombs (10%).
- 9,452'-9,464.5' Dolomite, dark brown to brown, gray, crystalline, soft sediment deformation, solution seams, horizontal anhydrite laminations, intraclasts, corals, ostracods in part, vertical fractures.
- 9,464.5'-9,466' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams.

TS: 9,466' Mudstone, dark brown, very fine grained, crystalline, fine carbonate mud matrix, burial compaction features.

9,466'-9,485' Dolomite, dark brown to brown, gray, crystalline, soft sediment deformation, solution seams, compaction features, horizontal anhydrite laminations, intraclasts, corals, ostracods in part.

Missing 9,485'-9,514'

9,515'-9,558' Dolomite, light to dark brown, light to dark gray, crystalline, solution seams, soft sediment deformation, sucrosic in part, compaction features, horizontal anhydrite laminations, intraclasts, sponge fragments, corals, vugs, patterned in part.

TS: 9,515' Anhydrite, light gray, crystalline, anhydrite cement with fine carbonate mud inclusions, peloids.

TS: 9,523' Dolomitic mudstone, dark to light gray, crystalline, dolomite rhombs occur in a fine carbonate mud matrix, intercrystalline porosity (10%).

TS: 9,532' Dolomite, light gray, crystalline, subhedral to euhedral dolomite rhombs occur, intercrystalline porosity (30%)

TS: 9,535' Dolomitic mudstone, dark brown to gray, very fine grained, crystalline, fine carbonate mud, subhedral to euhedral dolomite rhombs, solution seams, intercrystalline porosity (25%)

TS: 9,538' Dolomite, light gray, crystalline, subhedral to euhedral dolomite rhombs occur, intercrystalline porosity (30%)

TS: 9,549' Dolomite, light gray, crystalline, subhedral to euhedral dolomite rhombs occur, intercrystalline porosity (30%)

9,559'-9,562.5' Mudstone-Wackestone, dark brown to gray, very fine grained, crystalline, solution seams, anhydrite, sponges, corals, ostracods.

9,562.5-9,563' Wackestone-Packstone, brown, gray, fine grained, crystalline, solution seams, sponge fragments, corals, dolomitic in part.

9,563'-9,573' Stromatoporoid Boundstone-Floatstone, gray, brown, fine grained, crystalline, solution seams, compaction features, stromatoporoid framework, corals anhydrite.

TS: 9,563' Boundstone, gray to brown, fine grained, carbonate mud to crystalline sponge framework, dolomite rhombs, laminations of alternating dolomite and carbonate mud, interparticle porosity (10%)

9,573'-9,575' Wackestone, light brown to brown, fine grained, crystalline, soft sediment deformation, sponge fragments.

orals, sponges.



- 8,246.5'-8,251.5' Dolomite, light gray to gray, crystalline, anhydrite, wispy laminations, solution seams, compaction features, mottled in part.
- 8,251.5'-8,255' Mudstone, dark brown to brown, very fine grained, crystalline, solution seams
- 8,255'-8,264' Peloidal wackestone, light brown to brown, gray, very fine grained, crystalline, abundant peloids, stylolites, compaction features, soft sediment deformation, anhydrite, vertical fractures, corals, crinoids.
- Missing 8,264'-8,354'
- 8,354'-8,356' Mudstone, lt. brown, brown, very fine grained, crystalline, solution seams, algal laminations, compaction features, burrows, anhydrite in part.

**Well #11589 (3302300347)**  
**T161N, R95W, sec. 20 Divide County**

**Louisiana Land and Exploration**

- 9,485'-9,487.5' Mudstone-Wackestone, light brown to brown, gray, very fine grained, crystalline, solution seams, horizontal laminations, compaction features, ostracods, brachiopods, corals.
- 9,487.5'-9,499.5' Dolomite, light brown to brown, gray, crystalline, anhydrite, horizontal laminations, solution seams, compaction features, "pebbly" in part, soft sediment deformation, corals.
- 9,499.5'-9,502' Mudstone, brown, dk. gray, very fine grained, crystalline, solution seams, dolomitized in part, horizontal laminations.
- 9,502'-9,534' Dolomite, gray, light brown to brown, crystalline, solution seams, compaction features, patterned, horizontal anhydrite laminations, burrows, sponge framework in part, brachiopods, ostracods, crinoids, sponge fragments, limestone interbeds in part.
- 9,533'-9,534' Mudstone, dark gray to brown, very fine grained, crystalline, solution seams, vertical fractures, compaction features, anhydrite in part.

**Well #11437 (3302300334)**  
**T161N, R97W, sec. 19 Divide County**

**Louisiana Land and Exploration**

- 9,242'-9,290.5' Dolomite, gray, light to dark brown, crystalline, solution seams, anhydrite mottling in part, "pebbly" texture, occasional wispy laminations, soft sediment deformation, compaction features, stylolites, vugs, sponge fragments, corals, horizontal and vertical fractures, anhydrite interbeds in part.
- 9,290.5'-9,295' Mudstone, light brown to brown, tan, crystalline, algal laminations, dolomitic, solution seams, compaction features, anhydrite.

9,295'-9,318' Dolomite, dark gray, light brown to brown, crystalline, solution seams, abundant stylolites, salt nodules, soft sediment deformation, intraclasts, compaction features.

**Well #10653 (3310501103)**  
**T155N, R101W, sec. 11 Williams County**

**Atlantic Richfield Corporation**

- 11,162'-11,166.5' Dolomite, dark gray to brown, tan, crystalline, horizontal laminations, anhydrite, solution seams.
- 11,166'-11,169.5' Mudstone-Wackestone, dark gray, brown, very fine grained, crystalline, solution seams, micro stylolites, vertical fractures, crinoids.
- 11,169.5'-11,170.5' Dolomite, dark gray to brown, crystalline, anhydrite, compaction features.
- 11,170.5'-11,173' Mudstone, dark gray to brown, very fine grained crystalline, solution seams, flaser bedding.
- 11,173'-11,176' Dolomite, gray to light brown, crystalline, peloids, intraclasts, soft sediment deformation.
- 11,176'-11,191' Mudstone-Wackestone, dark gray to gray, dark brown, very fine to fine grained, solution seams, stylolites, compaction features, dark gray crystalline inclusions of anhydrite, soft sediment deformation, crinoids, sponge fragments, brachiopods, corals brecciated and dolomitic in part.
- 11,191'-11,201.5' Peloidal wackestone, light to dark gray, brown, very fine grained, crystalline, solution seams, compaction features, soft sediment deformation, abundant peloids, lesser amounts of crinoids and sponge fragments.
- 11,201.5'-11,204' Stromatoporoid Boundstone, dark gray to gray, tan, fine grained, crystalline, sponge framework, solution seams, burrows, sponge spicules and fragments, crinoids.
- 11,204'-11,208.5' Dolomite, brown, light to dark gray, crystalline, solution seams, horizontal anhydrite laminations, patterned in part.
- 11,208.5'-11,210' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, dolomitic.
- 11,210'-11,216' Dolomite, dark gray to gray, crystalline, "marled" texture, solution seams, intraclasts, anhydrite, soft sediment deformation, collapse breccia in part.
- 11,216'-11,220' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams.
- 11,220'-11,223' Wackestone-Packstone, dark brown to gray, fine grained, crystalline, anhydrite, brachiopod and bivalve shell fragments, burrows, sponges, sponge spicules.

**Well #1403 (3310500519)**  
**T155N, R96W, sec. 15 Williams County**

**Amerada Petroleum Corporation**

TS: 10,069' Packstone, dark to light brown, fine grained, carbonate mud matrix, abundant corals, brachiopod shell fragments, bivalve shell fragments, peloids, and ostracods, microspar occurs between corals, dolomite rhombs present in minor amounts.

TS: 10,102' Dolomitic wackestone brown to gray, fine grained, fine carbonate mud matrix, dolomite rhombs, bryozoans partly replaced by anhydrite, brachiopod, bivalve shell fragments, peloids, and crinoids present within dolomitized matrix, intraparticle porosity within bryozoan structure (10%).

TS: 10,134' Dolomitized mudstone, light to dark brown, fine grained, fine carbonate mud matrix, dolomite rhombs, peloidal compaction features, ostracods, rare anhydrite cement, stylolites.

10,164'-10,165.5' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, anhydrite in part.

10,165.5'-10,168.5' Dolomite, dark gray to gray, crystalline, horizontal solution laminations, soft sediment deformation, white silty intraclasts.

10,168.5'-10,192' Mudstone, dark brown to gray, very fine grained, crystalline, anhydrite, solution seams, inclusions of anhydrite, dissolved and replaced fossils/minerals, vertical fractures and pyrite in part, gypsum pseudomorphs and horizontal solution laminations in part, mud intraclasts.

10,192'-10,199.5' Microbially laminated wackestone, brown, gray, very fine grained, crystalline, solution seams, dolomitic, compaction features, anhydrite in part, corals, brachiopods, stromatolites. algal laminations.

10,199.5-10,200.5' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams.

10,200.5'-10,207' Microbially laminated dolowackestone, light to dark brown, very fine to fine grained, crystalline, abundant algal laminations, anhydrite mottling in part, solution seams.

10,207'-10,217 Dolomitic Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, dolomite interbeds, anhydrite and horizontal solution laminations in part, gypsum pseudomorphs

10,217'-10,218' Mudstone-Wackestone, dark gray to dark brown, very fine to fine grained, crystalline, sponges.

10,218'-10,225.5' Dolomitic Mudstone, dark brown to dark gray, very fine grained crystalline, solution seams, dolomite interbeds, light brown intraclasts, anhydrite and horizontal solution laminations in part.

- 10,225.5'-10,227.5' Wackestone, dark brown to gray, fine grained, crystalline, solution seams, corals, crinoids, pyrite in part.
- 10,227.5'-10,253' Dolomitic mudstone, dark brown to dark gray, very fine grained crystalline, solution seams, dolomite interbeds, light brown intraclasts, anhydrite and horizontal solution laminations in part, gypsum pseudomorphs.
- 10,253'-10,254' Wackestone, brown, to dark gray, very fine grained, crystalline, silty, solution seams, sucrosic.
- 10,254'-10,258' Dolomite, brown to gray, crystalline, solution seams, sucrosic, silty in part.
- Missing 10,258'-10,260'
- 10,260'-10,261.5' Mudstone, dark gray to brown, crystalline, solution seams, light brown intraclasts.
- 10,261.5'-10,264.5' Wackestone-Packstone, brown, dark gray to gray, crystalline, peloids, solution seams, soft sediment deformation, compaction features, corals, crinoids, sponge fragments.
- 10,264.5'-10,281.5' Dolomitic Mudstone, dark brown to dark gray, very fine grained crystalline, solution seams, dolomite interbeds, light brown intraclasts, anhydrite and horizontal solution laminations in part.
- 10,281.5'-10,288' Mudstone-Wackestone, dark brown to brown, gray, fine grained, crystalline, solution seams, soft sediment deformation, corals, brachiopods, brown intraclasts, anhydrite in part, stylolites.
- 10,288'-10,294' Wackestone-Packstone, dark brown to brown gray, fine grained, crystalline, soft sediment deformation, abundant bivalve shell fragments, ostracods, corals, crinoids, brown intraclasts.
- TS: 10,302' Mudstone, light to dark brown, very fine grained, fine carbonate mud matrix, mechanical compaction features occur, soft sediment deformation, anhydrite occurs in minor amounts as grains and cement, rare peloids.
- TS: 10,359' Boundstone-packstone, brown to dark gray, fine grained, fine carbonate mud sponge structure, dolomite rhombs, minor amounts of anhydrite cement, calcite replaces ostracods, brachiopod and bivalve shell fragments present, compaction features.

**Well #2887 (3310500599)**  
**T159N, R103W, sec. 20 Williams County**

**William Herbert Hunt Corporation**

- 9,365'-9,371' Dolomite, light to dark gray, crystalline, solution seams, anhydrite mottling.
- 9,371'-9,381' Mudstone-Wackestone, dark gray to gray, brown, very fine to fine grained, crystalline, solution seams, compaction features, horizontal laminations, dolomitic, ostracods, fractures
- TS: 9,375' Wackestone brown to dark gray, fine grained, fine carbonate mud matrix, abundant bivalve shell fragments and ostracods , calcite cement occurs within some burrows and replaces some shells, interparticle porosity (8%).
- Missing 9,381'-9,385'
- 9,385'-9,396.5' Mudstone-Wackestone, light brown to gray, very fine to fine grained, crystalline, solution seams, stylolites, ostracods, brachiopods, crinoids, burrows, anhydrite, fractures
- 9,396.5'-9,402' Dolomite, light gray to gray, tan, crystalline, wispy laminations, solution seams, soft sediment deformation, rip up clasts.
- 9,402'-9,406' Mudstone-Wackestone, dark to light gray, brown, fine grained, crystalline, soft sediment deformation, solution seams, anhydrite, stylolites, vertical fractures, burrows, sponge fragments, corals.
- 9,406'-9,409' Stromatoporoid Boundstone-Floatstone, light gray to gray, light brown, fine grained, crystalline, solution seams, sponge framework, abundant corals, dolomitic in part.
- TS: 9,409' Dolomitized Floatstone, gray to light brown, fine carbonate mud matrix, with large bulbous and tabular sponges, peloids present with small amounts of calcite cement filling in some pore space and shell fragments, brachiopods, well developed interparticle porosity (20%).
- 9,409'-9,412.5' Wackestone-Packstone, light gray to gray, brown, fine grained, crystalline, solution seams, soft sediment deformation, "pebbly" texture, ostracods, crinoids, peloids, brachiopods, corals, burrows.
- 9,412.5'-9,426' Stromatoporoid Boundstone-Floatstone, light to dark gray, brown, tan, fine grained, crystalline, stromatoporoid framework, soft sediment deformation, compaction features, crinoids, corals, stylolites, anhydrite, burrows and vertical fractures in part.
- 9,426'-9,428.5' Dolomite, dark gray to gray, brown, crystalline, anhydrite mottling.
- 9,428.5'-9,429' Wackestone, light gray to brown, fine grained, crystalline, solution seams, soft sediment deformation, crinoids.

- 9,429'-9,431' Dolomite, dark gray to gray, brown, crystalline, anhydrite mottling, fractures, stromatoporoids, soft sediment deformation.
- 9,431'-9,434' Packstone, dark gray to gray, brown, fine grained, crystalline, solution seams, compaction features, corals, stromatolites, burrows, dolomitized.
- 9,434'-9,440' Dolomite, light brown to light gray, tan, crystalline, anhydrite solution seams, soft sediment deformation, stromatolites, compaction features, stromatoporoid framework in part.
- TS: 9,436' Dolomitic wackestone, gray to brown, fine grained, carbonate mud matrix, euhedral to subhedral dolomite rhombs, peloids, anhydrite, interparticle porosity (20%).
- 9,440'-9,445.5' Stromatoporoid Floatstone, light to dark gray, fine grained, crystalline, solution seams, dolomitized, crinoids.
- TS: 9,445' Boundstone, light gray to brown, fine carbonate mud sponge framework with abundant corals, peloids, anhydrite.
- 9,445.5'-9,456' Dolomite, gray, dark brown to brown, crystalline, very fine grained, solution seams, soft sediment deformation, anhydrite, crinoids, sponge fragments, corals, burrows, brachiopods, limestone in part, ostracods, corals, crinoids, burrows.
- 9,456'-9,457' Wackestone, gray, brown, fine grained, crystalline, dolomitized, corals, crinoids, peloids.
- 9,457'-9,464.5 Dolomite, dark gray to gray, light brown, crystalline, solution seams, anhydrite mottling in part, "pebbly" texture, burrows.
- TS: 9,464' Dolomitic mudstone, dark brown to gray, very fine grained, fine carbonate mud matrix, euhedral dolomite rhombs, intercrystalline porosity (30%).
- 9,464.5'-9,469' Mudstone-Wackestone, dark gray to gray, very fine grained, crystalline, solution seams, compaction features, anhydrite, burrows, peloids, dolomitized, stylolites, brachiopods.
- 9,469'-9,475' Wackestone-Packstone, dark gray to gray, brown, fine grained, crystalline, solution seams, burrows, brachiopods, crinoids, peloids, anhydrite, corals, vertical fractures
- 9,475'-9,494' Dolomite, light brown to brown, gray, crystalline, algal laminations, corals, anhydrite, silty in part, crinoids, sucrosic, sponges, burrows.
- Missing 9,494'-9,497'
- 9,497'-9,505.5' Dolomite, light gray to gray, crystalline, solution seams, wispy laminations, burrows.
- 9,505.5'-9,532.5' Mudstone-Wackestone, dark gray to gray, brown, very fine to fine grained, crystalline, algal laminations, solution seams, stylolites, compaction features, anhydrite, corals, crinoids, peloids, vertical fractures, burrows, dolomitic in part.

TS: 9,516' Dolomitic wackestone, dark brown to gray, fine grained, carbonate mud matrix, euhedral dolomite rhombs, sparry calcite replaces some ostracods and shell fragments' interparticle porosity (10%)

TS: 9,530' Peloidal wackestone, gray to brown, very fine grained, fine carbonate mud matrix, peloids, well developed interparticle porosity (25%).

9,532.5'-9,540.5' Dolomite, light gray to gray, brown, crystalline, algal laminations, solution seams, anhydrite mottling.

9,540.5'-9,565' Mudstone-Wackestone, brown, dark gray, very fine grained, crystalline, solution seams, soft sediment deformation, compaction features, anhydrite replaces fossils, corals, crinoids, burrows, stylolite burrows.

9,565'-9,577' Dolomite, dark gray to gray, brown, tan, crystalline, solution seams, soft sediment deformation, compaction features, horizontal anhydrite laminations.

9,577'-9,579' Mudstone, dark gray to gray, brown, very fine grained, crystalline, solution seams, compaction features, dolomitic.

9,579'-9,592' Dolomite, light brown to brown, light to dark gray, crystalline, algal laminations, soft sediment deformation, compaction features, horizontal laminations, anhydrite mottling in part, burrows.

TS: 9,591' Dolomitic mudstone, light to dark brown, very fine grained, fine carbonate mud matrix, euhedral dolomite rhombs, anhydrite present in minor amounts between dolomite rhombs.

9,592'-9,594.5' Mudstone, brown, dark gray to gray, very fine grained, crystalline, burrows, dolomitic.

9,594.5'-9,598' Dolomite, gray, brown, tan, crystalline, horizontal solution laminations, anhydrite, mud intraclasts.

9,598'-9,601' Mudstone, brown, dark gray to gray, very fine grained, crystalline, anhydrite, burrows

Missing 9,601'-9,605'

9,605'-9,608.5' Dolomite, dark to light gray, tan, crystalline, solution seams, compaction features, algal laminations, stromatolites.

9,608.5'-9,626' Dolomitic Mudstone, dark brown to dark gray, very fine grained crystalline, solution seams, soft sediment deformation, compaction features, dolomite interbeds, light brown intraclasts, anhydrite mottling and horizontal solution laminations in part.

9,626'-9,634' Wackestone-Packstone, light to dark brown, dark gray to gray, fine grained, solution seams, crinoids, corals, sponges, horizontal laminations, compaction features, burrows, bivalve shell fragments, sponges.

9,634'-9,639' Stromatoporoid Boundstone-Floatstone, light brown to brown, dark gray, sponge framework, solution seams, compaction features, corals, crinoids.

- 9,639'-9,650.5' Dolomite, brown, dark gray to gray, crystalline, soft sediment deformation, anhydrite, corals, compaction features.
- 9,650.5'-9,652.5' Dolomitic Mudstone, brown, dark gray to gray, very fine grained, crystalline, solution seams, compaction features.
- 9,652.5'-9,659' Dolomite, light gray to gray, tan, crystalline, anhydrite mottling in part, stromatolites, solution seams, compaction features, algal laminations, burrows.
- 9,659'-9,661' Mudstone, dark gray, brown, very fine grained, crystalline, solution seams, vertical fractures, burrows
- 9,661'-9,676' Stromatoporoid Boundstone-Floatstone, light to dark brown, dark gray to gray, fine grained, solution seams, compaction features, stromatoporoid framework, brachiopods, crinoids, corals, anhydrite, sponge fragments, ostracods, stylolites.
- TS: 9,666' Boundstone, light to dark brown, fine grained, fine carbonate sponge framework, anhydrite, bivalve shell fragments and crinoids occur in minor amounts, , interparticle porosity (20%).
- 9,676'-9,680' Wackestone, light brown to brown, gray, fine grained, crystalline, solution seams, soft sediment deformation, anhydrite, ostracods, brachiopods, stylolites.
- 9,680'-9,690' Dolomite, dark gray to brown, crystalline, anhydrite, horizontal laminations, solution seams, soft sediment deformation, algal laminations, intraclasts.
- TS: 9,681' Dolomite gray to brown, crystalline, subhedral dolomite rhombs occur with minor amounts of fine carbonate mud and anhydrite, calcite cement present between some grains, brachiopod shell fragments, intercrystalline porosity (25%).
- 9,690'-9,695' Mudstone-Wackestone, brown, gray, fine grained, crystalline, solution seams, crinoids, bivalve shell fragments.
- 9,695'-9,697' Dolomite, light gray to gray, crystalline, solution seams, anhydrite mottling, algal laminations.
- 9,697'-9,718.5' Wackestone, brown to dark gray, very fine grained, crystalline, solution seams, soft sediment deformation, compaction features, calcite crystals, stylolites, burrows, horizontal solution laminations, mottled in part, crinoids, sponge fragments, ostracods, dolomitic.
- TS: 9,709' Dolomitic mudstone, dark brown to gray, fine grained, carbonate mud matrix, dolomite rhombs, anhydrite.
- 9,718.5'-9,720' Dolomite, light gray to gray, crystalline, anhydrite mottling.
- 9,720'-9,724' Wackestone, light brown to brown, tan, very fine grained, crystalline, solution seams, compaction features, anhydrite in part, brachiopods, corals, ostracods, sponge fragments, dolomitic.



TS: 9,722' Dolomitic mudstone, gray to dark brown, fine carbonate mud matrix, subhedral-euhedral dolomite rhombs, minor anhydrite, well developed intercrystalline porosity (30%).

**Well #11148 (3302300315)**  
**T161N, R99W, sec. 17 Divide County**

**Louisiana Land and Exploration**

9,150'-9,154.5' Mudstone, dark gray to gray, black, very fine grained, crystalline, solution seams, burrowed, anhydrite, vertical fractures.

TS: 9,150' Mudstone, dark gray to gray, very fine grained, fine carbonate mud matrix, dolomite rhombs occur in minor amounts, rare bivalve fragments and ostracods, stylolites, anhydrite occurs in minor amounts and replaces some shell fragments.

9,154.5'-9,155.5' Dolomite, light gray to gray, very fine grained, crystalline, solution seams, wispy laminations.

9,155.5'-9,157' Mudstone, dark gray to gray, brown, very fine grained, crystalline, solution seams, burrows, vertical fractures.

TS: 9,156' Mudstone, dark brown, very fine grained, fine carbonate mud matrix with dissolution structures occurring abundantly.

9,157'-9,162' Dolomite, light to dark gray, tan, light brown, crystalline, solution seams, compaction features, soft sediment deformation, anhydrite mottling, solution seams, stromatolite, arenaceous.

9,162'-9,165.5' Mudstone-Wackestone, light to dark gray, brown, very fine to fine grained, soft sediment deformation, stylolites, corals, brachiopods, ostracods, crinoids.

TS: 9,162' Wackestone, dark brown, fine grained, carbonate mud matrix, anhydrite occurs abundantly with peloids.

9,165.5'-9,168' Dolomite, light to dark gray, brown, crystalline, solution seams, soft sediment deformation, compaction features, stromatolites.

9,168'-9,173' Wackestone, dark gray to gray, brown, fine grained, crystalline, solution seams, compaction features, anhydrite, corals, brachiopods, crinoids, ostracods, burrows.

TS: 9,168' Wackestone, gray to brown, fine grained, carbonate mud matrix, abundant bivalve fragments, brachiopod fragments, ostracods, crinoids and coral fragments, peloids, anhydrite present within grains.

TS: 9,172' Mudstone, dark brown to gray, very fine grained, carbonate mud matrix with dark solution seams.

9,173'-9,178.5' Dolomite, dark gray to gray, light brown, crystalline, solution seams, compaction features, anhydrite mottling, horizontal and vertical fractures.

9,178.5'-9,180.5' Microbially laminated wackestone, dark gray to gray, light brown, algal mound, soft sediment deformation, burrows.

9,180.5'-9,191' Dolomite, dark gray to gray, brown, tan, very fine grained, crystalline, solution seams, anhydrite mottling in part, soft sediment deformation, brachiopods, corals, fossils replaced by anhydrite, "pebbly" texture, stromatolites, arenaceous.

TS: 9,181' Dolomitized packstone, gray to brown, carbonate mud matrix, abundant bivalve fragments, brachiopod fragments, ostracods and crinoids, peloids and anhydrite present in minor amounts.

TS; 9,182' Dolomite, gray, crystalline, euhedral to subhedral dolomite rhombs, intercrystalline porosity (15%)

9,191'-9,194' Mudstone-Wackestone, dark gray to gray, brown, fine grained, crystalline, solution seams, soft sediment deformation, crinoids, corals, sponges, fractures.

TS: 9,193' Dolomitic wackestone, dark gray to brown, fine grained, crystalline, euhedral to subhedral dolomite rhombs, sponges, corals.

TS: 9,197' Mudstone, brown to gray, very fine grained, subhedral dolomite rhombs, intercrystalline porosity (10%).

TS: 9,199' Dolomite, dark gray, crystalline, subhedral dolomite rhombs with well developed intercrystalline porosity (20%).

TS: 9,201' Boundstone, gray to dark brown, fine grained, sponge framework, dolomite rhombs (20%), fine carbonate mud peloids occur with dolomite rims, well developed interparticle porosity (15%), anhydrite cement and rugose coral molds present.

TS: 9,207' Dolomitic packstone, light to dark brown, fine grained, carbonate mud matrix, euhedral to subhedral dolomite rhombs, peloids, anhydrite occurs in minor amounts.

TS: 9,209' Dolomite light to dark gray, crystalline, coarse to medium dolomite rhombs, well developed intercrystalline porosity (35%).

### **Well #11734 (3302300356)**

**T161N, R100W, sec. 1 Divide County**

### **Louisiana Land and Exploration**

9,151'-9,154.5' Mudstone, light gray to gray, brown, very fine grained, crystalline, soft sediment deformation, burrowed, stylolites, dolomitic, vertical fractures;

- 9,154.5'-9,160' Dolomite, light to dark gray, light brown, tan, crystalline, solution seams, wispy laminations, soft sediment deformation, anhydrite mottling in part, stromatolites, flooding surface at contact with underlying limestone.
- 9,160'-9,162.5' Mudstone-Wackestone, light to dark gray, brown, fine grained, crystalline, burrowed, soft sediment deformation, solution seams, stylolite at contact with underlying dolomite
- 9,162.5'-9,166' Dolomite, light gray to gray, crystalline, solution seams, anhydrite mottling.
- 9,166'-9,171' Mudstone-Wackestone, light to dark gray, brown, very to fine grained, crystalline, burrows, algal laminations, anhydrite, solution seams, brachiopods, crinoids, burrows, algal mounds, anhydrite, ostracods. Anhydrite and solution seams at contact with underlying dolomite (flooding surface).
- 9,171'-9,194' Dolomite/Anhydrite, white, light gray, brown, anhydrite mottling, crystalline, soft sediment deformation, solution seams, compaction features.

### **Well #10927 (3302300297)**

**T163N, R100W, sec. 6 Divide County**

#### **Louisiana Land and Exploration**

- 8,288'-8,290' Wackestone, gray to brown, fine grained crystalline, dolomitized, anhydrite mottling.  
TS: 8,290' Wackestone, brown to dark gray, fine grained, carbonate mud matrix with anhydrite clusters, dolomitized.
- 8,290'-8,293' Microbially laminated dolowackestone, brown, dark gray, fine grained, crystalline, solution seams, soft sediment deformation, stromatolites, anhydrite laminations, dolomitic in part, solution seams.  
TS: 8,293' Wackestone, brown to gray, fine grained, carbonate mud matrix, dolomite rhombs (10%), algal laminations, solution seams.
- 8,293'-8,306' Dolomite, light gray to gray, dark to light brown, crystalline, solution seams, soft sediment deformation, wispy laminations in part, mottled, shaley interbeds.  
TS: 8,299' Wackestone, gray, dolomite cement, anhydrite grains present (15%).
- 8,306'-8,310' Microbially laminated dolowackestone, brown, dark gray, fine grained, crystalline, solution seams, soft sediment deformation, stromatolites, anhydrite laminations, dolomitic in part, solution seams, arenaceous.  
TS: 8,307' Wackestone, dark brown to brown, fine grained, carbonate mud matrix, minor amounts of anhydrite (5%), solution seams.
- 8,310'-8,328.5' Wackestone-Packstone, dark gray to gray, brown, fine grained, crystalline, solution seams, anhydrite, mottled in part, dolomitic interbeds, replaced bivalve shell fragments, brachiopods, crinoid columnals, stylolites.

TS: 8,310' Packstone, dark gray, fine grained, carbonate mud matrix with euhedral dolomite rhombs (10%), anhydrite crystals occur throughout (25%).

TS: 8,315' Wackestone, brown, fine grained, carbonate mud matrix, euhedral dolomite rhombs (20%), bivalves present with micrite enveloping, anhydrite crystals.

TS: 8,319' Wackestone-Packstone, brown to gray, fine grained, carbonate mud matrix, abundant bivalves and shell fragments, minor amounts of ooids, some replaced by calcite, subhedral calcite grains present.

TS: 8,325' Wackestone-Packstone, dark gray to brown, fine grained, carbonate mud matrix, dolomite rhombs (10%), bivalve shell fragments.

8,328.5'-8,335' Dolomite, light gray to gray, light brown, tan, crystalline, solution seams, soft sediment deformation, wispy laminations in part, anhydrite mottling, algal contorted bedding.

TS: 8,332' Micrite, brown, fine carbonate mud with abundant dolomite rhombs (40%).

8,335'-8,346' Mudstone-Wackestone, dark brown to brown, gray, very fine grained, crystalline, mottled, bioturbation, solution seams, dolomitic, "pebbly" texture, crinoids, stylolites.

TS: 8,336' Wackestone, dark brown to brown, very fine grained, carbonate mud matrix, subhedral calcite grains present with some altering to dolomite rhombs, bivalve shells and fragments, dissolved ooid clusters present in minor amounts.

TS: 8,338' Wackestone brown, very fine grained, carbonate mud matrix, bivalve shell fragments, brachiopod spines and shells, ostracods.

TS: 8,340' Wackestone, brown to gray, fine grained, carbonate mud matrix, partly dolomitized, large needle like grains of anhydrite with lesser amounts of calcite, bivalve shell fragments occur along with ooid remnants.

TS: 8,344' Wackestone, dark brown, very fine grained, carbonate mud matrix, dolomite rhombs occur with abundant bivalve shell fragments and crinoids, fine carbonate mud intraclasts occur throughout.

8,346'-8,348' Dolomite, light to dark gray, brown, crystalline, wispy laminations in part, anhydrite mottling, soft sediment deformation.

TS: 8,346' Dolomite, light to dark gray, crystalline, anhydrite mottling, burrows and/or intraclasts.

Missing 8,348'-8,395'

8,396'-8,400' Dolomite, light gray to gray, brown, crystalline, anhydrite mottling.

8,400'-8,403' Microbially laminated dolowackestone, dark brown to brown, fine grained, crystalline, algal mats, horizontal laminations, dolomitic in part, soft sediment deformation, arenaceous.

- 8,403'-8,410.5' Mudstone-Wackestone, dark gray to brown, fine grained, crystalline, solution seams, soft sediment deformation, mottled.
- 8,410.5'-8,413' Dolomite, light gray to brown, crystalline, anhydrite mottling.
- 8,413'-8,422' Mudstone-Wackestone, brown to dark gray, fine grained, crystalline, soft sediment deformation, anhydrite, "pebbly" texture, dolomitic in part, crinoids, corals, sponges, stylolites.
- 8,422'-8,428' Dolomite, light gray to gray, brown, crystalline, solution seams, soft sediment deformation, wispy laminations in part, anhydrite mottling.
- 8,428'-8,434' Microbially laminated dolowackestone, light brown to brown, fine grained, crystalline, stromatolite algal laminations, arenaceous, dolomitic, anhydrite in part, rare pyrite.
- 8,434'-8,443' Mudstone-Wackestone, brown, dark gray to gray, fine grained, crystalline, solution seams, soft sediment deformation, stylolites, crinoids.
- 8,443'-8,450.5' Wackestone-Packstone, dark gray to gray, brown, fine grained crystalline, solution seams, soft sediment deformation, anhydrite, crinoids, brachiopods, dolomitic in part.
- 8,450.5'-8,454' Dolomite, light to dark gray, brown, crystalline, soft sediment deformation, anhydrite mottling, rare pyrite.
- 8,454'-8,456' Microbially laminated dolowackestone, light brown, tan, crystalline, horizontal algal laminations, dolomitic, arenaceous.

### **Well #11005 (3302300307)**

**T163N, R101W, sec. 27 Divide County**

#### **Conoco Incorporated**

- 8,519'-8,522' Dolomite, light gray to gray, crystalline, solution seams, "pebbly" texture, argillaceous in part.
- TS: 8,519' Dolomite, gray, crystalline, minor amounts of calcite, carbonate mud intraclasts occur, minor amounts of intercrystalline porosity (10%).
- 8,522'-8,523.5' Dolomite, light gray to dark gray, crystalline, solution seams, anhydrite mottling.
- 8,523.5'-8,524.5' Dolomite, buff, dark brown to brown, stromatolites, anhydrite
- TS: 8,524' Dolomitic wackestone, brown to dark brown, fine grained, carbonate mud matrix, large (>500um) anhydrite clusters occur filling void space. Smaller, needle like anhydrite crystals present, minor amounts of interparticle porosity between carbonate grains (10%).

- TS: 8,526' Dolomitic wackestone, brown, fine grained to crystalline, carbonate mud matrix, euhedral dolomite rhombs, mottled fabric, microbial crusts, minor amounts of anhydrite present.
- 8,524.5'-8,528' Mudstone, dark brown to brown, black, very fine grained, crystalline, solution seams, soft sediment deformation, burrows, anhydrite
- 8,528'-8,534' Mudstone-Wackestone, dark brown to brown, fine grained, solution seams, soft sediment deformation, stylolites, anhydrite, brachiopods.
- TS: 8,528' Wackestone, dark brown to brown, fine grained, carbonate mud matrix, dolomite rhombs, anhydrite occurs in minor amounts, some with inclusions of dolomite rhombs. Minor amounts of bivalve shells and shell fragments
- 8,534'-8,539' Wackestone-Packstone, dark brown to brown, fine grained, solution seams, soft sediment deformation, vertical fractures, brachiopods, crinoids, ostracods.
- TS: 8,536' Packstone, dark brown to brown, fine grained, carbonate mud matrix, abundant bivalve shell fragments, brachiopods, gastropods, ostracods, calcispheres, and crinoid columnals, minor amounts of anhydrite.
- 8,539'- 8,541' Wackestone, brown, gray, fine grained, solution seams, soft sediment deformation, crinoids, brachiopods, stylolites, burrows, anhydrite.
- TS: 8,540' Wackestone-Packstone, gray to brown, fine grained, carbonate mud matrix, dolomite rhombs (10%), abundant bivalve shell and shell fragments, subhedral anhydrite grains occur in minor amounts.
- 8,541'-8,544' Wackestone-Packstone, brown, gray, fine grained, crystalline, soft sediment deformation, burrows, ostracods, crinoids, anhydrite.
- 8,544'-8,546' Mudstone-Wackestone, dark brown to brown, fine grained, solution seams, soft sediment deformation, burrows.
- TS: 8,546' Wackestone, brown, fine grained, carbonate mud matrix, anhedral dolomite rhombs, minor amounts of anhydrite, well developed intercrystalline porosity (25%).
- 8,546'-8,551' Dolomite, light gray to gray, light brown, crystalline, soft sediment deformation, solution seams, wispy laminations, rare crinoids.
- 8,551'-8,553' Dolomite, dark gray to gray, light brown, tan, crystalline, anhydrite mottling in part, stromatolites near contact with underlying limestone.
- TS: 8,552' Dolomite, light to dark gray, crystalline, abundant anhydrite grains occur, rare carbonate mud between dolomite rhombs.
- 8,553'-8,556.5' Wackestone, brown, dark gray to gray, fine grained, solution seams, anhydrite, crinoids, burrows, vertical fractures.
- TS: 8,553' Wackestone-Packstone, brown, fine grained, fine carbonate mud matrix, abundant bivalve shell and shell fragments, anhydrite grains fill in pore space.

TS: 8,555' Wackestone, dark gray to gray, fine grained, carbonate mud matrix, abundant bivalve shell and shell fragments, crinoids, gastropods, corals, and brachiopods, anhydrite replaces some skeletal grains.

8,556.5'-8,559' Dolomite, light gray to gray, brown, crystalline, soft sediment deformation, wispy laminations in part, anhydrite mottling.

TS: 8,557' Dolomite, gray, crystalline, carbonate mud intraclasts occur in minor amounts, dissolution structures present.

8,560'-8,562' Wackestone-Packstone, dark brown to dark gray, fine grained, crystalline, solution seams, soft sediment deformation, anhydrite in part, brachiopods, crinoids, ostracods, gastropods, dolomitic.

TS: 8,560' Dolomitic Packstone, dark brown to gray, fine grained, carbonate mud matrix, euhedral dolomite rhombs common (15%), anhydrite crystals present, carbonate mud intraclasts, brachiopod shells and shell fragments, crinoids.

8,562'-8,578' Anhydrite, tan, dark gray to brown, crystalline, mottled, solution seams, thin carbonate interbeds.

8,578'-8,580' Mudstone-Wackestone, dark brown to brown, very fine grained, crystalline, anhydrite, crinoids, burrows.

TS: 8,579' Wackestone, brown, very fine grained, carbonate mud matrix, rare dolomite rhombs, small anhydrite crystals occur with larger anhydrite grain clusters.

### **Well #2487 (3310500575)**

**T155N, R96W, sec. 12 Williams County**

**Amerada Petroleum Corporation**

10,238'-10,245' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, anhydrite in part, abundant fractures, soft sediment deformation, gypsum pseudomorphs and compaction features in part.

10,245'-10,253' Dolomite, gray to light gray to brown, crystalline, solution seams, wispy laminations in part, soft sediment deformation, horizontal anhydrite laminations, algal laminations in part

10,253'-10,258' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, stylolites, anhydrite in part.

10,258'-10,259' Wackestone, dark brown to brown, very fine grained, crystalline, solution seams, corals, ostracods, crinoids

10,259'-10,261' Wackestone-Packstone, dark brown to brown, fine grained, crystalline, abundant sponge fragments, corals, crinoids, bivalve shell fragments, fractures in part.

- 10,261'-10,265' Wackestone, dark brown to brown, very fine grained, crystalline, solution seams, corals, ostracods, crinoids.
- 10,265-10,266' Mudstone, dark brown to brown, very fine grained, crystalline, horizontal solution laminations, stylolites
- 10,266'-10,267' Dolomite, light brown to tan, crystalline, algal mound, limestone in part
- 10,267'-10,269' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams
- 10,269'-10,271.5' Wackestone, brown, gray to dark gray, fine grained, crystalline, abundant sponge fragments, corals, anhydrite in part, solution seams, stylolites
- 10,271.5'-10,273' Mudstone, dark brown to brown, dark gray, very fine grained, crystalline, solution seams, nodular anhydrite, horizontal solution laminations.
- 10,273'-10,275' Amphipora Boundstone-Floatstone, very fine grained, crystalline, small circular dot and line Amphipora, sponge fragments, corals, gypsum pseudomorphs
- 10,275'-10,279' Dolomite, light brown to brown, gray, crystalline, solution seams, soft sediment deformation, horizontal anhydrite laminations
- 10,279'-10,282.5' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, gypsum pseudomorphs, peloids in part, soft sediment deformation, compaction features, anhydrite in part.
- 10,282.5'-10,285' Wackestone, dark brown to brown, dark gray, very fine grained, crystalline, solution seams, corals, ostracods, sponge fragments, brachiopods
- 10,285'-10,294' Wackestone-Packstone, dark brown to dark gray, fine grained, crystalline, solution seams, compaction features, "pebbly" texture in part, abundant sponge fragments and spicules, corals, brachiopods, anhydrite in part.
- 10,294'-10,297.5' Wackestone, dark brown to brown, dark gray, very fine grained, crystalline, solution seams, light brown inclusions, anhydrite in part, sponge fragments, bivalve shell fragments.
- 10,297.5'-10,304' Dolomite, light gray to gray, crystalline, horizontal algal laminations, limestone in part, mottled with anhydrite in part.
- 10,304'-10,309.5' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, compaction features, rare sponge fragments.
- 10,309.5'-10,311.5' Wackestone, dark brown to brown, very fine grained, crystalline, abundant corals, sponge fragments, crinoids.
- 10,311.5'-10,314.5' Boundstone-Floatstone, abundant stromatoporoids, dark brown to brown, crystalline, gypsum pseudomorphs.
- 10,314.5'-10,315.5' Wackestone, dark gray to dark brown, very fine grained, crystalline, solution seams, compaction features, corals, sponge fragments.



- 10,315.5'-10,316.5' Dolomite, light gray to gray, crystalline, solution seams, anhydrite in part
- 10, 316.5'-10,321.5' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, anhydrite in part
- 10,321.5'-10,323.5' Dolomite, gray to gray, crystalline, solution seams, anhydrite in part, patterned in part, algal laminations in part.
- 10,334.5'-10,342' Mudstone, dark brown to dark gray, fine grained, crystalline, sucrosic, nodular calcite in part.
- 10,342'-10,358.5' Wackestone, dark brown to dark gray, very fine grained, crystalline, solution seams, soft sediment deformation, compaction features, peloids, ostracods, brachiopods, crinoids, corals, stylolites
- 10,358.5'-10,359.5' Dolomite, light gray to gray, brown, crystalline, horizontal solution laminations, limestone in part.
- 10,359.5'-10,360.5' Mudstone, dark brown to dark gray, very fine grained, crystalline, horizontal solution laminations, anhydrite and dolomitized in part.
- 10,360.5'-10,362.5' Dolomite, light brown to brown, gray, crystalline, anhydrite, solution seams, collapse features in part, soft sediment deformation, compaction features, algal laminations
- 10,362.5'-10,375' Mudstone, dark brown to dark gray, very fine grained, crystalline, horizontal solution laminations, sucrosic in part, stylolites.
- 10,375'-10,388.5' Wackestone, dark brown to brown, dark gray, fine grained, crystalline, solution seam, argillaceous inclusions, soft sediment deformation, compaction features, peloids, burrows, corals, stylolites.
- 10,388.5'-10,392.5' Dolomite, light brown to brown, dark gray, crystalline, horizontal solution laminations, soft sediment deformation, anhydrite in part.
- 10,392.5'-10,393.5' Mudstone, dark brown to dark gray, very fine grained, crystalline, horizontal solution laminations.
- 10,393.5'-10,402' Dolomite, light brown to brown, dark gray, crystalline, anhydrite mottling, horizontal solution laminations in part.
- 10,402'-10,407' Mudstone-Wackestone, dark brown to dark gray, fine grained, crystalline, solution seams, sucrosic in part, brachiopods, corals.
- 10,407'-10,409.5' Dolomite, brown, crystalline, sucrosic, solution seams, anhydrite crystals in part.
- 10,409.5'-10,412' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, compaction features, gypsum pseudomorphs.
- 10,412'-10,419.5' Dolomite, light brown to brown, gray, crystalline, anhydrite, horizontal solution laminations in part.

- 10,419.5'-10,422' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, anhydrite.
- 10,422'-10,424' Dolomite, light brown to brown, gray, crystalline, horizontal solution laminations, soft sediment deformation, limestone in part, rare corals
- 10,424'-10,425' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, anhydrite.
- 10,425'-10,427.5' Dolomite, light gray to gray, light brown, crystalline, anhydrite mottling.
- 10,427.5-10,431' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams vertical fractures filled with anhydrite, horizontal solution laminations.
- 10,431'-10,432.5' Dolomite, light gray to gray, light brown, crystalline, anhydrite mottling.
- 10,432.5'-10,436' Mudstone, dark brown to brown, fine grained, crystalline, solution seams, sucrosic in part.
- 10,436'-10,443.5' Dolomite, brown, dark gray to gray, crystalline, solution seams, soft sediment deformation, limestone in part, anhydrite mottling,
- 10,443.5'-10,450' Mudstone, dark gray to dark brown, very fine grained, crystalline, sucrosic in part, varying degrees of dolomitized, horizontal solution laminations, stylolites.
- 10,450'-10,452.5' Mudstone-Wackestone, dark brown to brown, dark gray, very fine grained, crystalline, solution seams, silty in part, corals, sponge fragments.
- 10,452.5'-10,457' Wackestone, brown, dark gray, fine grained, crystalline, sucrosic, sponge fragments, corals, crinoids, brachiopods.
- 10,457'-10,460' Wackestone-Packstone, dark gray to gray, brown, fine grained, crystalline, sucrosic, solution seams, abundant sponge fragments, corals, crinoids, dolomitic in part.
- 10,460'-10,463.5' Packstone, dark brown to brown, gray, fine grained, crystalline, sucrosic, solution seams, abundant sponge fragments, corals, dolomitic in part.
- 10,463.5'-10,466' Stromatoporoid Boundstone-Floatstone, brown, gray, fine grained, crystalline, stromatoporoid framework, dolomitic in part.
- 10,466'-10,472' Dolomite, brown, dark gray, crystalline, calcite cement in part, solution seams, anhydrite mottling, algal laminations in part.
- 10,472'-10,473' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams.
- 10,473'-10,475' Dolomite, light brown to brown, dark gray, crystalline, horizontal anhydrite laminations.
- 10,475'-10,489' Mudstone-Wackestone, dark brown, gray, very fine grained, crystalline, solution seams, compaction features, anhydrite in part, corals, crinoids, sponge fragments, stylolites.

- 10,489'-10,490' Stromatoporoid Boundstone, brown, gray, fine grained, crystalline, stromatoporoid framework.
- 10,490'-10,492' Wackestone-Packstone, brown, dark gray, very fine grained, crystalline, solution seams, anhydrite in part, sponge fragments, corals, gastropods, fractures.
- 10,492'-10,503' Dolomite, dark gray to gray, light brown, tan, crystalline, patterned in part, solution seams, compaction features, anhydrite solution laminations, soft sediment deformation.
- 10,503'-10,517' Mudstone-Wackestone, dark brown to dark gray, very fine grained, crystalline, solution seams, soft sediment deformation, peloids, brachiopods, corals.
- 10,517'-10,518.5' Dolomite, light brown to brown, gray, crystalline, patterned.
- 10,518.5'-10,520.5' Wackestone, brown, gray, fine grained, crystalline, solution seams, soft sediment deformation, anhydrite in parts, ostracods.
- 10,520.5'-10,523' Dolomite, light gray to gray, crystalline, patterned.
- 10,523'-10,526' Wackestone, brown, gray, fine grained, crystalline, solution seams, soft sediment deformation, anhydrite in parts, ostracods, dolomitic, intraclasts.
- 10,526'-10,532' Mudstone, brown to dark gray, very fine grained, crystalline, solution seams, dolomitic, anhydrite in part, gypsum pseudomorphs.
- 10,532'-10,537.5' Dolomite, light gray to gray, crystalline, patterned, limestone in part.
- 10,537.5'-10,539.5' Peloidal wackestone, dark brown, gray, very fine grained, crystalline, solution seams, compaction features, peloids, pisoids.
- 10,539.5'-10,557.5' Mudstone, dark brown to brown, dark gray, very fine grained, crystalline, solution seams, horizontal solution laminations, healed fractures replaced with anhydrite, rare crinoids and corals.
- 10,557.5'-10,560' Peloidal wackestone, dark brown to brown, dark gray, very fine grained, crystalline, solution seams, peloids, pisoids, stylolites, gypsum pseudomorphs.
- 10,560'-10,564.5' Dolomite, light gray to gray, crystalline, solution seams, limestone in part, "pebbly" texture, horizontal solution laminations.
- 10,564.5'-10,569' Mudstone-Wackestone, dark brown to dark gray, very fine grained, crystalline, solution seams, peloids in part.
- 10,569'-10,570' Dolomite, brown gray, crystalline, solution seams, soft sediment deformation, anhydrite mottling in part.
- 10,570'-10,581' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, soft sediment deformation, anhydrite, rare peloids, stylolites, gypsum pseudomorphs.
- 10,581'-10,586' Dolomite, light gray to gray, brown, crystalline, patterned, soft sediment deformation, dissolved solution seams, pyrite in part.

**Well #9754 (3310501035)**  
**T155N, R95W, sec. 30 Williams County**

**Amerada Hess Corporation**

- 10,107'-10,113.5' Wackestone, dark brown to brown, gray, very fine grained, crystalline, solution seams, soft sediment deformation, intraclasts, sponge fragments, corals, crinoids, stylolites, fractures.
- 10,113.5'-10,114.5' Dolomite, gray, brown, crystalline, patterned in part, solution seams, soft sediment deformation, brecciated at lower contact.
- 10,114.5'-10,121.5' Wackestone, dark brown to brown, gray, very fine grained, crystalline, solution seams, soft sediment deformation, intraclasts, sponge fragments, corals, crinoids, stylolites, fractures.
- 10,121.5'-10,122' Amphipora Boundstone, dark brown to brown, fine grained, crystalline, abundant circular line and dot Amphipora.
- 10,122'-10,127.5' Dolomite, brown, gray, crystalline, solution seams, sucrosic, horizontal solution laminations, intraclasts, limestone in part.
- 10,127.5'-10,129' Mudstone, dark brown, dark gray, very fine grained, crystalline, solution seams, soft sediment deformation, quartz inclusions.
- 10,129'-10,130' Wackestone, dark brown, dark gray, fine grained, crystalline, solution seams, dissolved and replaced crinoids and corals
- 10,130'-10,132.5' Packstone, brown, dark gray, fine grained, crystalline, solution seams, abundant sponge fragments, corals, and crinoids.
- 10,132.5'-10,134' Wackestone, dark brown, dark gray, fine grained, crystalline, solution seams, light brown intraclasts, replaced brachiopods and ostracods.
- 10,134'-10,136' Mudstone, dark brown, dark gray, very fine grained, crystalline, solution seams, soft sediment deformation.
- 10,136'-10,141' Amphipora Boundstone-Floatstone, dark brown to light brown, fine grained, crystalline, Small circular line and dot Amphipora.
- 10,141'-10,145.5' Mudstone-Wackestone, dark brown, dark gray, fine grained, crystalline, solution seams, "pebbly" texture, corals, crinoids, gypsum pseudomorphs.
- 10,145.5'-10,152' Dolomite, gray, brown, crystalline, solution seams, soft sediment deformation, brecciated in part, anhydrite mottling, horizontal solution seams.
- 10,152'-10,160' Mudstone, dark brown, dark gray, very fine grained, crystalline, solution seams, fractures.
- 10,160'-10,161' Stromatoporoid Boundstone-Floatstone, dark brown to brown, fine grained, crystalline, stromatoporoid framework, sponge spicules, corals.

- 10,161'-10,162' Wackestone, brown, gray, very fine grained, crystalline, sponge fragments, corals, crinoids.
- 10,162'-10,164' Mudstone, brown, gray, very fine grained, crystalline, solution seams, soft sediment deformation, flaser bedding.
- 10,164'-10,165' Dolomite, brown, gray, crystalline, solution seams.
- Missing 10,167'-10,215'
- 10,216'-10,236.5' Mudstone, dark brown, gray, very fine grained, crystalline, solution seams, quartz inclusions, fractures, soft sediment deformation, dissolved fossils, fractures, algal laminations in part.
- 10,236.5'-10,243' Dolomite, light brown to brown, gray, crystalline, horizontal solution laminations, anhydrite and algal laminations in part.
- 10,243'-10,244' Mudstone, dark brown, dark gray, very fine grained, crystalline.
- 10,244'-10,250.5' Dolomite, light brown to brown, gray, crystalline, horizontal anhydrite laminations, mottled in part, algal laminations, soft sediment deformation.
- 10,250.5'-10,254.5' Mudstone-Wackestone, dark brown, dark gray, very fine grained, crystalline, solution seams, fractures, Amphipora dissolved out in part.
- 10,254.5'-10,255.5' Dolomite, brown, gray, crystalline, solution seams, limestone in part, fractures.
- 10,255.5'-10,260.5' Wackestone, dark brown, dark gray, very fine grained, crystalline, "pebbly" texture, dolomitic, sponge fragments, corals, stylolite at lower contact.
- 10,260.5'-10,263.5' Dolomite, gray, brown, crystalline, horizontal anhydrite laminations.
- 10,263.5'-10,265.5' Mudstone, dark brown, dark gray, very fine grained, crystalline, solution seams, stylolites.
- 10,265.5'-10,268' Dolomite, gray, brown, crystalline, horizontal anhydrite laminations.
- 10,268'-10,269.5' Mudstone, dark brown, dark gray, very fine grained, crystalline, solution seams, stylolites, dolomitic.
- 10,269.5'-10,271' Dolomite, light brown, tan, crystalline, solution seams, anhydrite in part, intraclasts, fractures.
- 10,271'-10,272.5' Mudstone, dark gray, dark brown, very fine grained, crystalline, solution seams, dolomitic.
- 10,272.5'-10,273.5' Dolomite, light brown, gray, crystalline, anhydrite mottling.
- 10,273.5'-10,275' Mudstone, dark gray, dark brown, very fine grained, crystalline, horizontal solution seams, dolomitic, fractures.
- 10,275'-10,276' Dolomite, light brown, gray, crystalline, anhydrite mottling.

- 10,276'-10,293' Mudstone, dark brown, dark gray, very fine grained, crystalline, solution seams, dolomitic, horizontal solution laminations in part.
- 10,293'-10,294' Dolomite, gray, light brown, crystalline, solution seams.
- 10,294'-10,306' Mudstone, dark brown, gray, very fine grained, crystalline, dolomitic, compaction features, soft sediment deformation.
- 10,306'-10,309' Packstone, dark brown, dark gray, fine grained, crystalline, solution seams, abundant sponge fragments and corals, compaction features, sucrosic in part.
- 10,309'-10,314' Stromatoporoid Boundstone-Floatstone, brown, gray, fine grained, crystalline, sucrosic, stromatoporoid framework, gypsum pseudomorphs.
- 10,314'-10,317' Wackestone, light brown, gray, sucrosic, solution seams, sponge fragments.
- 10,317'-10,321' Dolomite, brown, gray, crystalline, patterned in part, horizontal anhydrite laminations.
- 10,321'-10,323.5' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams
- 10,323.5'-10,326' Dolomite, brown, gray, crystalline, horizontal anhydrite laminations,
- 10,326'-10,334' Wackestone, dark brown to gray, very fine grained, crystalline, solution seams, soft sediment deformation, corals, crinoids.
- 10,334'-10,336' Stromatoporoid Boundstone-Floatstone, dark brown to light brown, fine grained, crystalline, stromatoporoid framework, sponge fragments, corals, burrows in part.

**Well #9845 (3310501047)**

**T155N, R95W, sec. 20 Williams County**

**Amerada Hess Corporation**

- 10,330'-10,331' Dolomite, brown, gray, crystalline, anhydrite mottling, stromatolites.
- 10,331'-10,335' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, compaction features, soft sediment deformation, fractures.
- 10,335'-10,336.5' Dolomite, light brown to brown, gray, crystalline, horizontal solution laminations, limestone in part.
- 10,336.5'-10,339' Mudstone-Wackestone, dark brown to dark gray, very fine grained, crystalline, solution seams, compaction features, soft sediment deformation, fractures.
- 10,339'-10,350' Mudstone, dark brown to dark gray, very fine grained, crystalline, flaser bedding, solution seams, soft sediment deformation, sucrosic, anhydrite in part, stylolites.

- 10,350'-10,352' Wackestone, dark brown to gray, very fine grained, crystalline, Amphipora circular dot and line sponge fragments, solution seams, stylolites.
- 10,352'-10,355' Mudstone, dark brown to dark gray, very fine grained, crystalline, flaser bedding, solution seams, soft sediment deformation, sucrosic, anhydrite in part, stylolites, dolomitic.
- 10,355'-10,359' Wackestone, dark brown to dark gray, very fine grained, crystalline, sucrosic, solution seams, sponge fragments, ostracods, calcite nodules.
- 10,359'-10,360' Packstone, brown to gray, fine grained, crystalline, compaction features, abundant sponge fragments, corals, fractures.
- 10,360'-10,362.5' Stromatoporoid Boundstone-Floatstone, dark brown to light brown, fine grained, crystalline, sucrosic, stromatoporoid framework, corals, sponge spicules, vugs in part.
- 10,362.5'-10,364' Wackestone-Packstone, brown to gray, very fine grained, crystalline, sucrosic, nodular inclusions, sponge fragments, silty in part.
- 10,364'-10,366' Mudstone-Wackestone, brown to gray, very fine grained, crystalline, solution seams, soft sediment deformation,
- 10,366'-10,367' Stromatoporoid Boundstone-Floatstone, dark brown to gray, fine grained, crystalline, stromatoporoid framework, dolomitic.
- 10,367'-10,370.5' Mudstone, brown to gray, very fine grained, crystalline, solution seams, dolomitic.
- 10,370.5'-10,373.5' Dolomite, light gray to gray, brown, crystalline, patterned, horizontal anhydrite laminations, limestone in part, tan algal laminations at lower mudstone contact.
- 10,373.5'-10,375' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, gypsum pseudomorphs, fractures.
- 10,375'-10,379' Dolomite, brown to dark gray, crystalline, horizontal anhydrite laminations.

**Well #8140 (3310500886)**

**T155N, R98W, sec. 13 Williams County**

**Exxon Corporation**

- 11,550'-11,551' Dolomite, gray to brown, crystalline, anhydrite, solution seams.
- 11,551;-11,556.5' Mudstone-Wackestone, dark brown to dark gray, very fine grained, crystalline, flaser bedding, solution seams, corals, bivalve and brachiopod shell fragments, stylolites.
- 11,556.5'-11,557.5' Amphipora Floatstone, gray to brown, fine grained, crystalline, small circular line and dot Amphipora.

- 11,557.5'-11,558' Wackestone, dark brown to gray, very fine grained, crystalline, solution seams, corals, gastropods.
- Missing 11,558'-11,568'
- 11,568'-11,570' Dolomite, light gray to gray, crystalline, patterned, solution seams.
- 11,570'-11,574' Wackestone, dark brown to brown, dark gray, very fine grained, crystalline, solution seams, soft sediment deformation, sponge fragments, corals, brachiopods, ostracods, stylolites.
- 11,574'-11,576' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, flaser bedding, gypsum pseudomorphs.
- 11,576'-11,577.5' Amphipora Boundstone-Floatstone, dark brown to gray, fine grained, crystalline, small circular line and dot Amphipora.
- 11,577.5'-11,579.5' Wackestone, dark brown to brown, fine grained, crystalline, solution seams, burrows.
- 11,579.5'-11,584' Dolomite, brown to gray, crystalline, horizontal anhydrite laminations, limestone in part.
- 11,584'-11,595' Mudstone-Wackestone, dark brown to dark gray, very fine grained, crystalline, flaser bedding, solution seams, soft sediment deformation, sponge fragments, corals, brachiopods, fractures.
- 11,595'-11,596' Amphipora Boundstone-Floatstone, dark brown to light brown, fine grained, crystalline, small circular line and dot Amphipora.
- 11,596'-11,598.5' Stromatoporoid Boundstone-Floatstone, dark brown to brown, gray, fine grained, crystalline, solution seams, compaction features, stromatoporoid framework, corals, sponge fragments.
- 11,598.5'-11,601.5' Peloidal wackestone, dark brown to dark gray, very fine grained, crystalline, solution seams, "pebbly" texture, peloids, corals crinoids, brachiopods.
- 11,601.5'-11,603.5' Stromatoporoid Boundstone-Floatstone, dark brown to light brown, very fine grained, crystalline, corals, brachiopods, Amphipora in part.
- 11,603.5'-11,605' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams, flaser bedding, dolomitic.
- 11,605'-11,611' Dolomite, light gray to gray, crystalline, patterned, horizontal anhydrite laminations, mottled in part.
- 11,611'-11,616.5' Mudstone, dark brown to brown, dark gray, very fine grained, crystalline, flaser bedding, solution seams, fractures.
- 11,616.5'-11,620' Wackestone, dark brown to dark gray, fine grained, crystalline, solution seams, corals, sponge fragments, brecciated in part, dolomitic.



**Well #7712 (3310500845)**  
**T155N, R98W, sec.21 Williams County**

**Shell Oil Company**

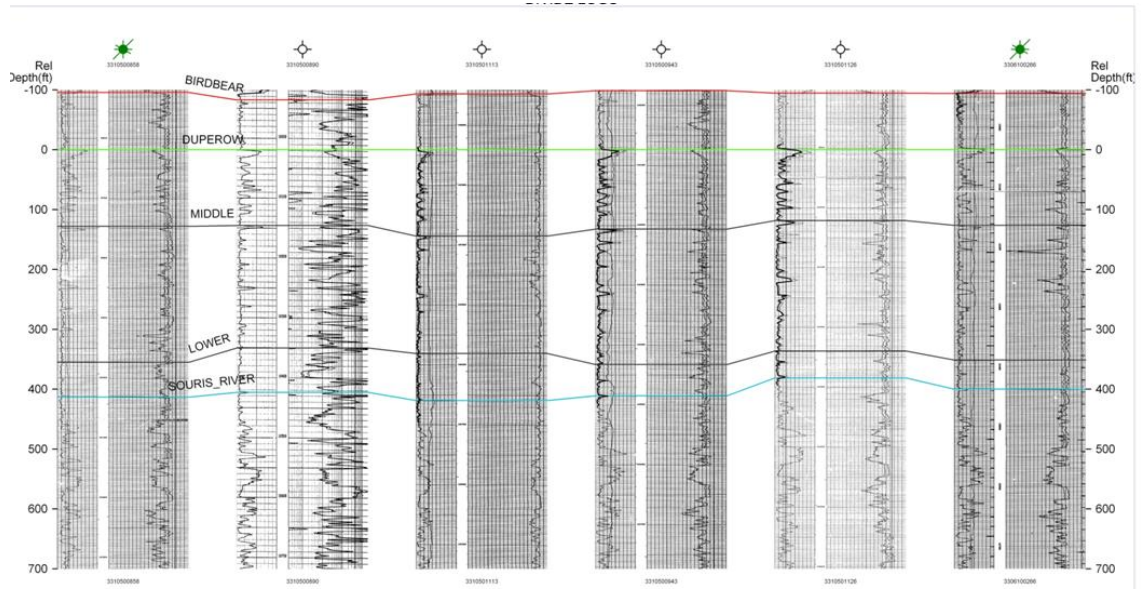
- 11,738'-11,743.5' Mudstone-Wackestone, dark brown to dark gray, very fine grained, crystalline, solution seams, peloids, anhydrite in part, dolomitic.
- 11,743.5'-11,746' Stromatoporoid Boundstone-Floatstone, dark brown to brown, gray, fine grained, crystalline, solution seams, stromatoporoid framework, corals.
- 11,746'-11,748' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams.
- 11,748'-11,759' Stromatoporoid Boundstone-Floatstone, dark brown to brown, gray, fine grained, crystalline, solution seams, sucrosic in part, stromatoporoid framework, corals, partly dolomitized.
- TS: 11,759' Dolomitic boundstone, dark brown to gray, fine grained, fine carbonate mud sponge framework with calcite grains filling in pore space, subhedral dolomite rhombs, solution seam occurs between sponge structure and dolomite.
- 11,759'-11,761.5' Mudstone, dark brown to dark gray, very fine grained, crystalline, solution seams.
- 11,761.5'-11,764.5' Dolomite, gray to brown, crystalline, soft sediment deformation, horizontal anhydrite laminations, algal laminations in part.
- 11,764.5'-11,766.5' Mudstone, dark brown to dark gray, very fine grained, crystalline, gypsum pseudomorphs.
- 11,766.5'-11,771.5' Dolomite, gray to brown, crystalline, soft sediment deformation, horizontal anhydrite laminations, algal laminations in part.
- 11,771.5'-11,783' Mudstone, dark brown to dark gray, very fine grained, crystalline, horizontal solution laminations, salt in part, rare corals.
- 11,783'-11,786' Wackestone, dark brown to brown, very fine grained, crystalline, solution seams, brachiopods, corals, fractures.
- 11,786'-11,788' Stromatoporoid Boundstone-Floatstone, dark brown to gray, fine grained, crystalline, soft sediment deformation, stromatoporoid framework, corals, sponge spicules.
- TS: 11,788' Wackestone-packstone, dark to light brown, gray, fine grained, fine carbonate mud matrix, dolomite rhombs, abundant crinoids, brachiopod and bivalve shell fragments, echinoderms, ostracods, and corals, solution seams.
- 11,788'-11,791' Mudstone, dark brown to dark gray, very fine grained, crystalline, nodular bedding, horizontal solution laminations.

11,791'-11,794' Dolomite, light gray to gray, crystalline, horizontal anhydrite laminations, patterned in part.

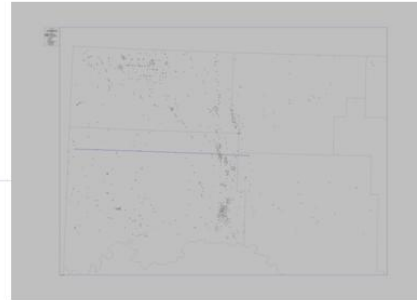
11,794'-11,795' Mudstone, dark brown to dark gray, very fine grained, crystalline, horizontal solution laminations.

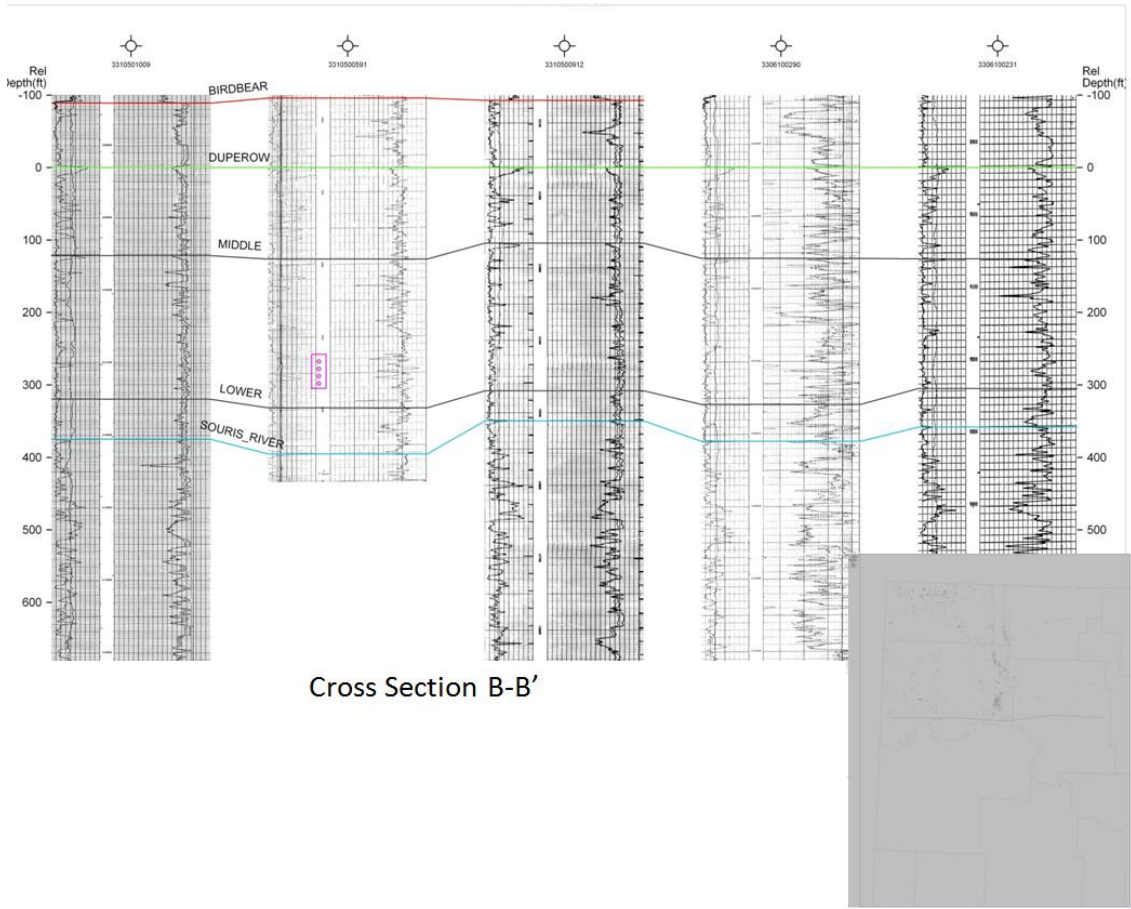
11,795'-11,798' Dolomite, light gray to gray, crystalline, horizontal anhydrite laminations, patterned in part.

## Appendix B Cross Sections

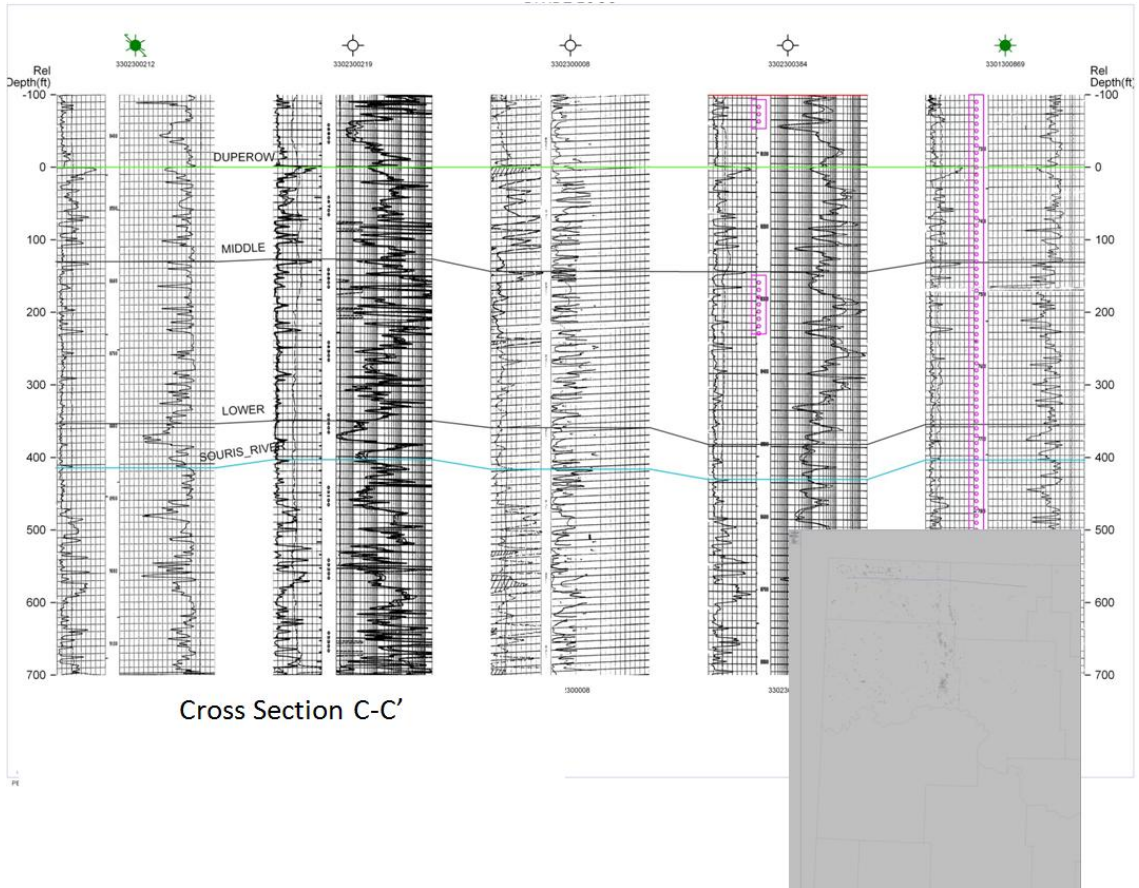


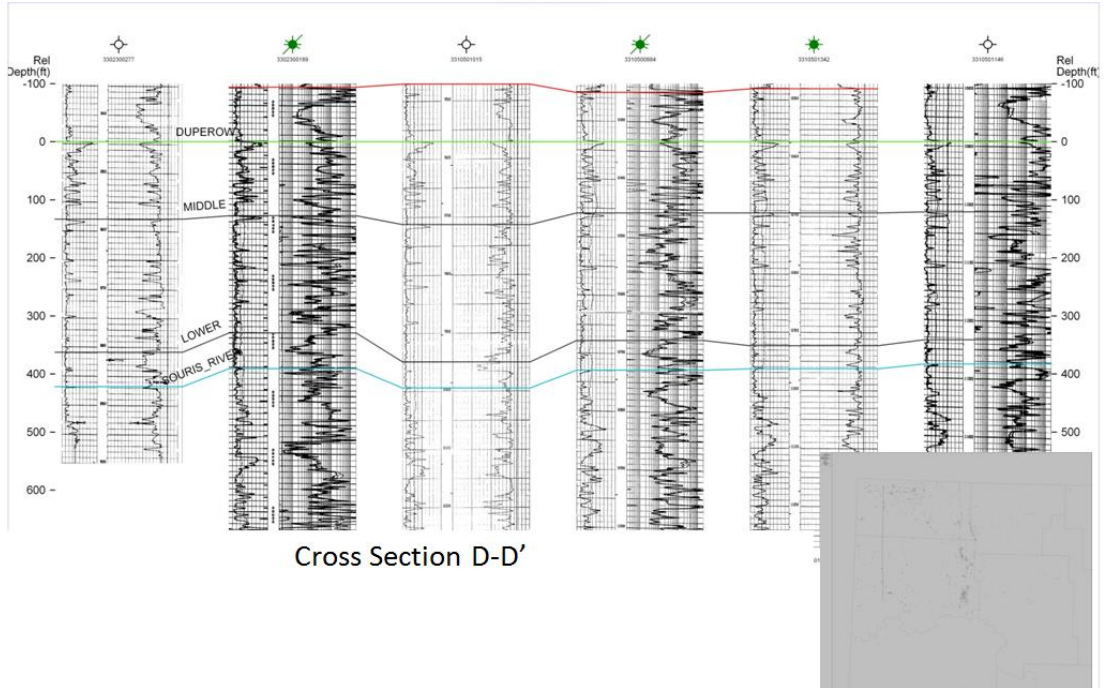
Cross Section A-A'

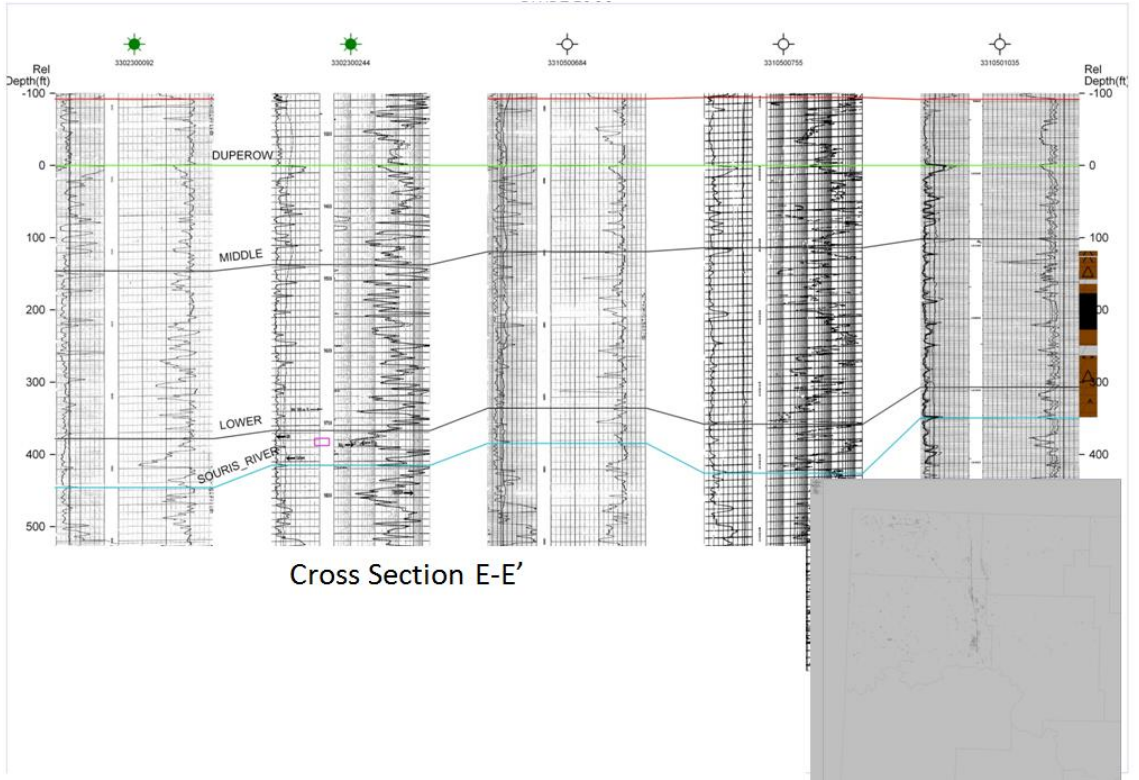


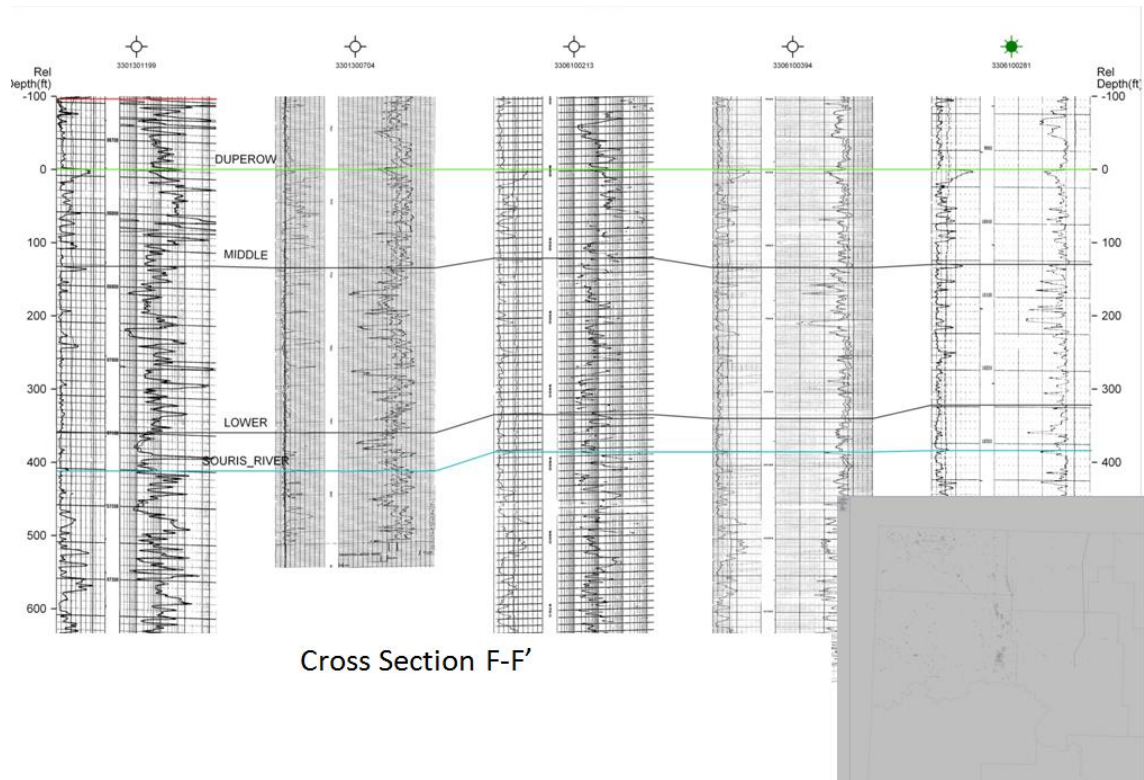


Cross Section B-B'









Cross Section F-F'



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