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Deposition and diagenesis of a portion of the Frobisher-Alida Interval (Mississippian Madison Group), Wiley Field, North Dakota

Mark R. Luther
University of North Dakota

DEPOSITION AND DIAGENESIS OF A PORTION OF THE FROBISHER-ALIDA INTERVAL (MISSISSIPPIAN MADISON GROUP), WILEY FIELD, NORTH DAKOTA

by
Mark R. Luther

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This thesis submitted by Mark R. Luther in partial fulfillment of the requirements for the degree of Master of Arts from the University of North Dakota has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

(Chairperson)

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

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Double, double toil and trouble;
Fire burn and cauldron bubble.
Macbeth, Act IV.

ABSTRACT

This study focused on the Frobisher-Alida interval, in particular, the Glenburn bed of the Mississippian Mission Canyon Formation. Wireline logs and cores from closely spaced wells in, and adjacent to, the Wiley Field, Williston Basin, North Dakota were examined. Information derived from the wireline logs was used to construct several maps which show that there was little or no topographic relief or slope in the study area during deposition of the Glenburn bed. In addition, the maps show that structural deformation occurred subsequent to deposition of the Frobisher-Alida interval.

Six distinct lithofacies were recognized in cores of the Glenburn bed from the Wiley Field area: 1) fossiliferous grainy mudstone-packstone (LF-1); 2) coated-grain wackestone-grainstone (LF-2); 3) peloidal/intraclastic wackestone-packstone (LF-3); 4) dolowackestone-mudstone and nodular anhydrite (LF-4); 5) massive anhydrite (LF-5); and, 6) siliciclastic sandstone-siltstone (LF-6). Of the six lithofacies, all but LF-6 were deposited in a low-energy, shallow-sublittoral, marine setting. The siliciclastic sandstone-siltstone lithofacies (LF-6) was deposited by eolian processes as a siliciclastic-dominated sabkha.

Facies within the Glenburn bed are stacked vertically rather than prograding either basinward or shoreward. Vertical stacking indicates that depositional processes were stable and did not shift laterally by any significant amount, and that equilibrium conditions existed between sedimentation rates and rates of subsidence/sea level-change. Near the end of "Glenburn time," the most shoreward lithofacies prograded across the study area in a basinward direction, indicating a

drop in sea level or an increase in sedimentation rate.

Within the study area, the distribution of fossils, dominant lithologies, and cement types indicate that lithofacies were formed in response to a horizontal salinity gradient in the water mass with salinities increasing to the northeast. The relative position of salinity values laterally across the area appears to have remained static during most of Glenburn bed deposition. Most of the sediments deposited in the study area are abiotic in origin, but may have formed due to, or in conjunction with, biochemical processes such as photosynthesis.

Marine water flowing into the study area to replace water lost by evaporation became increasingly saline as it evaporated along its flow path. A digitate pattern (in plane view) of carbonate and anhydrite deposition formed due to the shoreward flow of relatively fresh, marine-water plumes, and the laterally adjacent, basinward flow of dense, hypersaline brines respectively.

Diagenetic processes occurring due to the movement of surface or near surface hypersaline brines include dolomitization and calcite dissolution. Basinward-flowing, magnesium-rich brines derived from gypsum precipitating areas formed dolomite in a near surface, sublittoral setting. The same brines carried sulfide ions basinward where they were oxidized, creating an acid corrosive to carbonates that then caused vugular/enlarged fenestral porosity to develop in limestone lithofacies. The occurrence of plant megaspores (five new species) and fluorite in Mississippian rocks of the Williston Basin are reported for the first time in this report. Local hydrocarbon sourcing may have occurred.

INTRODUCTION

General Setting

The Wiley Field consists of an approximately 8 sq mi (20 sq km) area in western Bottineau County, North Dakota (Fig. 1). Located within township 161N ranges 81W and 82W, Wiley Field is one of several fields distributed along the northeastern margin of the Williston Basin which produce oil from Mississippian Mission Canyon Formation carbonates. Discovered in 1958, cumulative production through 1985 from the 123 wells drilled at Wiley Field was 10,487,756 bbls of oil and 26,840,901 bbls of water. Oil is trapped primarily by the updip facies change from porous carbonates to evaporites of the Charles Formation. In the study area both the upper Mission Canyon Formation and lower Charles Formation are included within the informal Frobisher-Alida interval.

Geologic Setting

The Williston Basin is a major structural feature of central North America that covers an area of approximately 200,000 sq mi (518,000 sq km) (Sheldon and Carter, 1979) and underlies major parts of Montana, North Dakota, South Dakota, and south-central Canada (Saskatchewan and Manitoba) (Fig. 2). An intracratonic basin, the Williston Basin is filled with approximately 16,000 ft (4,900 m) of sedimentary rocks (Gerhard and others, 1982) representing every geologic system of the Phanerozoic (Carlson and Anderson, 1965). The thickest accumulation of Paleozoic sedimentary rocks was deposited during the Mississippian, accounting for 2,500 ft (762 m) of Paleozoic section (Carlson and Anderson, 1965).

Figure 1: Outline of the study area and its location within Bottineau County, North Dakota.

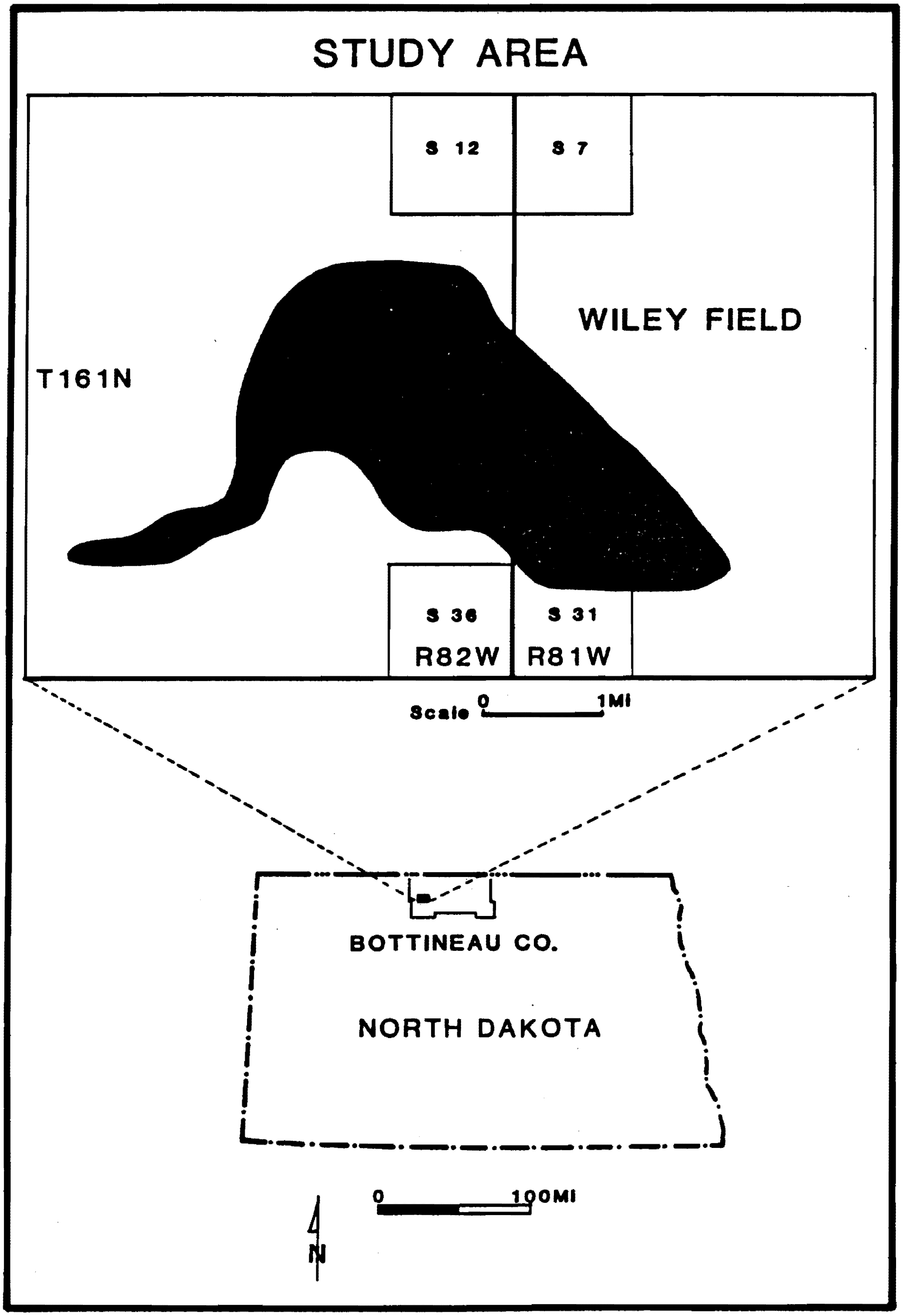
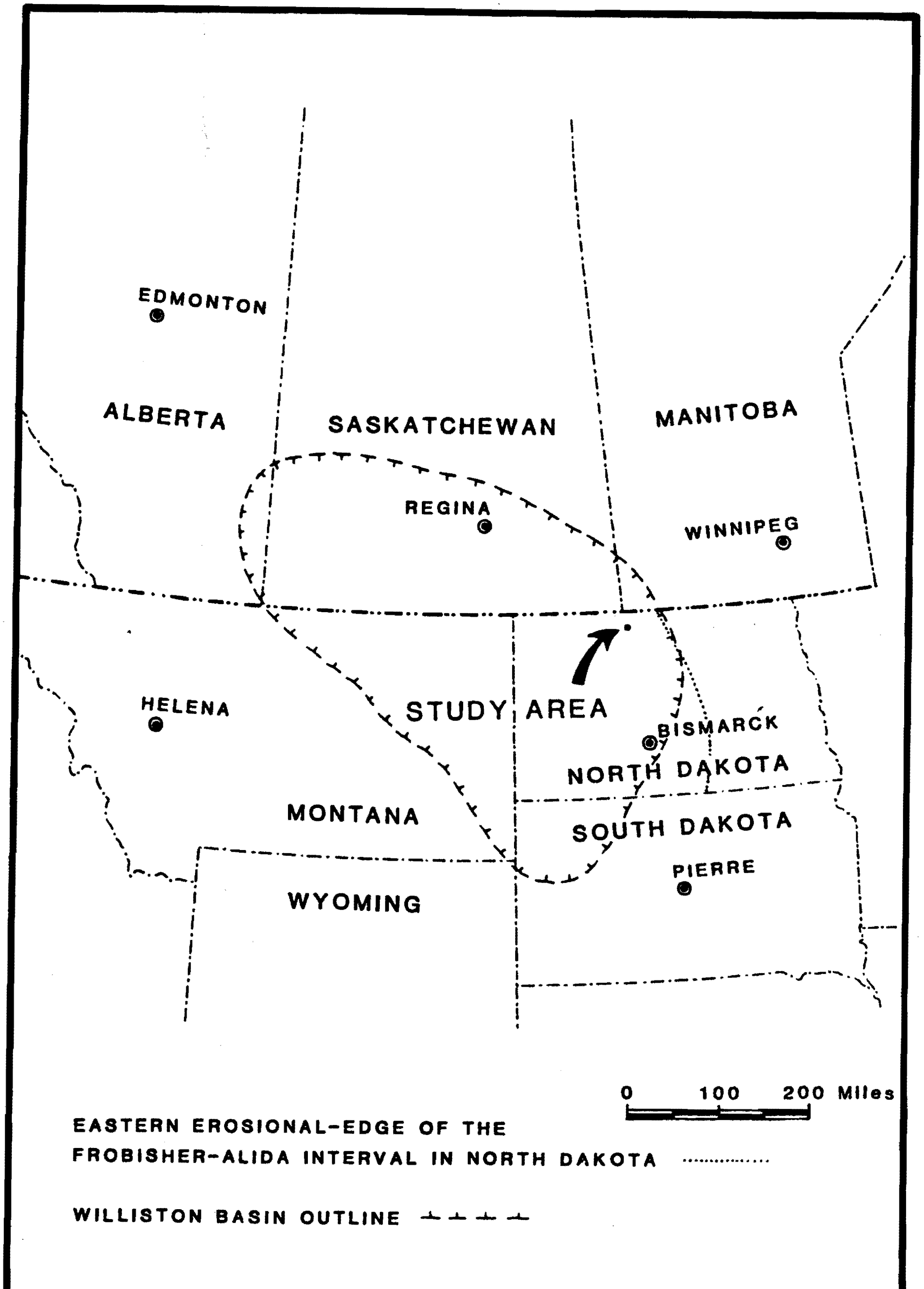

STUDY AREA
S 12
S 7
WILEY FIELD
T161N
S 36
S 31
R82W
R81W
Scale 0 1MI
BOTTINEAU CO.
NORTH DAKOTA
0 100MI
N

Figure 2: A map showing the outline of the Williston Basin and the location of the study area. Also shown is the erosional-edge of the Frobisher-Alida interval, east of which the interval has been removed by erosion (Mesozoic unconformity). Modified from Worsley and Fuzesy (1978), and Anderson (1974).



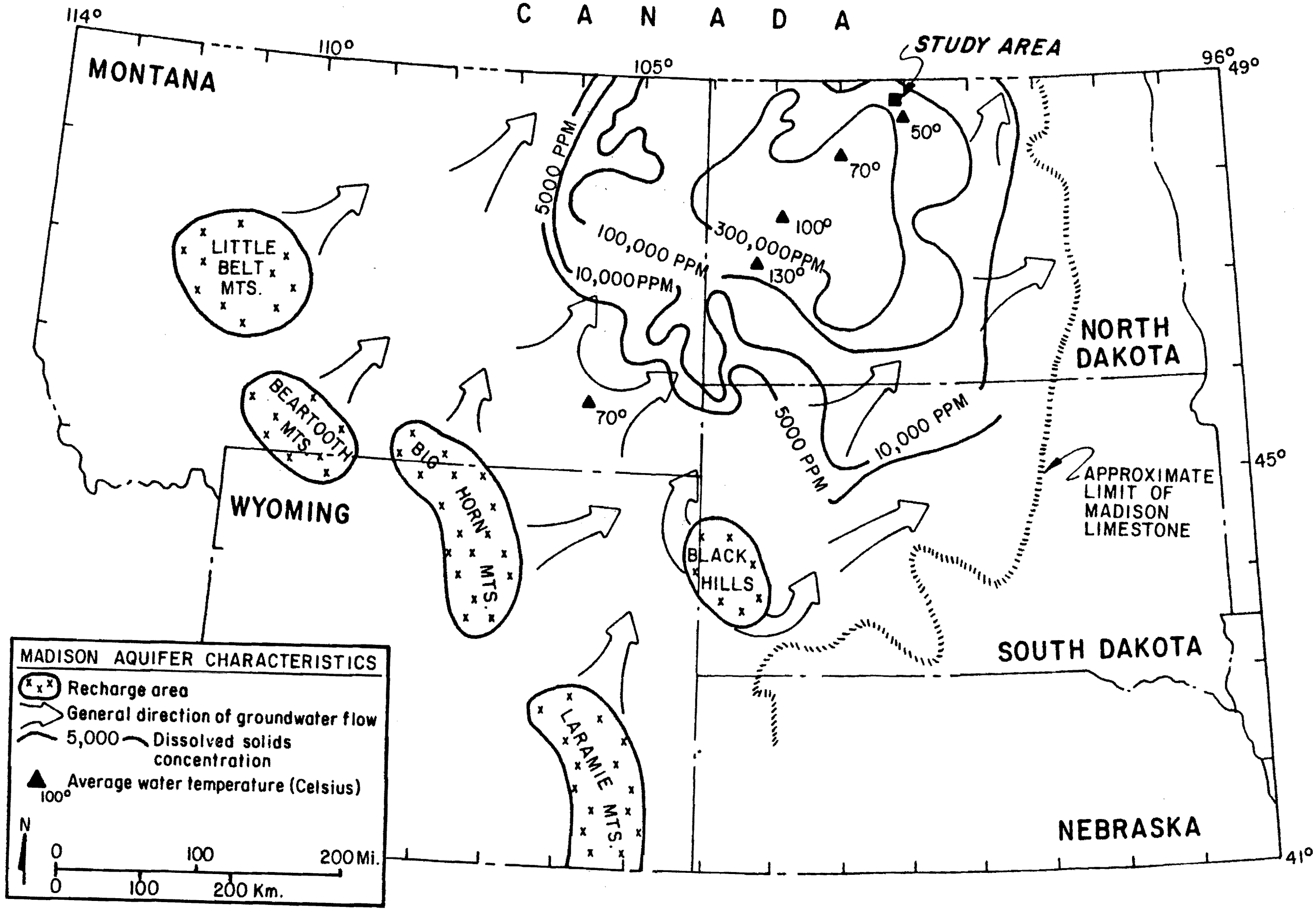
Modified from Worsley and Fuzesy (1978), and Anderson (1974).

The Mission Canyon Formation in the Williston Basin was deposited in a shallow epeiric sea with marine water probably supplied from an ocean basin to the west (Cordilleran miogeocline). Isopach maps (Craig, 1972) indicate that the Williston Basin was connected to the Cordilleran miogeocline by the Central Montana Trough. During the deposition of the Mission Canyon Formation, the Williston Basin is thought to have been located between 5 and 15 degrees north latitude (Habicht, 1979; Scotese and others, 1979). As a result of increasingly restricted conditions, evaporite deposition gradually extended basinward from the northeastern margin of the basin (Carlson and Anderson, 1966), forming the Charles Formation. In the study area, Mississippian strata are unconformably overlain by the Triassic Spearfish Formation.

There are several major structural features within the Williston Basin, including the Nesson, Cedar Creek, Little Knife, and Billings anticlines. However, the only reported major structures that may have affected sedimentation in the study area are the underlying contact of the Precambrian Superior and Churchill provinces (Trans-Hudson orogenic belt of Bickford and others, 1986), and the Central Montana Trough (Peterson, 1981), located on the western edge of the basin.

After the Cretaceous Laramide orogeny (to the south and west of the Williston Basin), regional groundwater flow in the Williston Basin similar to the present day flow system was initiated. Downey (1984) considered the carbonates of the Madison Group (Mission Canyon and Lodgepole Formations) to be a major regional aquifer, and developed a flow model for them (Fig. 3). The influences of the Madison aquifer groundwater flow pattern are many, including possible

Figure 3: Characteristics of the Madison Aquifer including: recharge areas, general direction of groundwater flow, lines of equal concentration of dissolved solids, and points of average water temperature (in celsius) between areas of recharge and the study area (solid arrow). Modified from Downey (1984).


C A N A D A
114°
110°
105°
96°
49°
45°
41°
MONTANA
WYOMING
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
STUDY AREA
LITTLE BELT MTS.
BEARTOOTH MTS.
BIG HORN MTS.
BLACK HILLS
LARAMIE MTS.
5000 PPM
10,000 PPM
100,000 PPM
300,000 PPM
10,000 PPM
5000 PPM
50°
70°
100°
130°
70°
APPROXIMATE LIMIT OF MADISON LIMESTONE
MADISON AQUIFER CHARACTERISTICS
Recharge area
General direction of groundwater flow
5,000 Dissolved solids concentration
100° Average water temperature (Celsius)
N
0 100 200 Mi.
0 100 200 Km.

hydrocarbon migration and trapping, and diagenesis of the rocks through which the water passes. Possible diagenesis caused by water-flow in the Madison aquifer will be discussed in more detail in the diagenesis section.

Purpose

Due to an infill drilling program at Wiley Field during the late 1970's, excellent core control from the Frobisher-Alida interval is available for study. The purpose of this study is to: 1) describe closely spaced cores of Mississippian strata (upper Mission Canyon and lower Charles Formations) from the Wiley Field; 2) interpret the depositional environment and history (emphasizing the Glenburn bed) for a small area on a scale not done in regional studies; 3) describe diagenetic features and interpret the diagenetic history; and 4) map and discuss local structure.

Stratigraphy

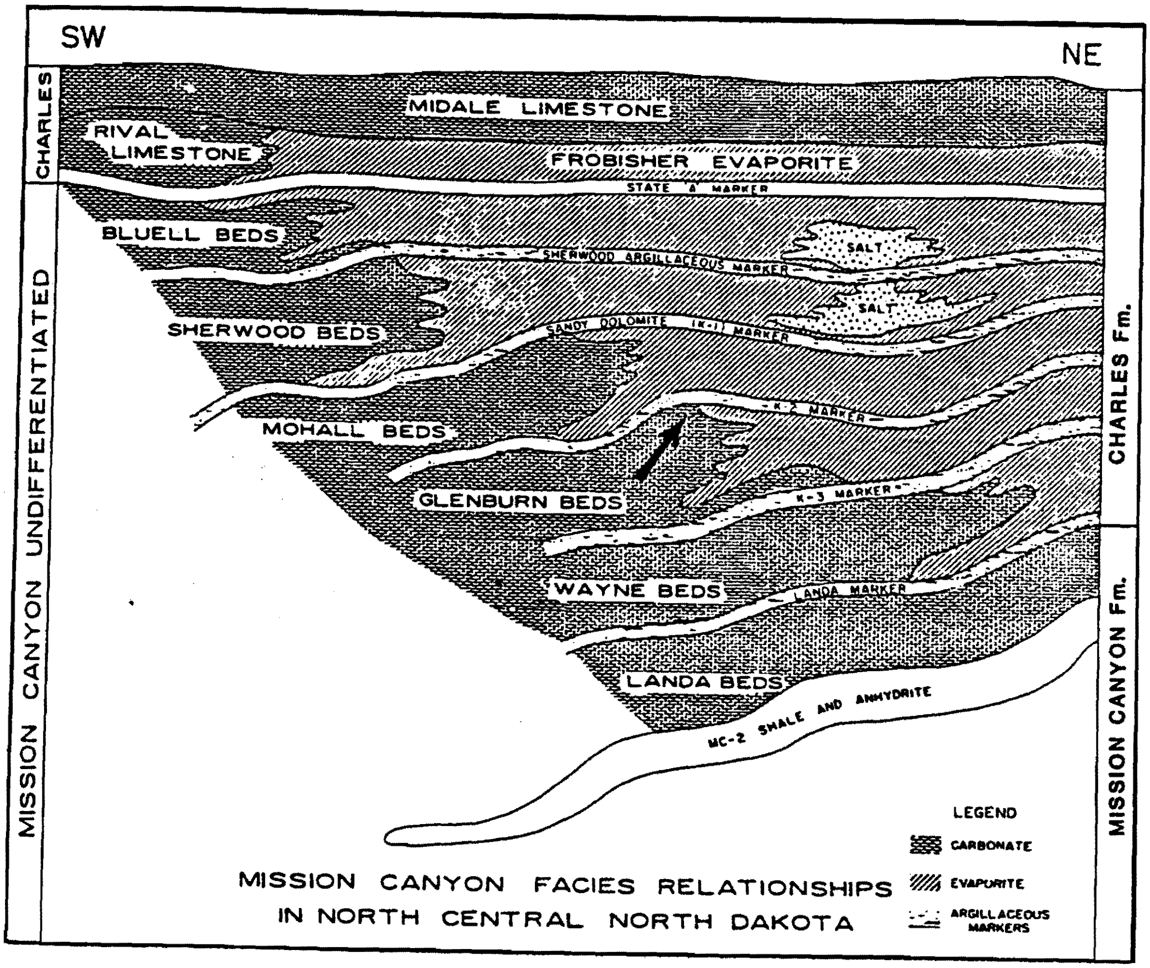
Peale (1893) first proposed the term Madison Formation for Lower Carboniferous carbonate rocks in the Three Forks region of Montana. He recognized three lithologic subdivisions of the Madison. Collier and Cathcart (1922) later assigned the Madison to group status and divided it into two formations, the Lodgepole Limestone and the overlying Mission Canyon Limestone.

Seager (1942) introduced the term "Charles Member" to describe a series of limestone, dolomite and anhydrite beds lying between the Madison Group and the overlying Big Snowy Group. He included the "Charles Member" within the Big Snowy Group. Seager and others (1942) use the term "Charles Formation" for the lowermost unit of the Big Snowy Group. Sloss and Moritz (1951) recognized similarities between the Charles Formation and the Madison Group and considered the Charles to be the uppermost formation of the Madison Group. The Mission Canyon-Charles Formation boundary was arbitrarily placed at the base of the lowest anhydrite by Edie (1958). Bluemle and others (1980) described the Lodgepole, Mission Canyon and Charles Formations as facies that cut across log markers.

In the northeastern portion of the Williston Basin, informal subdivisions of the Madison Group are based upon thin argillaceous or silty zones and their associated electric log responses. Thomas (1954) was the first of several writers to propose a nomenclature scheme based on marker-horizons. Fuller (1956) proposed a six fold division of the "Upper Madison Limestone", which corresponds to the Mission Canyon Formation. The six divisions, termed beds, were named after hydrocarbon producing fields in Saskatchewan and were based on marker-horizons. The nomenclature of Fuller (1956) was adopted with slight modification by the Saskatchewan Geological Society in 1956, with the Frobisher-Alida bed as one of the divisions. The term "bed" was replaced with "interval" by Smith (1960).

Harris and others (1966) further subdivided the Frobisher-Alida interval, called the upper Mission Canyon Formation in the study area, into six beds based upon six cyclic sedimentary units that they mapped (Fig. 4). The cycles were separated by thin, clastic-rich, markerbeds which were persistent and cross-cut lithologies. These marker beds are, in ascending order: Landa, K-3, K-2, K-1, Sherwood Argillaceous, and State A. Harris and others (1966) considered these clastic-rich

Figure 4: Southwest-northeast schematic section demonstrating the argillaceous markers cross-cutting the evaporite and carbonate lithologies in north-central North Dakota. The arrow indicates the position that the Wiley Field reservoir would occupy in the Glenburn bed in this schematic diagram (modified from Harris and others, 1966).



MISSION CANYON FACIES RELATIONSHIPS
IN NORTH CENTRAL NORTH DAKOTA

marker beds to be reliable time-stratigraphic markers in the upper Mission Canyon succession. The six cyclic units or "beds", were named after hydrocarbon-producing fields in north-central North Dakota, and in ascending order are Landa, Wayne, Glenburn, Mohall, Sherwood, and Bluell beds (Fig. 4). A more thorough review of Frobisher-Alida interval nomenclature can be found in Shanley (1983) and Obelenus (1985).

In this study, subsurface terminology of the North Dakota Geological Survey (Bluemle and others, 1980), and Harris and others (1966) is used (Fig. 5). The position of the boundary between the Mission Canyon and Charles Formations is placed at the base of the lowest evaporite deposit (Edie, 1958), which lies in the lower half of the Frobisher-Alida interval within the study area. The top of the Frobisher-Alida interval is placed at the base of the State 'A' marker (Shanley, 1983).

Nearly all cores studied are Mission Canyon Formation carbonates from the Glenburn bed defined by Harris and others (1966), with minor additions from the underlying Wayne bed. Lesser amounts of Charles Formation core from the Glenburn and overlying Mohall beds were also studied. Cored intervals studied ranged from 47 ft (14 m) above to 54 ft (16.5 m) below the Mission Canyon and Charles Formation contact; the upper 30 ft (9 m) of Mission Canyon Formation rocks were the primary interval of interest.

Previous Works

Many workers have studied the Mississippian rocks of the Williston Basin. Shanley (1983) and Obelenus (1985) discuss previous

Figure 5: Stratigraphic nomenclature of the Madison Group (Mississippian) which has been proposed by various writers.

SLOSS & MORITZ 1951	THOMAS 1954	SASKATCHEWAN GEOLOGICAL SOCIETY 1956	(NDGS) SMITH 1960	HARRIS LAND MC KEEVER 1966	SHANLEY 1983	THIS REPORT STUDY AREA ONLY
CHARLES FORMATION	CHARLES FORMATION	POPLAR BEDS	POPLAR INTERVAL	CHARLES FM.: (NOT DISCUSSED)	POPLAR INTERVAL	SPEARFISH FM. (TRIASSIC)
		RATCLIFFE BEDS	RATCLIFFE INTER. / MIDALE SUB-INT.	MIDALE LIMEST.	RATCLIFFE INTER. / MIDALE SUB-INT.	CHARLES FM. / RATCLIFFE INT.: MIDALE SUB-INT.
		MIDALE BEDS	RIVAL SUB-INTER.	RIVAL L.S. FROBISHER EVP.	RIVAL SUB-INT.	RIVAL SUB-INT.
				BLUELL BEDS / STATE 'A' MARKER	STATE 'A' MARKER	STATE 'A' MARKER
MISSION CANYON FORMATION	MC-5	FROBISHER-ALIDA BEDS	FROBISHER-ALIDA BEDS	U. MISSION CANYON FM.: SHER- SHER. ARG. MAR.	FROBISHER-ALIDA INTERVAL: BLUELL	FROBISHER-ALIDA INTER.: BLUELL BED / S.A.M.
	MC-4			WOOD BEDS	SHERWOOD	SHERWOOD BED / K-1
				MOHALL BEDS / K-1 MARKER	MOHALL	MOHALL BED / K-2
	MC-3			GLEN-BURN BEDS / K-2 MARKER	GLENBURN	GLENBURN BED / K-3
				WAYNE BEDS / K-3 MARKER		WAYNE BED
				LANDA BEDS / LANDA MAR.		
	MC-2	TILSTON BEDS	TILSTON INTERVAL	MC-2 EVAPOR. / LOWER MISSION CANYON FORMATION	TILSTON INTERVAL	MISSION CANYON FM.: TILSTON INTERVAL
	MC-1					
LODGEPOLE FORMATION	LODGEPOLE FORMATION	SOURIS VALLEY BEDS	BOTTINEAU INTERVAL	LODGEPOLE FORMATION	BOTTINEAU INTERVAL	L. FM.: BOTTINEAU INTERVAL

MADISON GROUP (MISS.)

basinwide studies in considerable detail. Works of interest to this study are restricted to descriptions of rock types found in the Frobisher-Alida interval in north-central North Dakota.

Lithologies in the study area have generally been described as cyclic and regressive in nature. Harris and others (1966) recognized four major rock types which they described as occurring in each of six shoaling upward cycles (Fig. 4). Obelenus (1985) described rocks in the study area as regressive, and suggested that vertical and lateral variations of rocks resulted from lateral migration and progradation of a complex "digitate shoreline" rather than sea level fluctuations. He suggested that deposition in the study area was in a tidal flat, clastic-rich sabkha, and salt pan setting.

Shanley (1983) recognized twelve distinct lithofacies which he interpreted to represent deposition in a microtidal shelf and peritidal environment marginal to an arid sabkha and evaporitic, hypersaline lagoon-coastal plain. Shanley described sedimentation as not strictly cyclic and as punctuated by eolian deposition (marker beds) during several sea level "stillstands".

LeFever and Anderson (1986) in a wireline log study of the Frobisher-Alida interval, covering an area which includes the Wiley Field, discussed structural characteristics of the area and mapped distribution of carbonates, anhydrite plugged-carbonates, and anhydrite. A channel-like feature was also mapped approximately 15 mi (24 km) northwest of Wiley Field. They interpreted several local structural features to be a result of dissolution of the underlying Devonian Prairie salt. The dissolution of the Prairie salt was suspected to have been caused by movement along the Superior-Churchill province boundary. This movement is interpreted by LeFever and Anderson (1986) to have allowed fluid migration into the Prairie salt, which caused dissolution of the salt beginning in the Devonian and continuing into the present time.

Bickford and others (1986) present a map that illustrates the region lying between the Precambrian Superior craton (on the east) and Wyoming craton (on the west), which they interpret to be the Trans-Hudson orogen (THO). The THO has been considered the Churchill province until recently. The eastern boundary of the THO roughly parallels the 100.5 degree longitudinal line, and the western boundary roughly coincides with the western border of North Dakota (approximately 104 degree longitudinal line). The Wiley field is located above the THO belt, approximately one degree west of the eastern margin.

In addition to the aforementioned regional studies, a number of smaller studies of hydrocarbon-producing fields have been completed. Elliot (1982), in an excellent study of the Haas Field (Glenburn bed) noted two main depositional facies. A cyclic coated-grain facies, located on the downdip (basinward) margin of the field, and a peloidal, intraclastic facies located in the updip part of the field. He discusses shoaling-upward cycles which are interpreted to have restricted water circulation periodically, and formed evaporitic dolomite "marker beds" landward of the shoals. Elliot (1982) interpreted the Haas Field reservoir to be a product largely of late, burial diagenesis rather than near-surface processes.

Gerhard (1985), in a study of the Glenburn Field (Glenburn bed), recognized three forms of anhydrite, two forms of dolomite, and three forms of limestone. The limestone forms are: 1) skeletal pisolitic wackestone; 2) mudstone, and; 3) pisolitic packstone or grainstone. Gerhard (1985) interpreted the carbonate fabrics to represent deposition of carbonate-mud-rich sediments in a shallow transgressive sea, followed by regression and exposure of topographic highs. Subaerial diagenesis of the exposed carbonates was interpreted to have formed a major portion of the grains and fabrics found. Evaporites represented penecontemporaneous deposition in adjacent topographic lows during exposure of carbonate topographic highs. Gerhard (1985) stated that the lithology, porosity, and hydrocarbon trapping mechanisms in the Wiley Field were similar to those at the Glenburn Field.

Another interpretation of deposition at Glenburn Field is presented by Fischer and others (1984), who described deposition as taking place in a shallow sea with numerous shoals acting as baffles to restrict water circulation. This baffle effect allowed precipitation of evaporites leeward of the shoals while coated grains were forming in the higher-energy environment of the shoals themselves. Storm transport of coated grains from shoals into adjacent, low-energy intershoal lows, resulted in a mud-rich wackestone lithology. Fischer and others (1984) interpreted conditions to be more restricted in the north, and more open marine in the southern part of the Glenburn Field.

Luther and Quinn (1985), in a core and wireline log study covering a narrow area between Wiley Field and the Donnybrook Field to the southwest (downdip), described the uniform and widespread nature of the marker beds as they cross-cut several lithofacies. Structural features were uniformly superimposed from lower through upper marker beds, and a similar structural pattern was seen on the Madison Group top (Mesozoic unconformity). Luther and Quinn (1985) interpreted the uniform nature of the marker beds to represent eolian deposition on a very low-relief surface, with structural deformation after deposition on the Mesozoic unconformity surface.

Quinn (1986), in a study of the Frobisher-Alida interval (Sherwood and Bluell) beds), which covered four townships southwest of the Wiley Field, recognized six lithotypes. They include: 1) pisoid-ooid-intraclast wackestone to packstone; 2) mudstone to stromatolite boundstone; 3) massive anhydrite; 4) argillaceous silty dolomudstone; 5) ooid grainstone; and 6) sandy carbonates. He found that lithotypes within individual beds form bands parallel to regional strike. The lithofacies were interpreted to represent deposition on an arid, peritidal carbonate buildup, bordered by a restricted sea basinward, and a shallow, evaporite-precipitating lagoon landward (northeast).

Quinn (1986) interpreted the argillaceous marker beds in his study area to represent progradation of an eolian "continental"- type sabkha which was deposited during a basin-wide sea-level drop. He considered the marker beds in the study area to be "quasi-lithochronozones".

Methods

Preliminary work consisted of examination of wireline logs (on file with the North Dakota Geological Survey) of wells drilled within the study area (Fig. 6 and Appendix A), picking formation tops, intervals, and beds based on the log response (Fig. 7 and Appendix B),

Figure 6: Map showing location and North Dakota Geological Survey (NDGS) numbers for wells in the study area (modified from NDGS Field Map A-8).

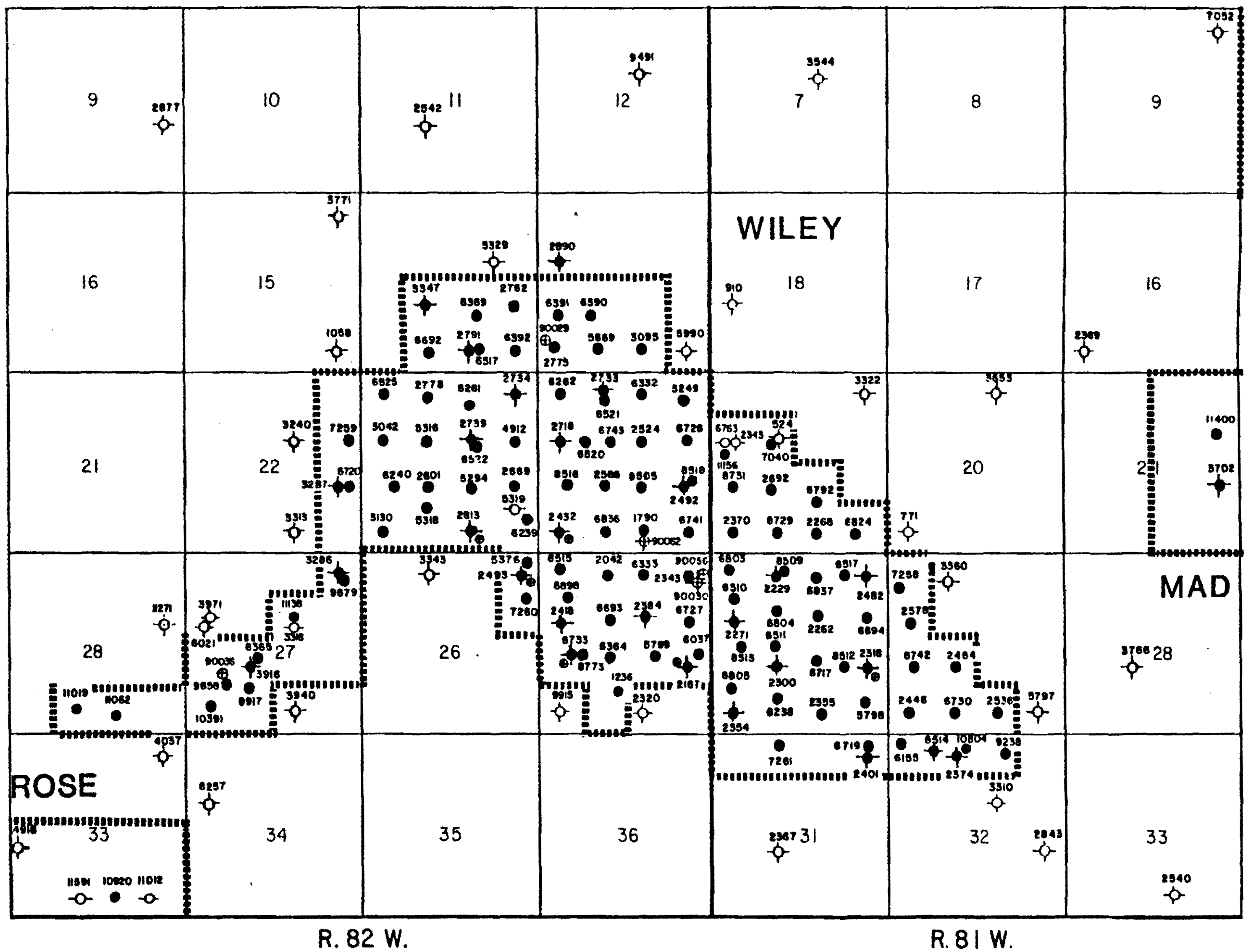
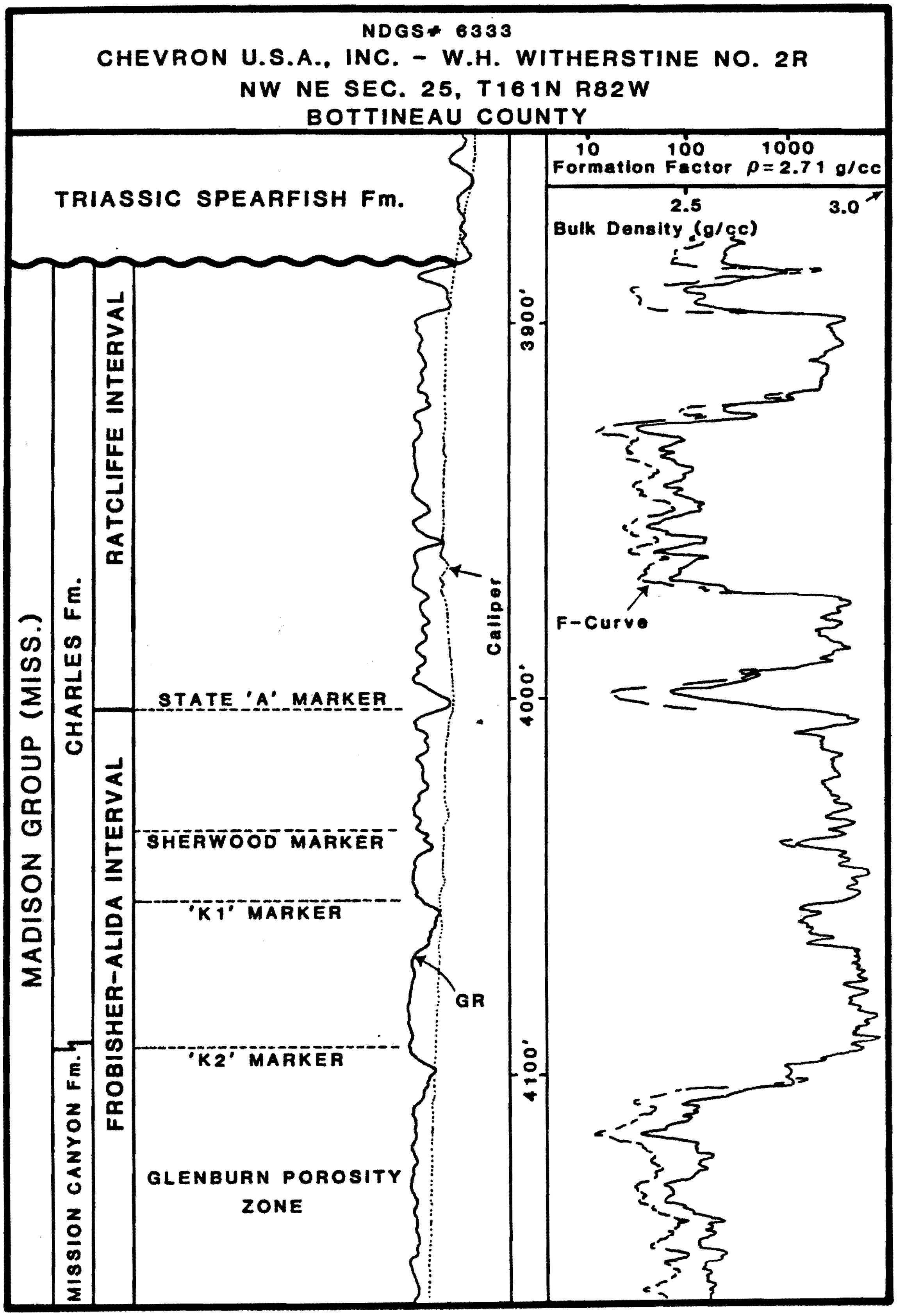

WILEY
MAD
ROSE
R. 82 W.
R. 81 W.

Figure 7: An example of a gamma ray (GR) and density log that illustrates the characteristic log response to the formations, marker beds, and porosity zones in the study area.

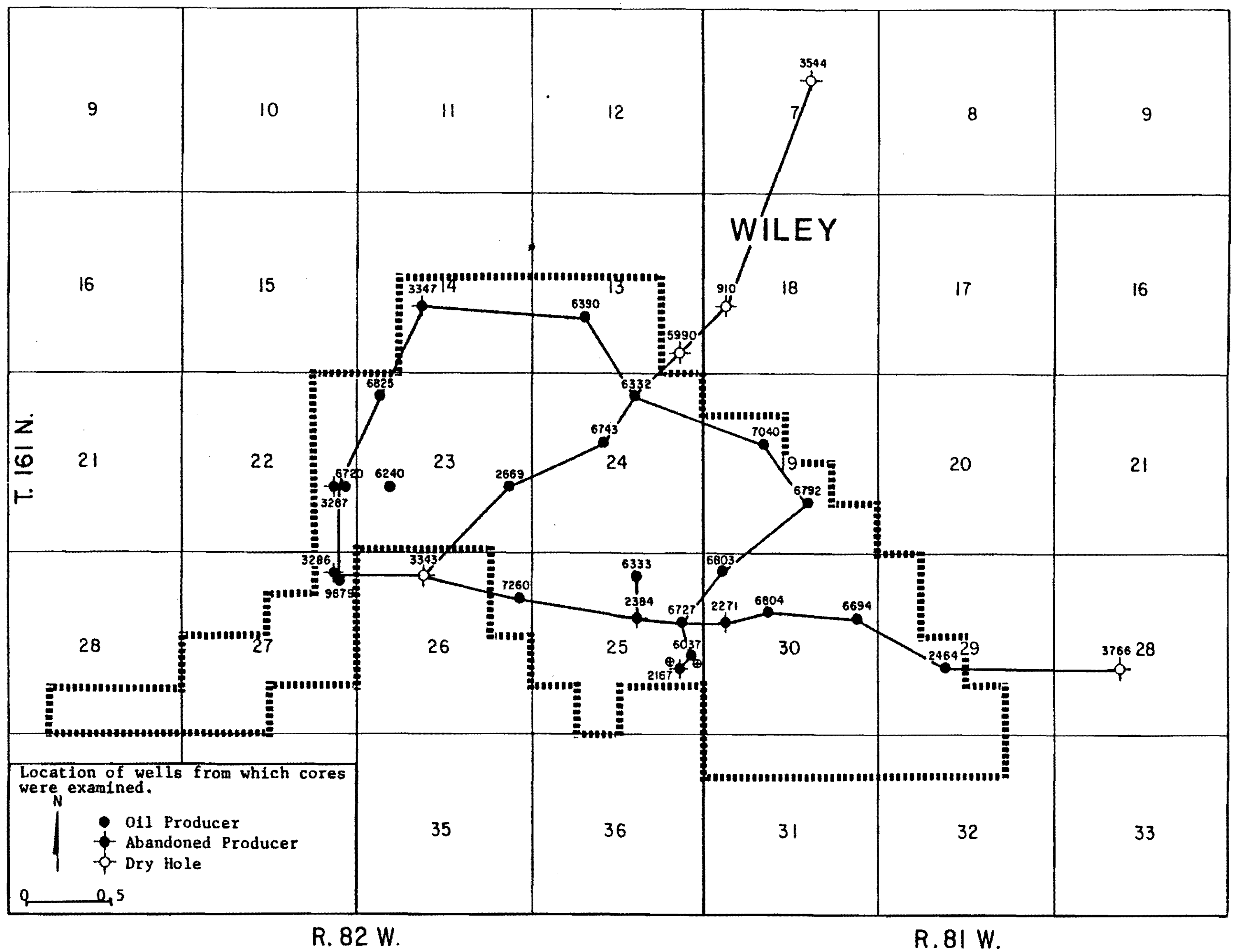

NDGS# 6333
CHEVRON U.S.A., INC. - W.H. WITHERSTINE NO. 2R
NW NE SEC. 25, T161N R82W
BOTTINEAU COUNTY
TRIASSIC SPEARFISH Fm.
MADISON GROUP (MISS.)
CHARLES Fm.
MISSION CANYON Fm.
RATCLIFFE INTERVAL
FROBISHER-ALIDA INTERVAL
STATE 'A' MARKER
SHERWOOD MARKER
'K1' MARKER
'K2' MARKER
GLENBURN POROSITY ZONE
Caliper
GR
3900'
4000'
4100'
10
100
1000
Formation Factor ρ=2.71 g/cc
2.5
3.0
Bulk Density (g/cc)
F-Curve

and constructing various maps based on this information. Selection of cored wells used (Fig. 8) for detailed lithologic description was based on several characteristics, including the amount of difference between drillers and loggers depth for the well, proximity to, and spacing along desired cross-section lines, and a cored interval which included the upper 30 ft (9 m) of the Mission Canyon Formation. Description of the upper 30 ft (9 m) of carbonates was emphasized because the majority of cored wells in the field contained core from that interval. This was supplemented by descriptions of the upper 54 ft (16.5 m) of the Mission Canyon Formation in places along five cross sections (Fig. 8). Due to their exceptionally close spacing, eight wells in an area less than 1 sq mi (1.6 sq km) in the south-central portion of the Wiley Field (Fig. 8), were described in detail in an attempt to document very localized lithologic variation.

Cores described in this study are permanently stored in the Wilson M. Laird Core and Sample Library, operated by the North Dakota Geological Survey, and located on the University of North Dakota campus. Approximately 1070 ft (327 m) of core from a total of twenty-nine wells within the study area were described (Fig. 8 and Appendix C).

Nearly all cores were slabbed and polished with 400 grit, before examination with a reflected light microscope and hand lens. Distinction between limestone, dolostone, and evaporites in slabbed cores was based in part on the observed reaction of dilute HCl (10%) applied to the core surface. Photographed core slabs were polished with 600 grit and coated with a 50:50 mixture of glycerin and water. Porosity was visually estimated.

Figure 8: A map showing wells from which cores were described, and their position within and adjacent to the Wiley Field.


WILEY
T. 161 N.
R. 82 W.
R. 81 W.
9
10
11
12
7
8
9
16
15
14
13
18
17
16
21
22
23
24
19
20
21
28
27
26
25
30
29
28
35
36
31
32
33
3544
910
5990
3347
6390
6332
6825
6743
7040
6720
6240
2669
6792
3287
3286
3343
9679
7260
6333
6803
2384
6727
2271
6804
6694
6037
2167
2464
3766
Location of wells from which cores were examined.
N
Oil Producer
Abandoned Producer
Dry Hole
0
0.5

Small slabs, approximately 1 in. x 2 in. (2.5 cm x 5 cm) in size, were cut from the described and photographed core slabs for the preparation of 227 thin sections. Thin sections were stained to differentiate between calcite and dolomite, using alizarin red-S (Friedman, 1959) on approximately one-third of each slide. The thin sections were examined using a polarizing microscope, microfiche reader, and JEOL 35C Scanning Electron Microscope/Microprobe. All thin sections and core slabs were described using the classification system of Dunham (1962) with modifiers (Appendix C).

Additionally, a portion of several feet of core from one well (NDGS #3343), was dissolved with dilute acetic acid (10%) to recover organic floral and faunal elements (Appendix D). The SEM/Microprobe was used to photograph a high resolution image of these elements and other samples, and also for qualitative and quantitative geochemical analysis. A Phillips x-ray diffractometer was also utilized for mineralogical analysis of some samples.

Both English and metric units are used in this study. Conventional units that are most widely used for a specific purpose are employed. For example, footage is used for descriptions of cores which are marked in feet below the Kelly bushing. When appropriate, the corresponding converted value (either metric or English) is given in parentheses.

Structure

Mapping of structure within the study area is based on interpretation of wireline logs, with some supplementation by core descriptions. Numerous marker beds can be recognized, and gross lithology can be interpreted from the log response (Fig. 7). Both formation tops and markers are frequently mapped in the Williston Basin.

Due to its widespread, uniform and persistent nature, the State 'A' marker is commonly mapped in the basin. A structural map based on the subsea elevation of the State 'A' marker (Fig. 9), illustrates several points. First, regional structure dominates the attitude of beds in the study area, which dip southwest (basinward) less than 1 degree. Second, the Wiley Field is located on a weak structural nose that has several small folds which are oriented parallel to regional dip. Third, relatively sudden changes in elevation, such as in the SE 1/4 of section 22, T161N, R82W, indicate possible faulting.

The K-2 marker, which forms the top of the Glenburn bed (Fig. 4), lies approximately 100 ft (30.5 m) below the State 'A' marker within the study area. A structure map of the top of the K-2 marker (Fig. 10) illustrates relief virtually identical to that of the overlying State 'A' marker.

This nearly identical relief indicates no major lithostratigraphic thickening or thinning in the upper Frobisher-Alida interval within the study area. The abrupt change in elevation seen in section 22 on the State 'A' structure map (Fig. 9) can also be seen on the K-2 structure map. If faulting is the cause for this abrupt elevation change, it uniformly affected the studied section, and occurred after deposition of the State 'A' marker. In fact, structure maps of the top of the Madison Group (Mesozoic unconformity) show this same abrupt elevation change. This may indicate post-Mississippian faulting; LeFever and Anderson (1986) also presented maps on which they indicate faulting in the study area.

Figure 9: A structure map of the top of the State 'A' marker bed in the study area.

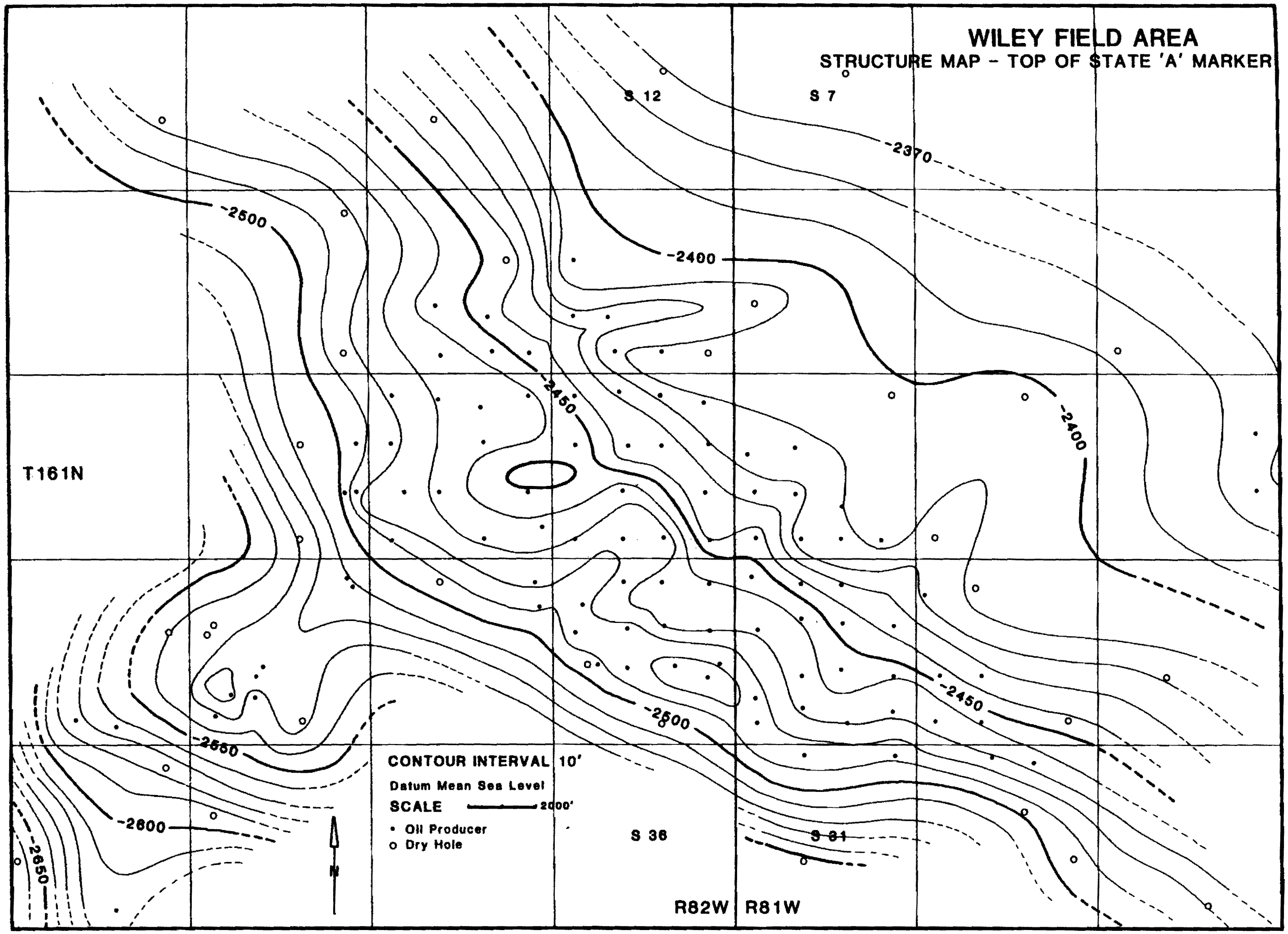
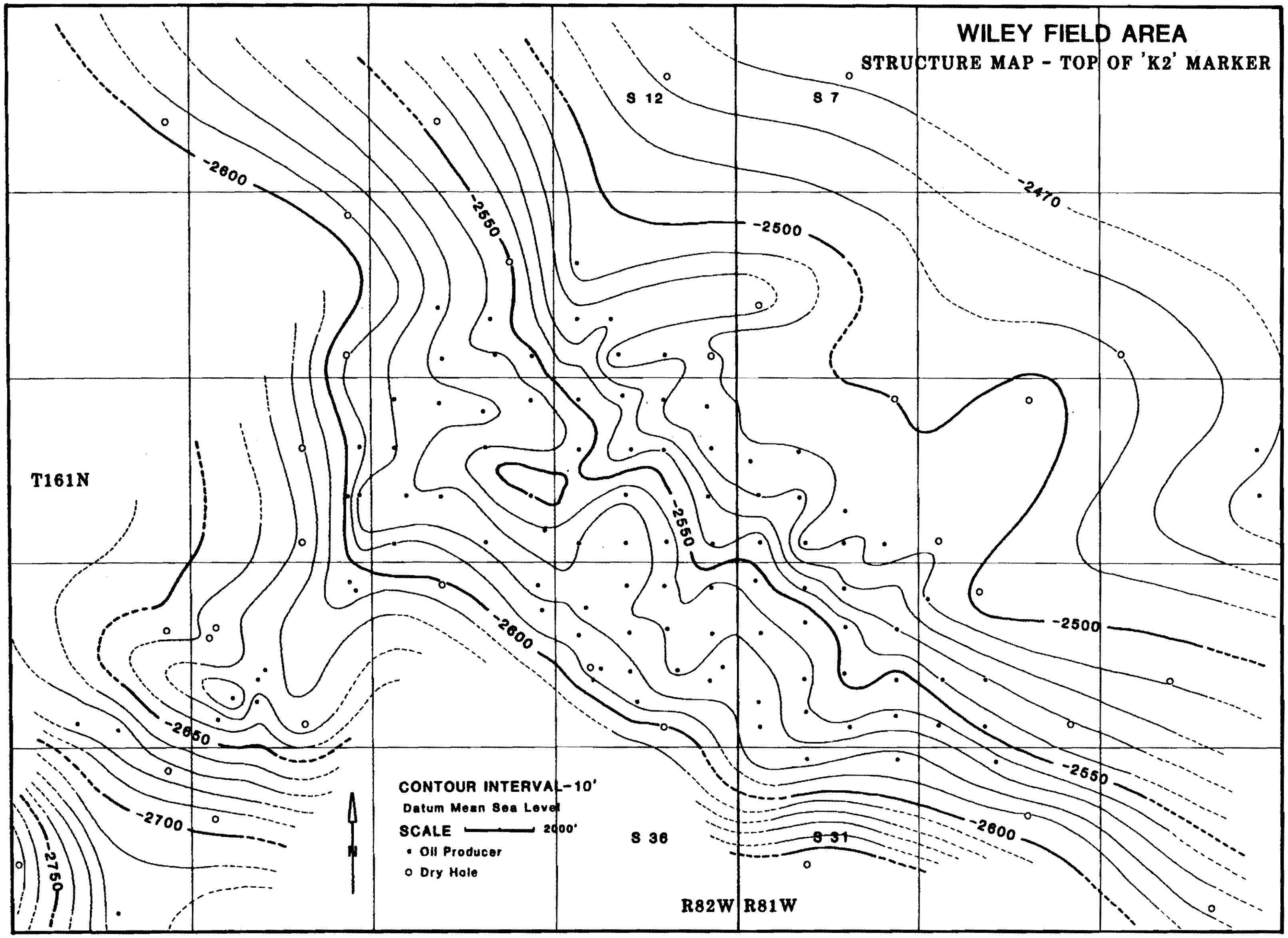

WILEY FIELD AREA
STRUCTURE MAP - TOP OF STATE 'A' MARKER
S 12
S 7
-2370
-2500
-2400
-2450
-2400
T161N
-2450
-2500
-2550
CONTOUR INTERVAL 10'
Datum Mean Sea Level
SCALE 2000'
• Oil Producer
○ Dry Hole
-2600
-2650
S 36
S 31
N
R82W R81W

Figure 10: A structure map of the top of the K-2 marker bed (Kisbey sandstone) in the study area.

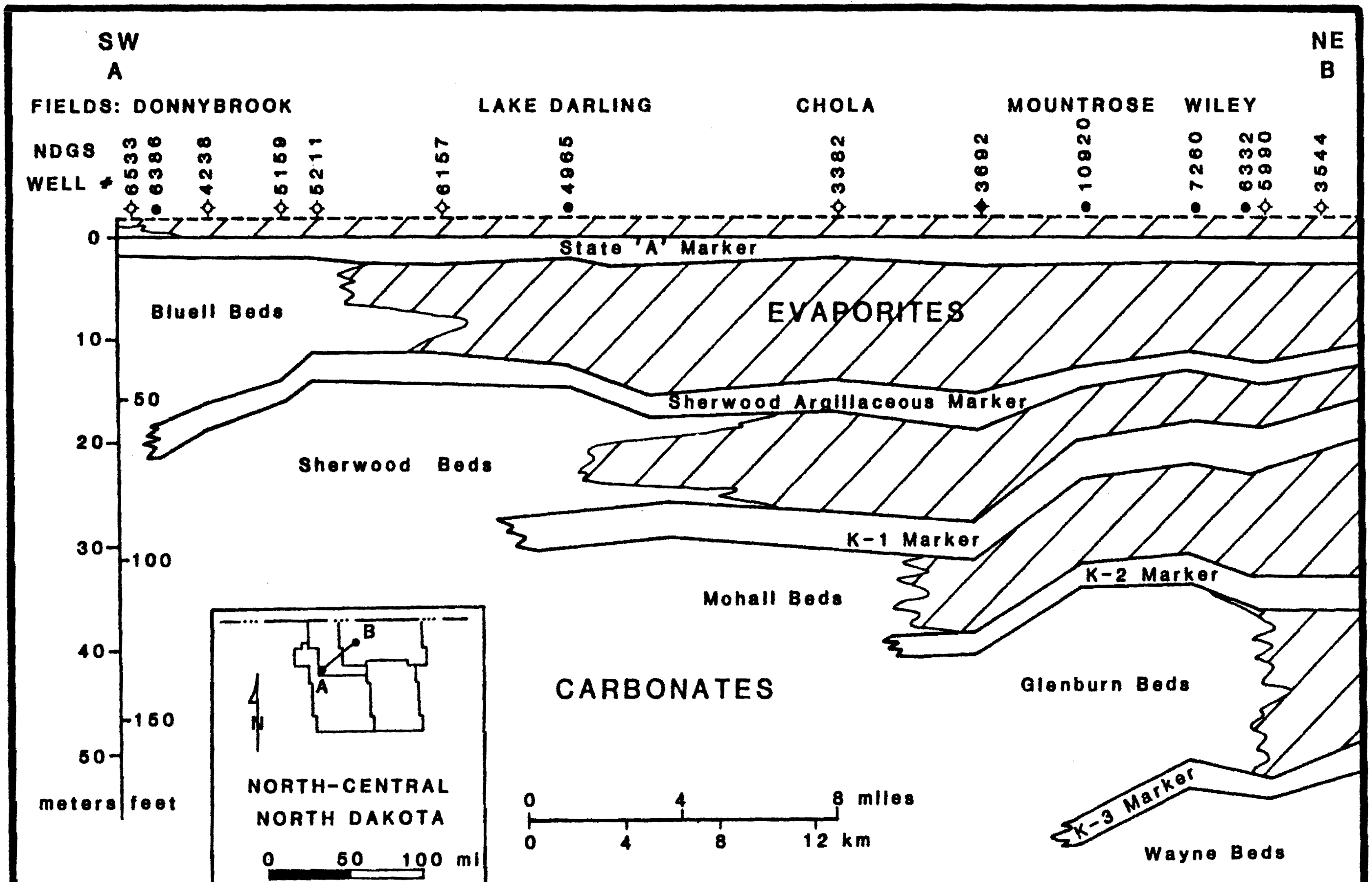

WILEY FIELD AREA
STRUCTURE MAP - TOP OF 'K2' MARKER
S 12
S 7
-2470
-2600
-2550
-2500
T161N
-2550
-2600
-2500
-2650
-2550
-2700
-2600
-2750
CONTOUR INTERVAL-10'
Datum Mean Sea Level
SCALE 2000'
• Oil Producer
○ Dry Hole
N
S 36
S 31
R82W R81W

Evidence indicating that very little structural development took place during deposition of the Frobisher-Alida interval, can be seen in a cross-section (Fig. 11) extending from near the Wayne Field (northeast) to the Donnybrook Field (southwest). The most obvious structural development, the subtly steeper dip of marker beds in descending order, is probably the result of greater subsidence towards the basin center (southwest).

Local, minor structural development may be a result of faulting in some cases, but differential compaction is also a probable cause. The transition from gypsum to anhydrite is characterized by a 38% volume decrease (Blatt, Middleton, and Murray, 1980, p.547) in addition to the volume decrease due to the reduction of primary porosity. Differential compaction, or rates of compaction, between cemented carbonates and evaporites may explain minor thickness changes in overlying deposits in the study area and may result in stress fractures where lithology changes laterally. In fact, most fractures observed in cores from the study area came from core that was taken near the carbonate/evaporite lateral contact.

Also illustrated in Figure 11 is the extremely uniform and widespread nature of the marker beds. Deposition of such uniformly thin markers was presumably as nearly horizontal sheets on a very low-relief surface. If surface relief of a few meters or greater was present during deposition there would probably be anomalous thick and thin sections associated with topographic lows and highs respectively. The less than 1 degree dip toward the basin center of the State 'A' marker at the present time, subsequent to millions of years of higher subsidence rates in the basin center, suggests that the markers were deposited on a nearly horizontal surface.

Figure 11: A southwest-northeast cross section illustrating the relative positions of the Charles Formation evaporites and Mission Canyon Formation carbonates. Cutting across the two formations are the informally named marker beds and porosity zones, shown extending in a down-dip direction from the Wiley Field (north-central North Dakota). The vertical exaggeration is 422X. Datum is the top of the State 'A' marker bed (from Luther and Quinn, 1985).



From Luther and Quinn (1985).

A structure map of the Frobisher-Alida interval carbonates (Mission Canyon Formation) illustrates the discrete nature of the carbonate body and the relation between hydrocarbon production and structural position (Fig. 12). Wells drilled off structure or in the interbedded anhydrite and impermeable carbonates (up-dip, lateral seal) do not produce hydrocarbons in commercial quantities.

Assuming that the State 'A' marker bed in the study area was deposited as a nearly horizontal sheet, measuring the distance between it and the underlying carbonate top allows one to construct a map that may approximate the carbonate surface prior to structural deformation (Fig. 13). Topographic highs and lows on the map may then represent the actual topographic relief in the area during deposition. Alternatively, this type of map may show areas of locally prolonged carbonate deposition, or differential compaction.

Interpretation of described cores indicate that the southwest half of this map (Fig. 13) approximates the actual topographic relief present during deposition of the Glenburn bed. The northeast half of the map may represent the surface of the Wayne bed (extreme northeast corner of the map) and the steeply-dipping contact between Glenburn bed carbonates and evaporites. Comparing the position of dry holes on Figure 13 with those of Figure 12 illustrates how important post-depositional structural deformation is to hydrocarbon production locally.

Figure 12: Structure map of the Mission Canyon Formation (Frobisher-Alida interval carbonates) in the study area, illustrating the position of hydrocarbon producing wells relative to local structure.

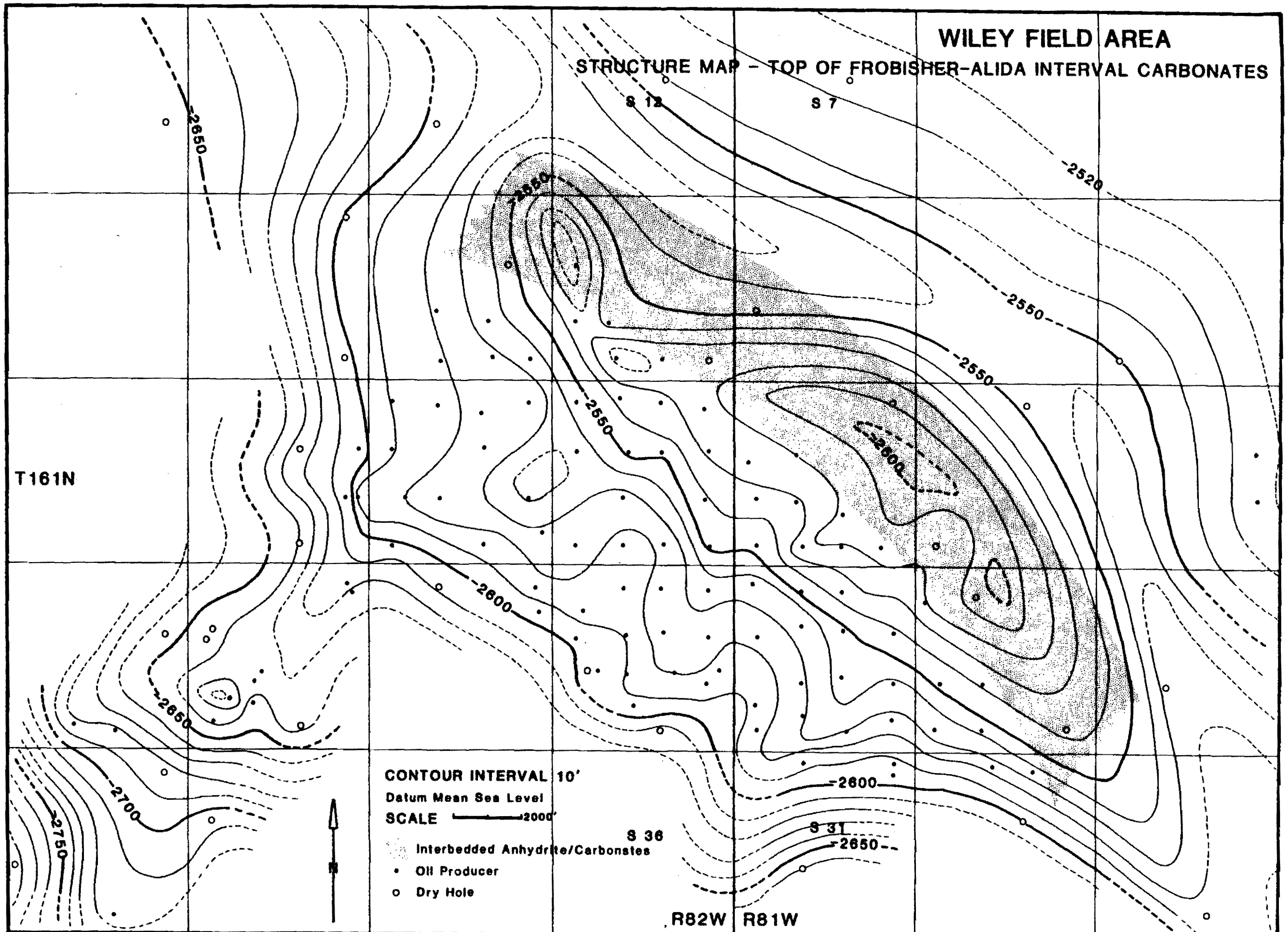
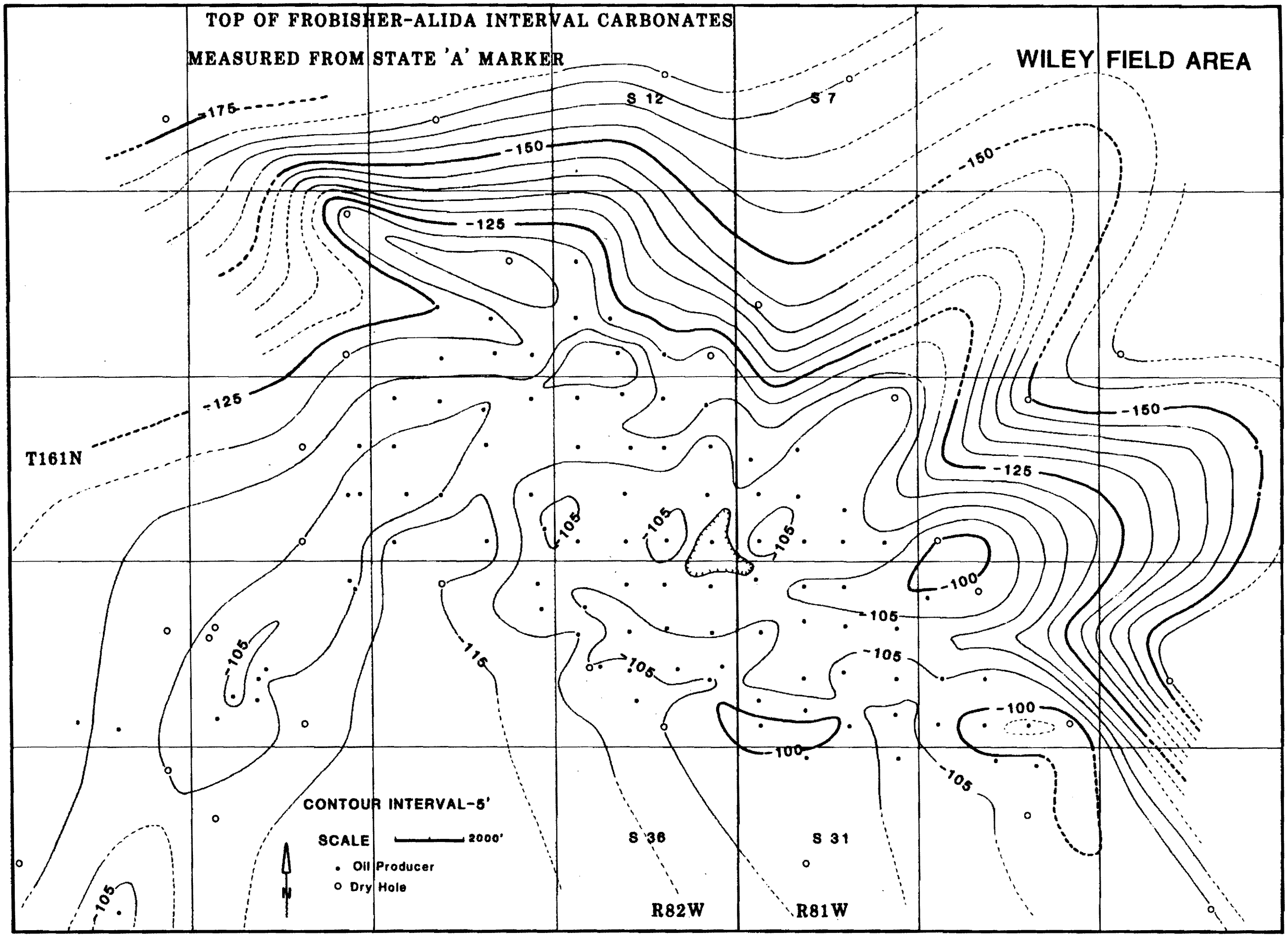

WILEY FIELD AREA
STRUCTURE MAP - TOP OF FROBISHER-ALIDA INTERVAL CARBONATES
S 12
S 7
-2520
-2550
-2550
-2550
-2560
-2600
-2650
-2650
-2600
-2650
-2700
-2750
-2600
-2650
T161N
S 36
S 31
R82W
R81W
CONTOUR INTERVAL 10'
Datum Mean Sea Level
SCALE 2000'
N
Interbedded Anhydrite/Carbonates
Oil Producer
Dry Hole

Figure 13: A map of the study area showing the depth below the State 'A' marker of the Mission Canyon Formation (Frobisher-Alida interval carbonates). This map may approximate topographic relief during the latter stages of carbonate deposition. Anomalous low areas in the north and northeast portion of the map represent areas dominated by sulfate precipitation during deposition of the Glenburn bed.


TOP OF FROBISHER-ALIDA INTERVAL CARBONATES
MEASURED FROM STATE 'A' MARKER
WILEY FIELD AREA
S 12
S 7
-175
-150
-125
-150
-125
-150
-125
T161N
-105
-105
-105
-100
-105
-105
-105
-115
-105
-100
-100
-105
-105
CONTOUR INTERVAL-5'
SCALE
2000'
Oil Producer
Dry Hole
N
S 36
S 31
R82W
R81W

PETROGRAPHIC DESCRIPTIONS

Introduction

Carbonate allochems, and both carbonate and sulfate orthochems, form the majority of rock components found in the study area. Depositional environment interpretations are based on types, quantities, locations and fabrics of these components.

Folk (1959) named discrete particles (grains) formed within the basin of deposition allochems, and any normal precipitate formed within the basin of deposition orthochems. Nine allochem types occur in the study area: 1) peloids, 2) intraclasts, 3) composite-coated grains, 4) fossils, 5) radially-fibrous ooids, 6) micritic-coated grains, 7) oncoids, 8) spherulites and 9) radially-fibrous pisoids. Orthochems include microcrystalline ooze (micrite) and sulfates, which form the matrix of most rocks in the study area, as well as sparry calcite, sulfates, and silicates which form cements. Cements will be discussed in the diagenesis chapter.

Of the 227 thin-sections examined, 163 contained recognizable carbonate grains whose presence and sizes (minimum, maximum, and average) were entered in a computer in spreadsheet form. The results are given in Table 1. In addition, the average size and relative percent of each type of carbonate grain found is illustrated for thin-sections from lithofacies 1-4 (Table 1).

Allochems

Peloids

Peloids are considered to be any round to subround, structureless micritic grain (Fig. 14) ranging in size from approximately 0.03 mm up to 0.15 mm in diameter. Peloids are the most common grain type in the

Table 1: Allochem types, average sizes, and frequency of occurrence.

TABLE I - Allochem Types, Average Sizes, and Frequency of Occurrence

ALLOCHEM TYPES	PELOID	INTRA	C.C.G.	R.F.O.	R.F.P.	SPHER.	M.C.G.	ONCOID	FOSS.
PERCENTAGE OF OCCURRENCES OVERALL AREA WIDE	85	75	50	23	2	3	19	6	34
% OF OCCURRENCES WITHIN LF-1	53	60	47	0	0	0	40	13	80
% OF OCCURRENCES WITHIN LF-2	82	59	59	39	3	5	25	3	28
% OF OCCURRENCES WITHIN LF-3	92	87	43	17	1	3	12	10	29
% OF OCCURRENCES WITHIN LF-4	100	93	43	14	0	0	0	0	29
AVERAGE SIZE (mm) OVERALL (Area wide)	0.095	0.47	1.13	0.56	3.17	0.12	0.9	1.28	0.41
AVERAGE SIZE WITHIN LF-1	0.091	0.28	0.5	-	-	-	0.83	0.75	1.45
AVERAGE SIZE WITHIN LF-2	0.076	0.47	1.39	0.52	3.5	0.14	0.84	0.75	0.094
AVERAGE SIZE WITHIN LF-3	0.11	0.5	1.04	0.7	2.5	0.09	1.07	1.58	0.1
AVERAGE SIZE WITHIN LF-4	0.11	0.46	0.68	0.2	-	-	-	-	0.26

Key to abbreviations: INTRA = Intraclast ; C.C.G. = Compound-coated grain ; R.F.O. = Radially-fibrous ooid ; R.F.P. = Radially-fibrous pisoid ; SPHER. = Spherulite ; M.C.G. = Micritic-coated grain ; FOSS. = Fossil fragment

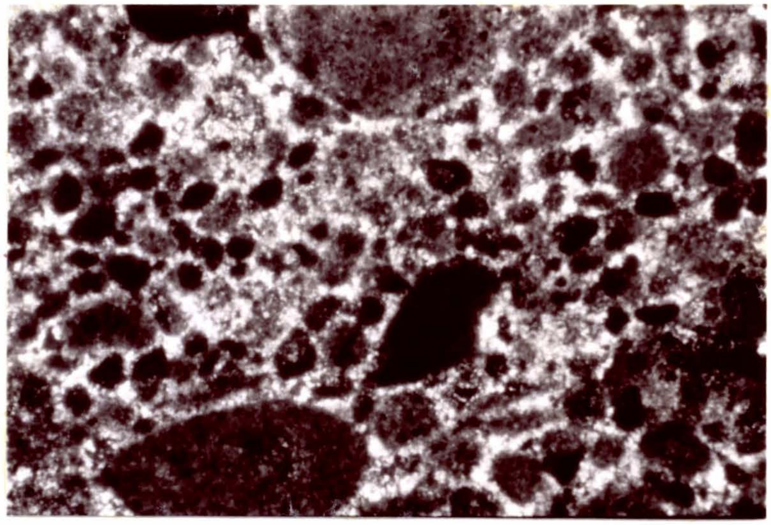


Figure 14: Peloids (small allochems) and intraclasts (largest allochems) in a dolopackstone-grainstone. NDGS# 6803, depth 4089.5 ft, field of view is 1.8 mm wide, plane-polarized light (PP).

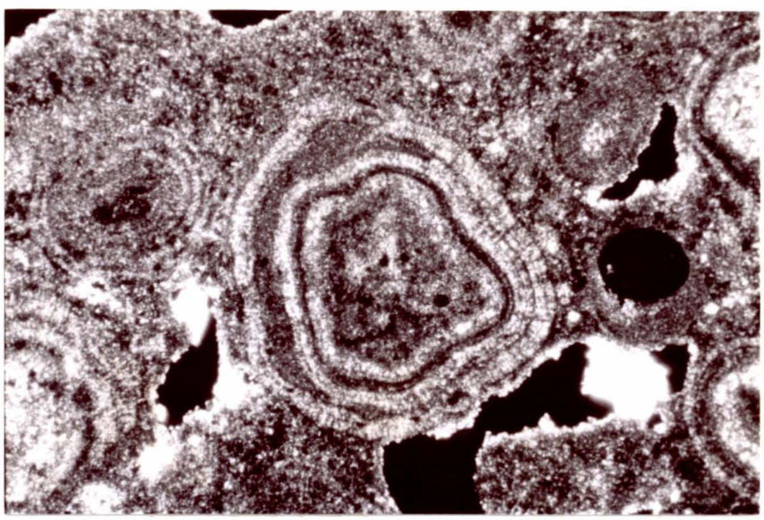


Figure 15): A compound-coated grain (center) showing the characteristic micritic (dark) and radially-fibrous (light) laminations. Notice the irregular shape of the grain and uneven thicknesses of the laminations. NDGS# 7260, depth 4156.8 ft, field of view is 1.8 mm wide, cross-polarized light (XP).

study area and are present in 85 percent of 163 thin-sections containing recognizable carbonate grains (Table 1). Peloid size ranges from less than 0.03 mm up to 0.15 mm in diameter, but averages 0.1 mm in diameter. Peloids occur as matrix for larger grain types and also in well-sorted grainstones.

Intraclasts

Intraclasts are any piece of penecontemporaneous, weakly to well-cemented carbonate sediment, which has been torn up and redeposited by currents (Folk, 1980). In this study, grains which may be a result of brecciation and thus involve little or no transport, are considered to be intraclasts due to lack of sufficient evidence to the contrary. Intraclasts are the second most common grain type in the study area, and are present in 75 percent of the thin sections which contained recognizable carbonate grains (Table 1). Intraclast size ranges from 0.15 mm (cut-off point with peloids) up to 15 mm in longest dimension, but averages 0.5 mm in size.

Intraclasts are often gradational in size with peloids and are typically composed of micrite, or cemented micrite and peloids (Fig. 14). Intraclasts may also contain smaller intraclasts, fossils, or coated grains and are usually poorly to moderately sorted.

Coated grains

Coated grains in the study area were separated into six types based on size, laminae microtexture, number of laminae, and evidence of an organic origin. The types include: 1) compound-coated grain, 2) radially-fibrous ooid, 3) micritic-coated grain, 4) oncoid, 5) spherulite and 6) radially-fibrous pisoid. Ooids are less than 2 mm, and pisoids are greater than 2 mm and less than 10 mm in size (Peryt, 1983). Descriptions of the six types are given below.

Compound-coated grain: Compound-coated grains are typically round to subround, although broken and irregular shaped grains are frequently found (Fig. 15). They consist of two to tens of alternating micritic and radially fibrous concentric laminae (may include the superficial-coated grains of Simone, 1981). Micritic laminae frequently appear to have been dolomitized, with no visible effect on the adjacent radially-fibrous laminae. Laminae thickness is highly variable. Grain cores are often large, and are generally composed of peloids or intraclasts, and less frequently of other coated grains and fossils. Grains are poor to very well preserved. Compound-coated grains range in size from a minimum of 0.05 mm to a maximum of 11.5 mm. The average size is 1.13 mm (Table 1).

Compound-coated grains are the most common coated grain type and the third most common grain type overall, occurring in 50 percent of the thin sections (Table 1). Zones which contain abundant coated grains of pisoid size nearly always consist of compound-coated grains. Grains are generally poorly sorted and gradational from ooid to pisoid size, although bimodal sorting does occur.

Radially-fibrous ooid: Radially-fibrous ooids are typically spherical, with two to more than ten radially-fibrous, concentric laminations (Fig. 16). Cores are generally small to not visible at 30X magnification, and consist of peloids, small intraclasts, or infrequent fossils. Grains are infrequently broken and recoated. Laminae thickness is highly variable, but generally symmetrical.

Radially-fibrous ooids are present in 23 percent of the thin sections, and range from a minimum of 0.1 mm to a maximum of 2 mm

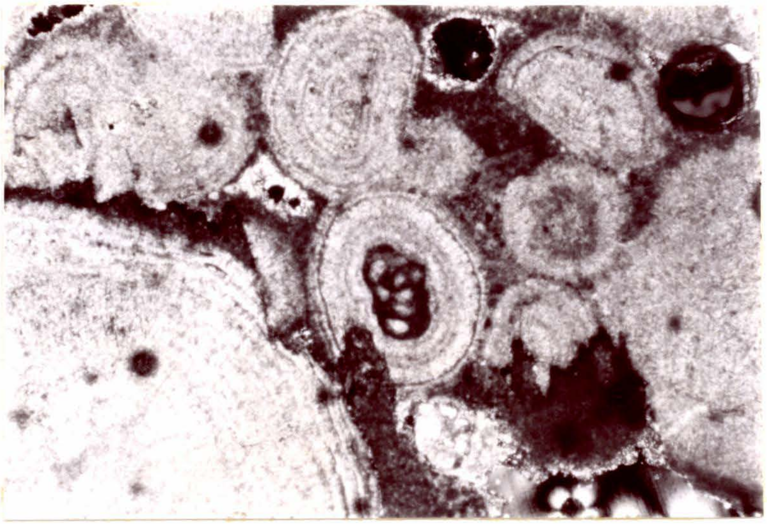


Figure 16: Radially-fibrous ooids (small) and a radially-fibrous pisoid (large grain in corner). Note the foram forming the the core of the ooid in the center, and the overpacked appearance of the sample. NDGS# 6720, depth 4170.4 ft, field of view is 2.6 mm, XP.

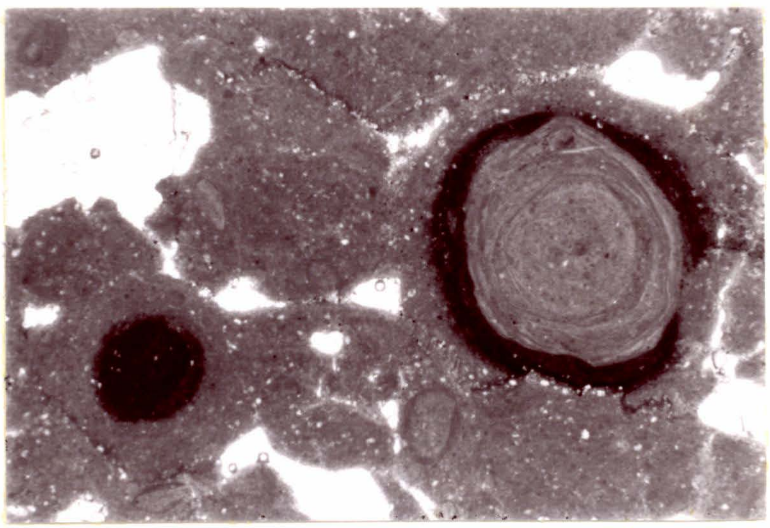


Figure 17: Micritic-coated grain with pyrite replaced laminae (dark bands). NDGS# 9679, depth 4214 ft, field of view is 3.7 mm, PP.

(cutoff with pisoids) in diameter. The average diameter is 0.56 mm (Table 1). Radially-fibrous ooids occur with other types of coated grains in poorly sorted deposits, but also occur as well-sorted, thin grainstone beds.

Micritic-coated grains: Micritic-coated grains are typically round to subround, with asymmetric to symmetrical, thin to thick laminations. A variety of lamination types sometimes occur in different grains within the same population. Grain cores may be micritic, or composed of peloids and small intraclasts. Grains do not appear to have been broken, although compaction has occurred. Individual laminae may contain, or be replaced by, pyrite (Fig. 17). Micritic-coated grains frequently occur with compound-coated grains, and nearly always occur with peloids and intraclasts in poorly sorted deposits.

Micritic-coated grains are present in 19 percent of the thin sections, and range in size from a minimum of 0.15 mm to a maximum of 8 mm. The average size is 0.9 mm in diameter (Table 1).

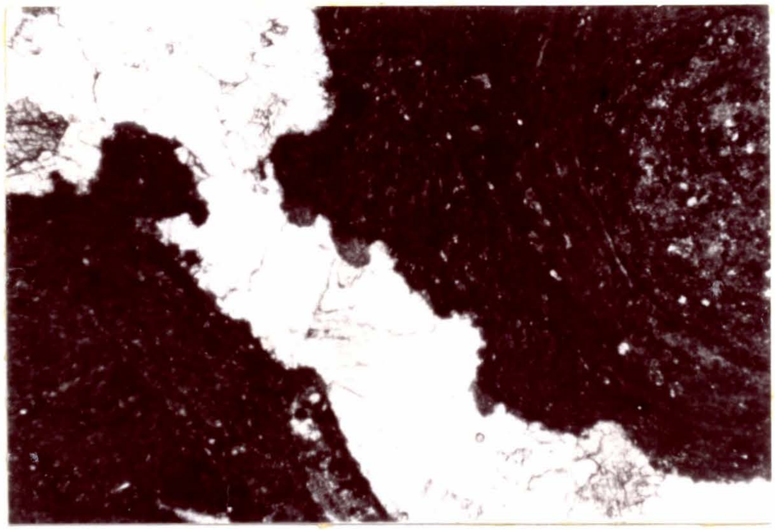
Oncoids: Coated grains which exhibit evidence of organic origin are here considered to be oncoids. Oncoids are typically round to subround, but elongate grains are also very common. Laminations are of variable thickness, often asymmetrical and discontinuous, and are typically micritic or dolomitized. Many Paleozoic oncoids were constructed by the genus Girvanella (Wray, 1977).

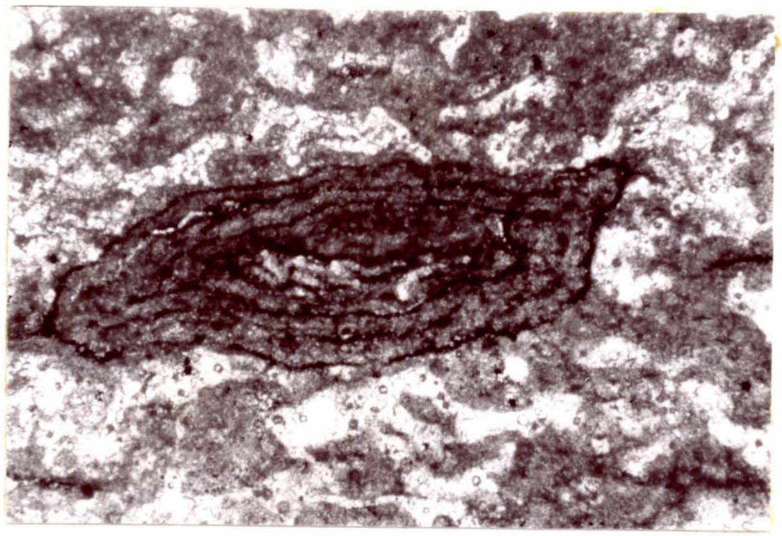
Interwoven Girvanella filaments form concentrically laminated grains (Fig. 18), or form bundles of interwoven filaments which may be mistaken for intraclasts if the filaments are not well preserved. Dolomitized oncoids do not contain preserved filaments, but are

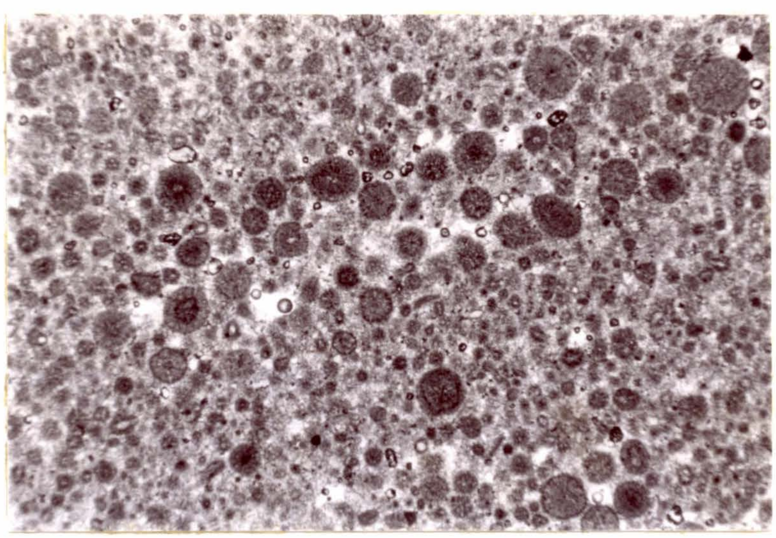
Figure 18: Portions of two oncoids showing the well preserved remains of the algae Girvanella. The light-colored area consists of blocky-calcite cement, filling interparticle pores. NDGS# 3343, depth 4172.5 ft, field of view 2.1 mm wide, PP.

Figure 19: Probable oncoid that has been compacted and dolomitized. NDGS# 6720, depth 4143.5 ft, field of view 3.2 mm wide, PP.

Figure 20: A grainstone composed of cross-bedded spherulites, with fibrous, isopachous-calcite interparticle cement. NDGS# 7260, depth 4142.6 ft, field of view 3.2 mm wide, PP.







considered oncoids due to the similarity of laminae in planar stromatolites to those of possible oncoids. The typically compacted appearance (Fig. 19) of the dolomitized oncoids is suggestive of early compaction of a soft, organic bound grain.

Oncoids generally occur with other fossils, peloids and intraclasts, and infrequently with other coated grains. Deposits are typically poorly sorted, although oncoid size is often fairly uniform. Oncoids are present in 6 percent of the thin sections and range in size from a minimum of 0.15 mm to a maximum of 3 mm. The average size is 1.28 mm (Table 1).

Spherulites: Spherulites (as used in this study) are radially-fibrous calcium carbonate grains which are similar to radially-fibrous ooids, but show no obvious evidence of a core or internal laminations (Fig. 20) (Obelenus, 1985, p. 70).

Spherulites occur with other coated grains, but are usually associated with radially-fibrous ooids. They occur in both poor- and well-sorted deposits, sometimes forming thin grainstone beds (Fig. 20). Spherulites are present in 3 percent of the thin sections and grain size ranges from a minimum of 0.03 mm to a maximum of 0.3 mm, with an average diameter of 0.12 mm (Table 1).

Radially-fibrous pisoids: Radially-fibrous pisoids are typically round to subround, made up of concentric, radially-fibrous laminations, are often broken and are sometimes recoated. Many grains contain internal fractures which are usually spar-filled. Cores are usually made of peloids or intraclasts, and sometimes fossils. Laminae thickness is variable, but usually symmetrical.

Radially-fibrous pisoids are found in 2 percent of the thin sections and range in size from a minimum of 2 mm (the cutoff point with ooids) to a maximum of 7 mm. The average diameter is 3.2 mm (Table 1). Radially-fibrous pisoids occur with other coated grains and peloids, and are usually gradational in size with radially-fibrous ooids (Fig. 16). Sorting is typically poor.

Fossils

The most common types of fossils in the study area include, in decreasing abundance, calcispheres, algae, and ostracods. These three types were widespread through most of the study area. Other, less common fossil types will be discussed in the description of the lithofacies in which they occur.

Calcispheres: In the study area, calcispheres are single- or double-walled with a smooth or spiny outer wall (Fig. 21). Preservation varies from poor to good. Hollow centers of the calcispheres are generally filled with fibrous spar, and their walls are composed of either spar or micrite.

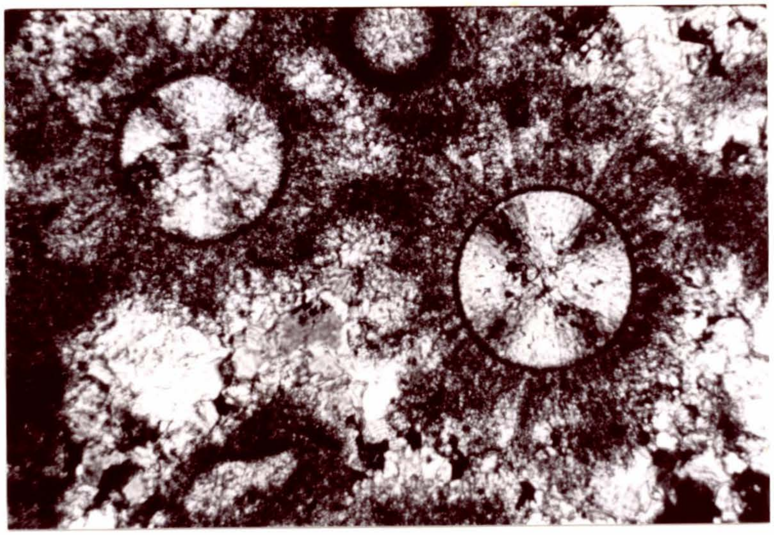
Calcispheres are found in approximately 30 percent of the thin sections containing recognizable carbonate grains. The small (0.03-0.2 mm), typically spherical fossils occur in poorly-sorted deposits, often with algae but also frequently associated with intraclasts and peloids. Calcispheres form wackestones which approach packstones in their density of packing.

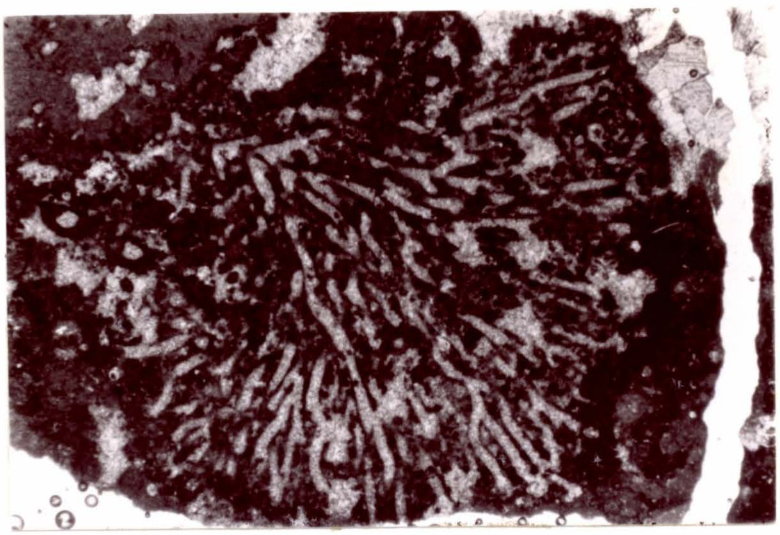
Algae: In the study area, the main algal group is the Cyanophyta (blue-green), which can be divided into skeletal and nonskeletal types. Two calcareous skeletal types have been identified in the study area, and consist of members of the genera *Ortonella* (Fig. 22)

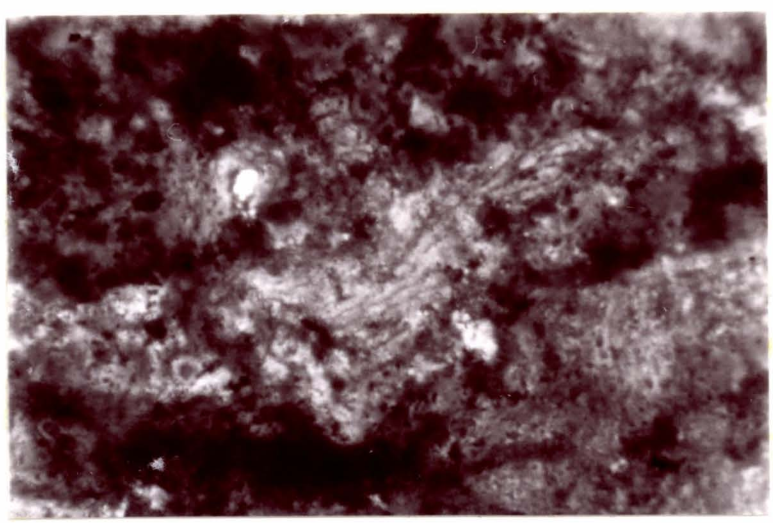
Figure 21: Calcispheres with fibrous/spiny outer covering and calcite filled centers. Note the dark cross formed in the center of the calcisphere by cross-polarized light. Calcite becomes more blocky toward the center of the calcisphere. NDGS# 2167, depth 4146.4 ft, field of view 0.65 mm wide, XP.

Figure 22: A good example of the algae Ortonella showing the characteristic forking of the calcareous tubules (now spar-filled). NDGS# 3343, depth 4167.8 ft, field of view 3.2 mm wide, up is toward the left (toward binding), PP.

Figure 23: A bundle of Girvanella tubules (calcite-filled), forming a grain which may easily be mistaken for an intraclast in core. NDGS# 6332, depth 4092 ft, field of view 1.3 mm wide, XP.







and Girvanella (Fig 23). The genus Hedstroemia (Wray, 1977) may also be present but was not positively identified.

Ortonella is a delicate, branching, tubiform algae type which forms subspherical nodules up to 3 mm in size, as well as irregular masses larger than 1 cm in width. The nodules often appear to have been transported due to their common orientation in other than growth positions. Ortonella is typically associated with numerous calcispheres and peloids, and lesser amounts of other fossil types and intraclasts. The hollow calcareous (usually micritic) tubes are always spar-filled, and are approximately 0.05 mm in diameter. Ortonella is typically well preserved.

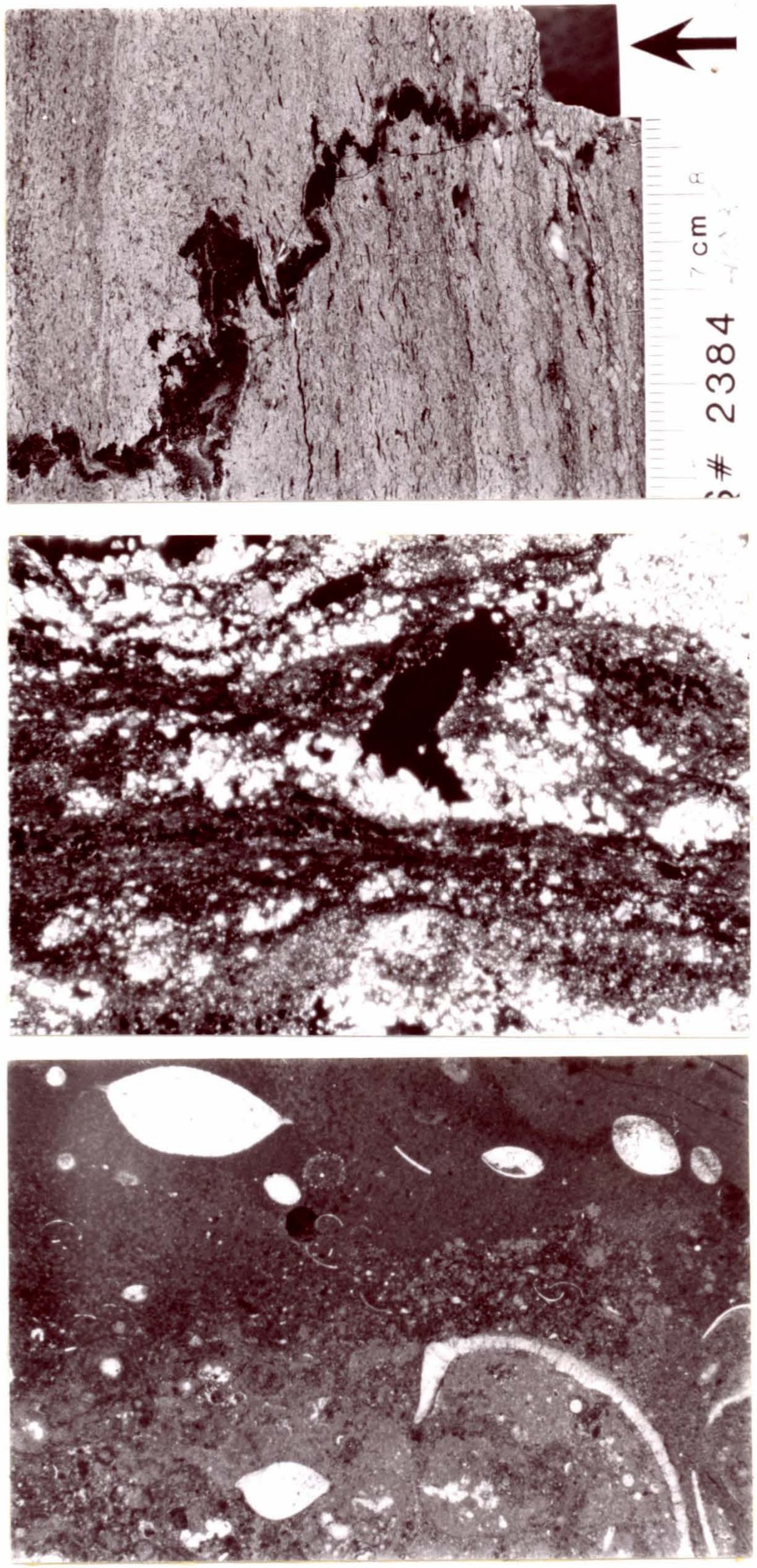
Girvanella consists of intertwined, calcareous-tubular filaments. These intertwined filaments form mats, oncoids (discussed previously), and small clumps or clasts approximately 1 mm in size. Girvanella is typically associated with peloids and intraclasts, and to a lesser extent with calcispheres. The hollow, calcareous (usually micritic) tubes are spar- or micrite-filled, and are approximately 0.02 mm in diameter. Preservation ranges from good to very poor, and poorly preserved examples may easily go undetected.

Nonskeletal Cyanophyta belong to a variety of genera (Wray, 1977) which are often characterized by the organo-sedimentary structures that they create. As a group, these structures are commonly called stromatolites. Within the study area, the most predominant stromatolite structures are a fine-grained, horizontally-laminated fabric (Fig. 24 and 25), with or without fenestrae, and possible spherical oncoids. Traces of algal filaments are sometimes evident within the fine-grained laminations, in which case the origin of the

Figure 24: Core photograph of horizontally-laminated, stromatolite doloboundstone. Dark, near vertical line is an anhydrite-filled crack. NDGS# 2384, depth 4103 ft.

Figure 25: Photomicrograph of horizontal, traces of algal laminations. Coarse, dolomite crystals (light) are interlaminated with dark laminations containing numerous small pyrite framboids. NDGS# 6803, depth 4092.3 ft, field of view 1.6 mm wide, XP.

Figure 26: Photomicrograph of articulated ostracods (spar-filled) in fine-grained matrix. NDGS# 3343, depth 4167.8 ft, field of view 3.7 mm wide, PP.


7 cm
2384

lamination can be determined. However, most stromatolites do not contain preserved filaments and are often dolomitized. These are interpreted to be stromatolites based on their thinly laminated, discontinuous and/or fenestral appearance. In many cases, algal-laminated sediments cannot be separated from inorganically produced structures with a similar morphology (Wray, 1977).

Ostracods: Ostracods are common throughout most of the study area. Carapace size ranges from 0.2 mm to 1.5 mm and individuals are often articulated. Carapaces are usually well preserved, although many are recrystallized. Articulated carapaces are generally filled with calcite spar. Two carapace morphologies were observed in thin section. A thin-walled variety is most abundant, and a thick-walled variety is least abundant. Ostracods are found associated with nearly every grain type, but are most abundant in rocks containing an abundance of algae. Articulated ostracods generally occur in fine-grained sediments (Fig. 26), or packed within large, spar-filled vugs.

Orthochems

Microcrystalline Minerals

All of the cores described in the study area are composed in part of microcrystalline minerals. Microcrystalline minerals occur as interparticle or intraparticle matrix, or forming grain-free, microcrystalline rocks. Microcrystalline minerals found in the study area consist of calcite, dolomite, and anhydrite. These three types are areally restricted and in a southwest to northeast cross section of the study area, grade from dominantly calcite in the southwest, to dolomite in the center, to anhydrite in the northeast.

Microcrystalline calcite or micrite (Folk, 1980) is nearly opaque in thin section and consists of crystals generally between 1 and 4 um. In the study area, microprobe analysis shows that these small crystals are composed of low-Mg calcite. Micrite is usually associated with calcium carbonate allochems of various types.

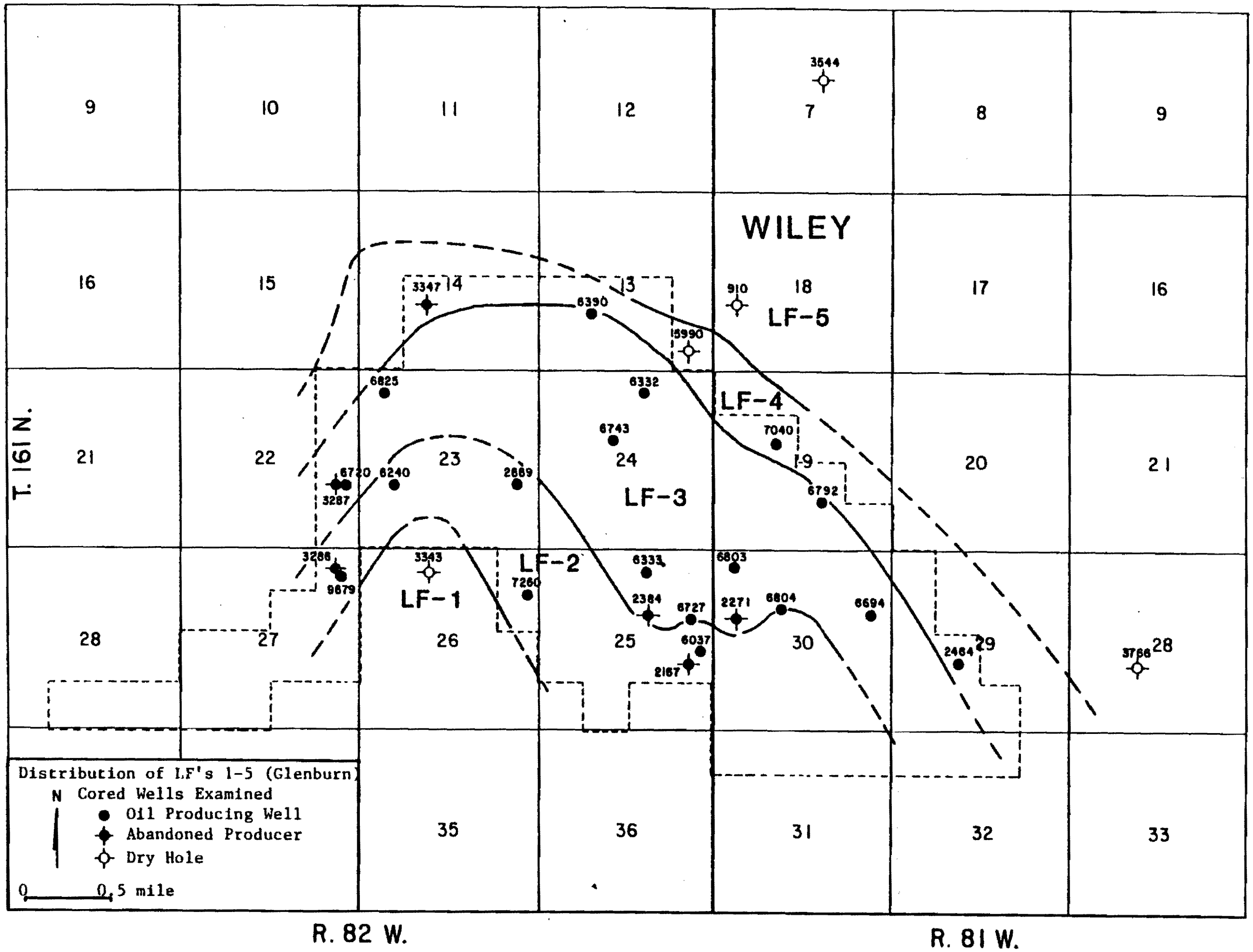
Microcrystalline dolomite (dolomicrite, micritic dolomite) consists of crystals generally less than 5 um in size. Microcrystalline dolomite forms matrix between carbonate allochems, and also is the dominant constituent of thin, locally continuous, argillaceous-dolomudstone beds. These fine-grained dolomites are often associated with sulfate minerals. Rarely, well preserved, low-angle crossbedding is found in the argillaceous dolomudstone beds.

Microcrystalline anhydrite (micritic anhydrite) consists of crystals generally less than 5-10 um in size that form bedded/massive anhydrites, and also commonly occur as matrix between detrital-quartz grains of the siliciclastic sandstone-siltstone lithofacies.

Lithofacies Descriptions

The cores described in this study were divided into six lithofacies based on the commonality of depositional and postdepositional features observed in each (Fig. 27). Major lithology, distinguishing allochem(s), and major cement type, are used to characterize each lithofacies. The six lithofacies include: 1) fossiliferous grainy mudstone-packstone (LF-1); 2) coated-grain wackestone-grainstone (LF-2); 3) peloidal/intraclastic wackestone-packstone (LF-3); 4) dolowackestone-mudstone and nodular anhydrite (LF-4); 5) massive anhydrite (LF-5) and; 6) siliciclastic sandstone-siltstone (LF-6).

Figure 27: Areal distribution of lithofacies one through five in the Glenburn bed. Boundaries are transitional and their positions are based on descriptions of the cored wells shown, aided by wire-line log interpretations.



WILEY
LF-1
LF-2
LF-3
LF-4
LF-5
T. 161 N.
R. 82 W.
R. 81 W.
Distribution of LF's 1-5 (Glenburn)
N
Cored Wells Examined
Oil Producing Well
Abandoned Producer
Dry Hole
0 0.5 mile

In the thin sections studied, both the percentage of occurrence and the average size of allochems is generally greatest for the distinguishing allochem(s) in each lithofacies (Table 1), i.e., fossils are largest and most common in the fossiliferous grainy mudstone-packstone lithofacies (LF-1). It appears, therefore, that conditions were optimum for formation of the distinguishing allochem(s) at the site of deposition of each lithofacies. One exception can be seen in LF-4 (Table 1), where percentages and sizes of peloids and intraclasts appear greater than in the adjacent peloidal/intraclastic wackestone-packstone lithofacies (LF-3). This is misleading however, due to the large number of thin sections from LF-4 that were not counted because they contained no carbonate allochems.

Fossiliferous grainy mudstone-packstone (LF-1)

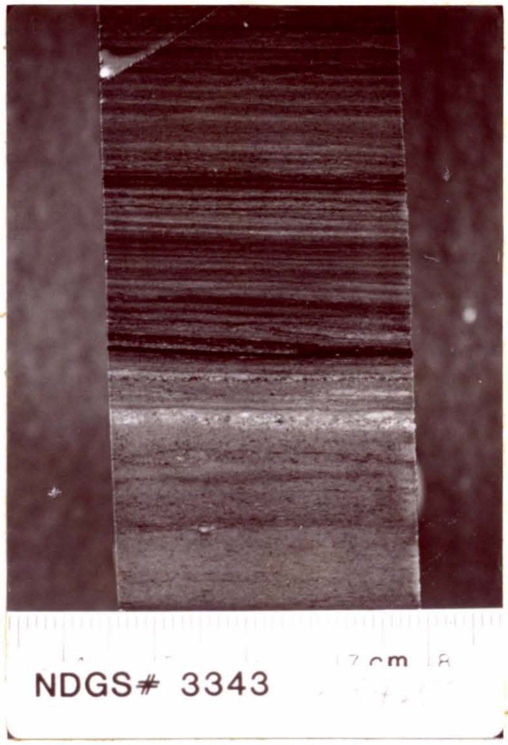
The rocks of LF-1 range from light-gray brown to light-olive gray, but light brown is the most common color. The rocks are composed almost entirely of limestone, but dolomite is present in thin zones a few feet in thickness. LF-1 rocks are laminated (Fig. 28) to massive (Fig. 29) and typically poorly sorted, commonly with a weak-fenestral appearance (Fig. 30). Pressure solution features are common in LF-1, with Type II stylolites (Wanless, 1979) the most common and Type I stylolites the least.

Rocks of LF-1 contain by far the greatest diversity and numbers of both faunal and floral elements. Fossils make up over 50 percent of a sample locally, and are found in a much higher percentage of thin sections than in other lithofacies (Table 1). Preservation in LF-1 of

Figure 28 (upper left): Core photograph of a thinly-laminated, dolomitic, fossiliferous grainstone-wackestone (LF-1). NDGS# 3343, depth 4184.5 ft.

Figure 29 (upper right): Core photograph of a massive, bioclastic, peloidal, grainstone-packstone (LF-1). NDGS# 910, depth 4145 ft.

Figure 30 (bottom): Core photograph of a peloidal, fossiliferous, packstone-grainstone showing weakly developed, calcite-filled fenestrae (LF-1). NDGS# 3343, depth 4173.7 ft.


7 cm
8
NDGS# 3343


NDGS# 910 cm 4145'


4
5
6
7 cm
8
NDGS# 3343
4173.7'

fossils composed of carbonates ranges from good to complete removal. In thin section, average fossil size is 1.45 mm, but brachiopods 3.0 cm wide were observed in core. Calcispheres were the smallest individual recorded fossils.

Peloids, intraclasts, and coated grains make up the bulk of the allochems found in most samples, but their average grain size is generally smaller than in adjacent lithofacies (Table 1). Rocks in LF-1 generally have a micrite matrix and spar cement.

Rocks of LF-1 occur in both the Wayne and Glenburn beds within the study area; LF-1 occurs farther updip in the older Wayne beds. There is some variation in the amounts and types of fossils between the two beds.

Fossils in the Wayne beds include numerous small echinoderm fragments (up to 60%), and a larger number of foraminifera than in the overlying Glenburn bed. Forams include Septabrunsiina, Endothyra, Paracaligella, Septaglomospiranella, Latiendothyra?, and Tuberendothyra? (K. Eylands, verbal comm., 1987). These forams indicate an Osagean age for the Wayne bed (K. Eylands, verbal comm., 1987). Corals, tentatively identified as Sychnoelasma sp., and bryozoans also occur in the Wayne bed.

Fossils which are found in both beds in approximately equal numbers include ostracods, calcispheres, gastropods, and brachiopods. The Glenburn bed contains numerous algae (Ortonella, Girvanella) in addition to the above common fossils, and contains coral tentatively identified as Lophophyllum sp.. Foraminifera, although less common than in the Wayne beds include Septatournayella (K. Eylands, verbal comm., 1987). Fossils found only in the Glenburn bed include at least

5 new species of megaspores, poorly preserved plant fragments, and well-preserved scolecodonts (Luther and others, 1987), (Appendix D, this paper).

Coated-grain wackestone-grainstone (LF-2)

LF-2 is dominated by limestone for more than 80 percent of each described section. Dolostone and some anhydrite make up the remainder. Light-gray brown is the most common color, but color ranges from light gray to medium brown, depending on oil staining. Fine-grain dolostone sections are generally light gray in color.

Packstones (Fig. 31) are the most common lithology, although grainstones (some cross-bedded) (Fig. 32) and wackestones (Fig. 33) are also common. Carbonate grainstones are more common in LF-2 than in other lithofacies within the study area. Sorting is usually poor, although well-sorted grainstones occur. Matrix is typically micrite, some of which is now microspar.

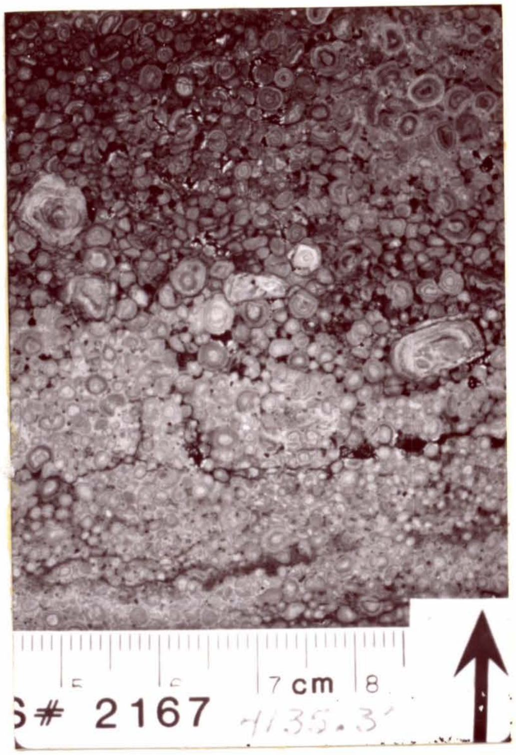
Rocks of LF-2 are generally thin-bedded to laminated. Individual laminae are distinguished by a change in packing from mudstone to packstone within adjacent laminae. Reverse grading dominates, although no type of grading is common. Fenestral fabrics are common (Fig. 34), as are thin, fine-grained laminae or crusts. Fine-grained laminae or crusts commonly occur draped over grains, or at sharp lithologic changes. Rare radially-fibrous crusts or laminae are also present. Grain-filled cracks, 1-2 cm wide and up to 5 cm long vertically, are sometimes found within LF-2. Infrequent, thin zones (less than 2 ft), of LF-1 or LF-3 are found interfingering with LF-2. These may be either more fossiliferous than LF-2, or composed almost totally of peloids and intraclasts, respectively.

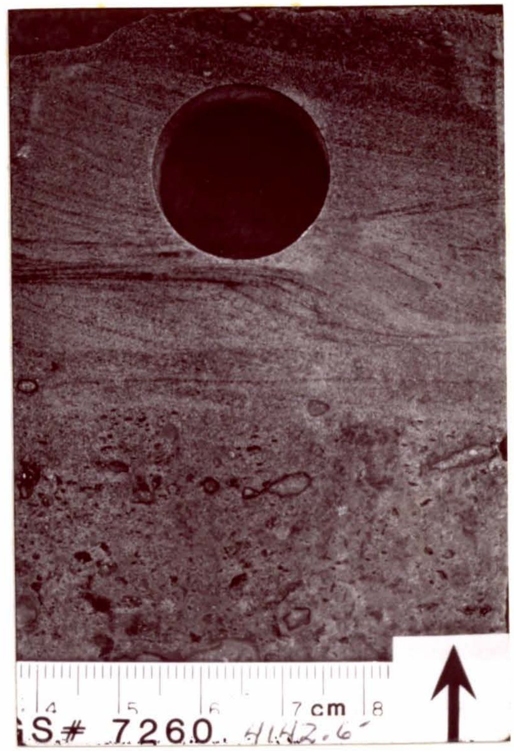
Figure 31 (upper left): Core photograph of a typical, poorly-sorted, coated-grain packstone from the coated-grain wackestone-grainstone lithofacies (LF-2). NDGS# 2167, depth 4135.3 ft.

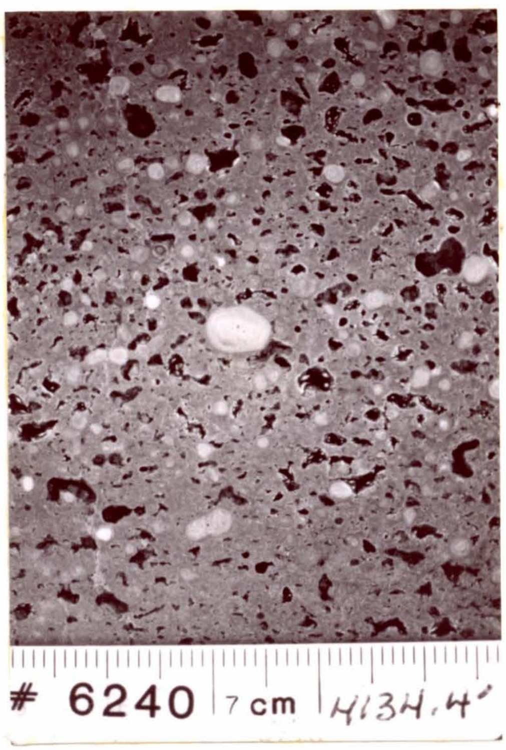
Figure 32 (upper right): Core photograph of small, coated-grains (spherulites) forming a rare, cross-bedded deposit (LF-2). Dark circle is where a sample plug has been removed. NDGS# 7260, depth 4142.6 ft.

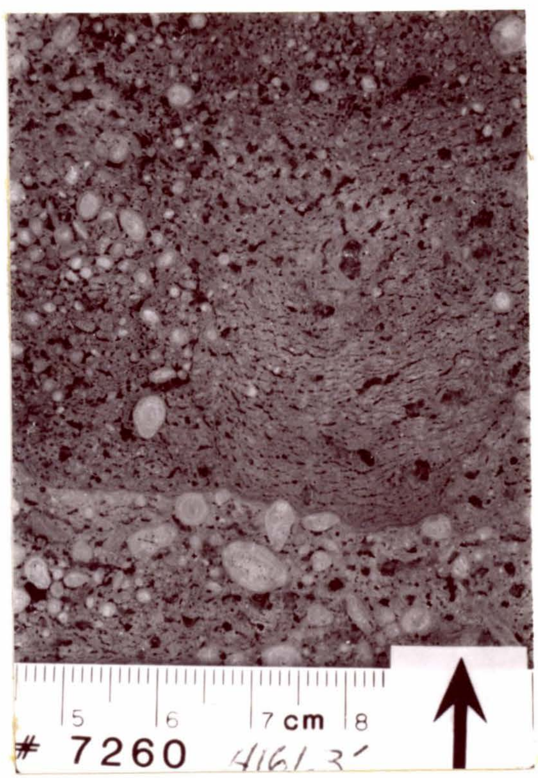
Figure 33 (lower left): Core photograph of a typical wackestone from LF-2, containing coated grains, peloids, and micrite. Note the well-developed vugular porosity. NDGS# 6240, depth 4134.4 ft.

Figure 34 (lower right): Core photograph of a peloidal, coated-grain packstone with well-developed fenestrae. Best-developed fenestrae occur in a "U-shaped" form. NDGS# 7260, depth 4164.3 ft.


7 cm
S# 2167 4135.3'


7 cm
S# 7260 4142.6'


6240 7 cm 4134.4'


7 cm
7260 4161.3'

Spar generally fills or lines primary and secondary pores, but anhydrite is the dominant cement in some thin zones. Chlorite rarely fills fractures, some vugs, and stylolitic pores. Coarse (up to 70 um), euhedral dolomite crystals are commonly associated with pressure solution features. Coarse dolomite crystals less commonly line pores, or occur as scattered crystals within limestone grains or matrix.

Rocks of LF-2 contain the greatest numbers and types of coated grains and a larger average size for most types of coated grains than in adjacent lithofacies (Table 1). Locally, within LF-2, rocks are composed of greater than 90 percent coated grains. Composite-coated grains are the most commonly encountered type, and average 1.39 mm in size. Peloids and intraclasts are also common, often occurring mixed with, or as matrix for, larger coated grains. Fossils are much less common than in LF-1 (Table 1), and consist almost entirely of calcispheres, ostracods, and various types of blue-green algae.

Pressure solution responses are very common in LF-2; Type I, II, and fitted fabric responses all occur. Pressure solution features are more common in LF-2 than in any other lithofacies within the study area.

<u>Peloidal/intraclastic wackestone-packstone (LF-3)</u>

LF-3 is variable, with limestone the dominant lithology (up to 80 percent) in sections near LF-2; dolostone comprises up to 70 percent of the section near LF-4. Light brown is the most common color, although colcr ranges from light gray to medium brown. Fine-grain dolostone or anhydrite sections are generally light gray in color.

Wackestones (Fig. 35) and packstones are the most common packing types, although mudstones are also common. Grainstones are present, but uncommon. Sorting is typically poor. Matrix consists of either micrite or dolomite, but microspar is also present. Rocks of LF-3 are generally thin-bedded to thinly laminated. Individual laminae are distinguished by a change in packing ranging from mudstone to packstone textures, or less frequently, by laminar stromatolites. Fenestral fabrics are common, and ripped-up, fine-grained sections occur infrequently (Fig. 36).

Both calcite spar and anhydrite fill or line pores in the part of LF-3 that is adjacent to LF-2. In the part adjacent to LF-4, anhydrite is the major mineral which occludes porosity, and also commonly replaces calcite. Anhydrite often fills pores in thin zones, while adjacent, similar pores remain unfilled and are typically oil stained (Fig. 37). Silicified zones, fluorite, and celestite occur within LF-3, nearly always near the gradational boundary with LF-4.

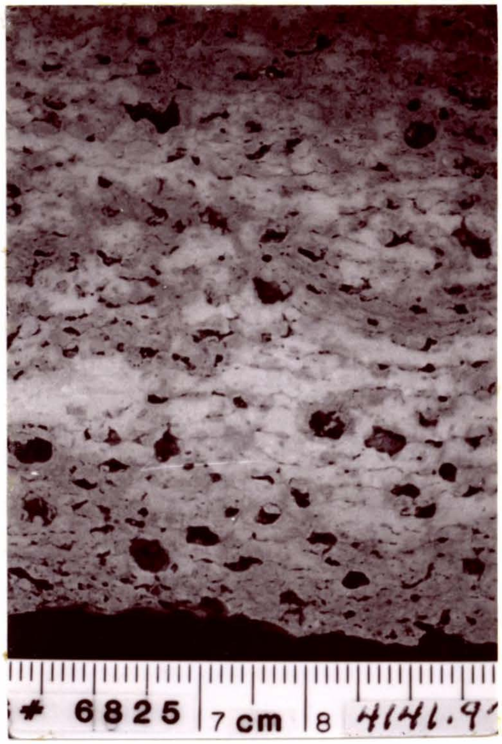
Silicified zones are usually 8-15 cm thick with sharp upper and lower boundaries. In these zones, carbonate grains are silicified and pores are usually open, but some pores are partially lined with quartz. Celestite occurs as individual subrounded grains, as vug fillings, or as euhedral crystals. Fluorite occurs as small (approximately 100 um) cubic crystals within carbonate allochems, concentrated by stylolites, within silicified zones, and within anhydrite-replaced carbonates.

Rocks of LF-3 contain the greatest numbers and largest average sizes of both peloids and intraclasts (Table 1). Locally, within LF-3, rocks are composed of greater than 90 percent peloids and

Figure 35 (upper left): Typical wackestone from the peloidal/intraclastic wackestone-packstone lithofacies (LF-3) composed of peloids, intraclasts, and micrite. Note the weak-fenestral appearance and large vugs. NDGS# 6825, depth 4141.9 ft.

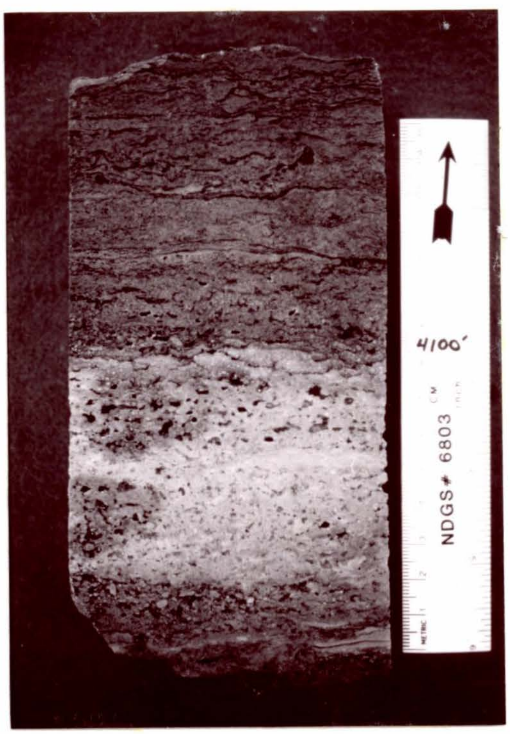
Figure 36 (upper right): Example of infrequently encountered, ripped-up, fine grained laminations. NDGS# 6743, depth 4096.5 ft.

Figure 37 (bottom): Light-colored zone caused by anhydrite occluding pores. Dark areas are not anhydrite-cemented, and are oil stained (dark brown color). NDGS# 6803, depth 4100 ft.



6825
7 cm
8
4141.9'

4
5
6
7 cm
8
NDGS# 6743
4096.5'



4100'
NDGS# 6803

intraclasts. Fossils are much less common than in LF-1, and consist almost entirely of calcispheres. Blue-green algae and ostracods, as well as thin zones containing coated grains, are also present. All grain types in LF-3 are frequently composed of dolomite.

Dolomite ranges from submicron-sized crystals to greater than 100 um. The largest crystal sizes line celestite- or anhydrite-filled vugs, or are associated with pressure solution features.

Pressure solution is very common in LF-3, with the Type II stylolite the most common response. Pressure solution does not seem to be present in dolostone sections, but may have concentrated dolomite in calcite-dominated sections. Anhydrite commonly has replaced calcite adjacent to stylolites.

Dolovackestone-mudstone and nodular anhydrite (LF-4)

LF-4 is variable, with dolostones the most common lithology, closely followed by nodular anhydrite. Thin, limestone- or massive anhydrite-dominated zones are also present. Light brown and light gray are the most common colors, although darker shades occur locally. Typically, zones containing more siliciclastic grains (quartz sand or clays) are darker gray, and oil-stained areas darker brown.

Wackestones and mudstones are the most common packing types. Packstones are present, but much less common. Sorting is typically poor. Matrix usually consists of dolomite, but microspar and micrite are also present locally. Rocks of LF-4 are generally bedded to thinly laminated. Individual beds or laminae are marked by a change in the relative amount of anhydrite and dolomite or changes in the packing of grains within dolostone. Fenestral fabrics are rare.

Isolated, crossbedded dolomite or sulfate laminations are present, as well as more common thinly laminated dolomudstones and patterned dolomudstones (Figs. 38 and 39).

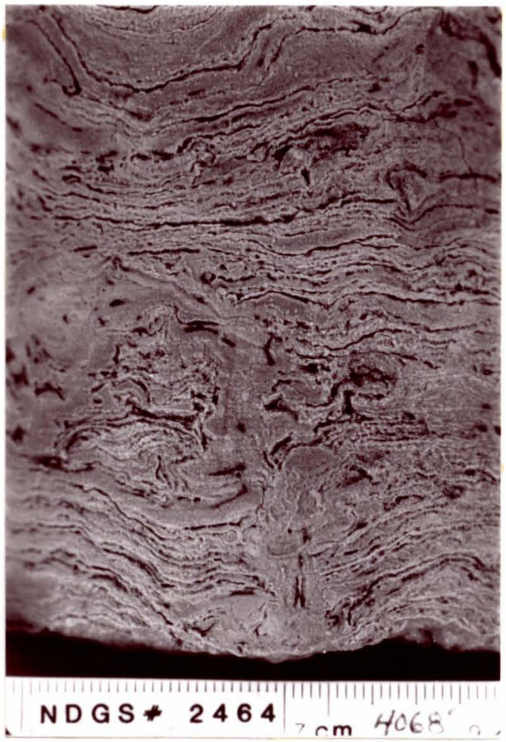


Figure 38: (on the left) Contorted, thinly laminated dolomudstone. NDGS# 2464, depth 4068 ft.

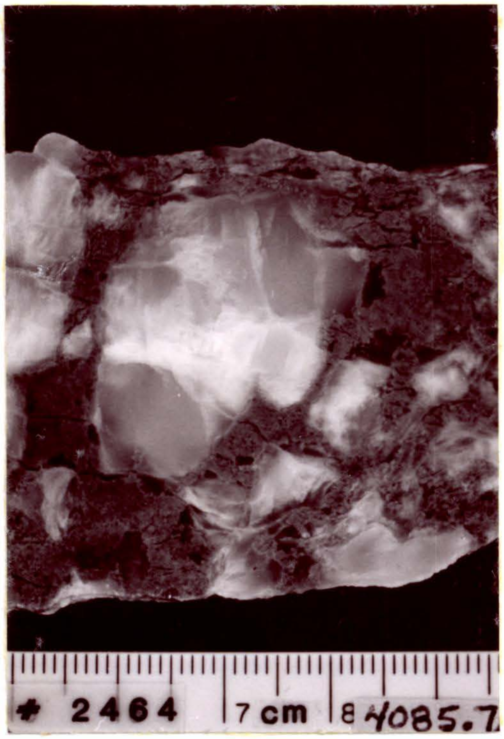
Figure 39: (on the right) Patterned dolomudstone. Dark areas typically contain greater amounts of small pyrite crystals than do light areas. NDGS# 6792, depth 4070.5 ft.

Anhydrite occurs as nodules (up to several centimeters in size) (Fig. 40), and vertically elongate crystals (fig. 41). Anhydrite also occurs thinly interlaminated with dolomite (Fig. 42), in massive beds, as pore filling, as sulfate sand grains, and replacing carbonates. Silica occurs as replacement of carbonates and filling small, vertical fractures. Celestite occurs as a pore filling, as isolated subrounded

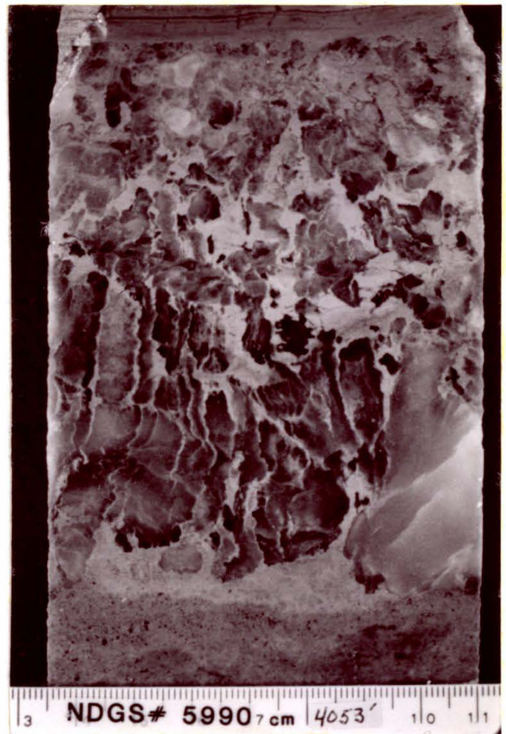
Figure 40 (upper left): Large anhydrite nodules (light areas) within dolomudstone (dark areas). NDGS# 2464, depth 4085.7 ft.

Figure 41 (upper right): Vertically elongate anhydrite crystals (dark areas) within dolomudstone (light areas). Elongate anhydrite crystals may be relicts of originally subaqueously precipitated, vertically growing gypsum crystals. NDGS# 5990, depth 4053 ft.

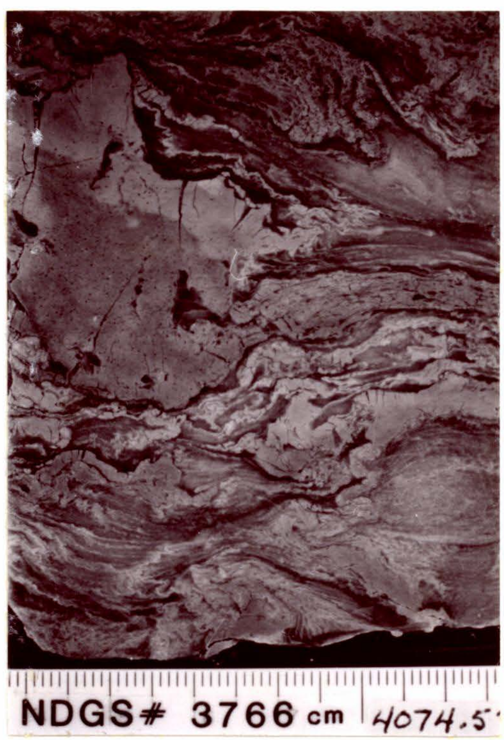
Figure 42 (bottom): Interlaminated and contorted dolomudstone (light) and anhydrite (dark). NDGS# 3766, depth 4074.5 ft.



2464
7 cm
8 4085.7



NDGS# 5990 7 cm
4053'



NDGS# 3766 cm
4074.5

grains, rosettes, and euhedral crystals. Fluorite occurs within LF-4 as small (approximately 100 um) cubic crystals. Fluorite is present within carbonate allochems, concentrated by stylolites, within silicified zones, and within anhydrite-replaced carbonates.

Virtually all filled pores in LF-4 are filled with anhydrite. Lesser amounts of celestite and thin silicified zones are also present. Sparry calcite occurs in trace amounts in thin, isolated zones.

Rocks of LF-4 show the lowest diversity and numbers of allochems (Table 1) of the carbonate lithofacies. The two most common allochems are peloids and intraclasts, with peloids in 100 percent of the thin sections containing recognizable carbonate grains. Fossils also occur in LF-4, and consist almost entirely of calcispheres, ostracods, and possible planar stromatolites. Some relatively large, thin-shelled, articulated ostracods or bivalves are present locally. These increase the average size of fossils in LF-4 relative to those found in LF-2 and LF-3 (Table 1). Also present in LF-4 are scattered silt- to sand-sized grains of quartz and euhedral to rounded sulfate crystals.

Pressure solution is present, but much less common than in LF's 1-3. Stylolites are usually Type II or wispy swarms.

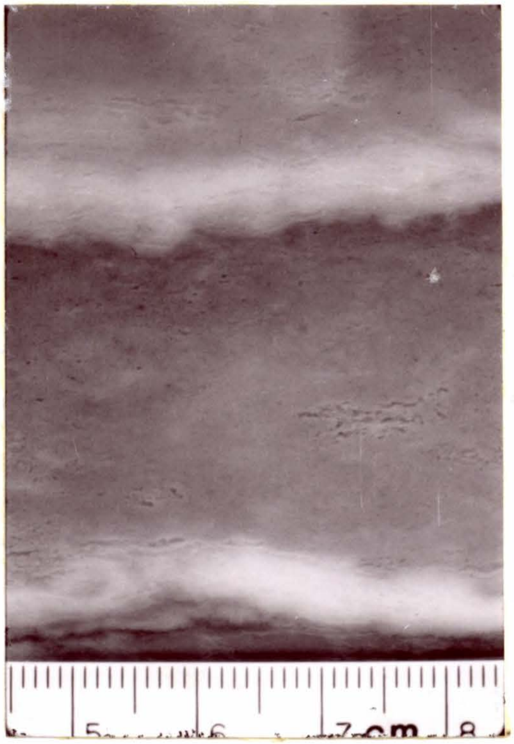
Massive anhydrite (LF-5)

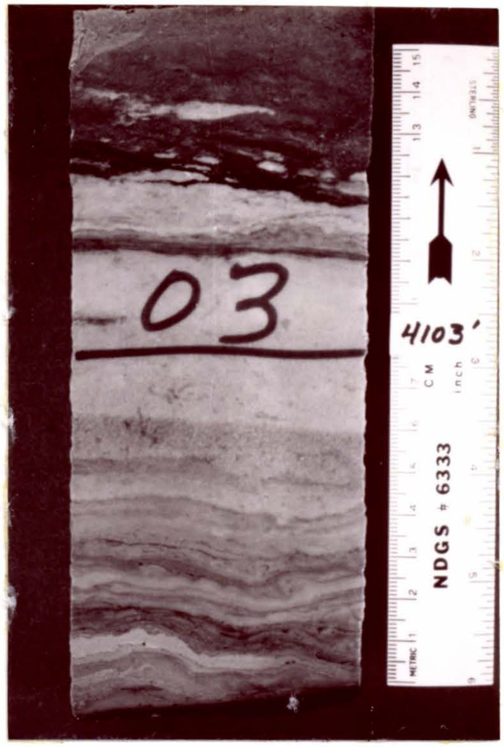
Rocks of LF-5 consist almost entirely of various forms of anhydrite. Fabrics include: 1) massive, featureless, fine-grained anhydrite (Fig. 43); 2) nodular-mosaic anhydrite; 3) bladed anhydrite; 4) laminated, fine-grained anhydrite (Fig. 44); and 5) clastic anhydrite. Anhydrite ranges from thickly bedded to thinly laminated.

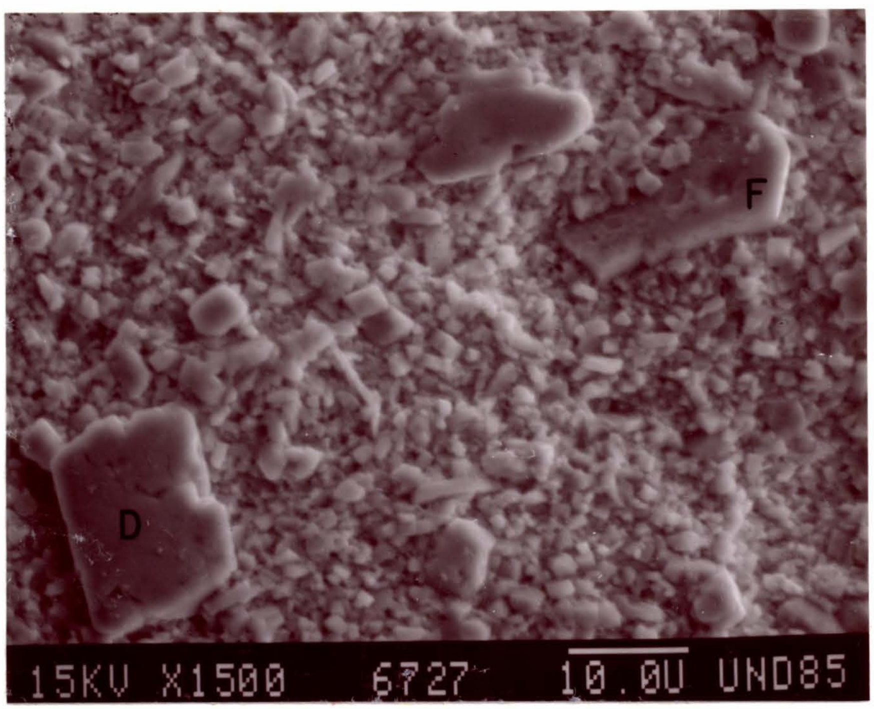
Figure 43 (upper left): Massive, featureless, fine-grained anhydrite. NDGS# 3286, depth 4148 ft.

Figure 44 (upper right): Laminated, fine-grained anhydrite taken from just below LF-6. Dark area at the top contains increasing (upward) amounts of detrital silts and clays. NDGS# 6333, depth 4103 ft.

Figure 45 (bottom): SEM image of fine-grained anhydrite sample containing euhedral potassium feldspar (F) and dolomite (D) crystals. NDGS# 6727, depth 4094.7 ft, scale bar = 10 microns.


5
6
7 cm
8


03
4103'
NDGS # 6333
CM
inch


F
D
15KV X1500 6727 10.0U UND85

Minor constituents of LF-5 include dolomite, celestite, quartz silt and sand, clays, and authigenic potassium feldspar (Fig. 45). Dolomite may make up as much as 50 percent of the rock in thin, nodular anhydrite or clastic anhydrite zones. Anhydrites of LF-5 which are near the boundary with LF-6 frequently contain large volumes of clays and/or thin, isolated, quartz sand-rich laminae.

Rocks of LF-5 occur updip (basin marginal) of LF's 1-4, as well as above LF-6. A thin zone (0.5 ft - 3.0 ft) of LF-5 also underlies LF-6 throughout much of the study area.

Siliciclastic sandstone-siltstone (LF-6)

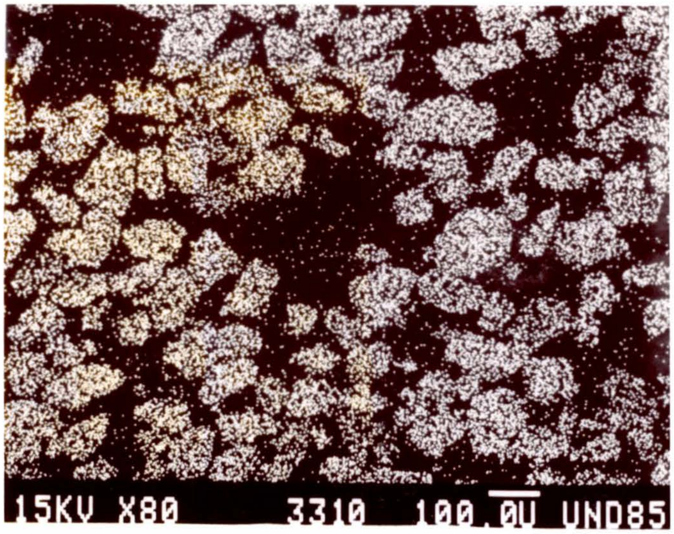
Rocks of LF-6 are markedly different from the five previously described lithofacies, in that they are dominated by siliciclastic sand and silt grains. LF-6 is within the K-2 marker bed in the study area, and forms the highest peak on a gamma-ray log of the K-2 marker bed. LF-6 commonly consists of greater than 70 percent siliciclastic grains (Fig. 46), with the remainder almost totally composed of anhydrite (Figs. 47 and 48). Clays and trace amounts of dolomite and pyrite are also present. Medium gray is the most common color of LF-6, with very little variation.

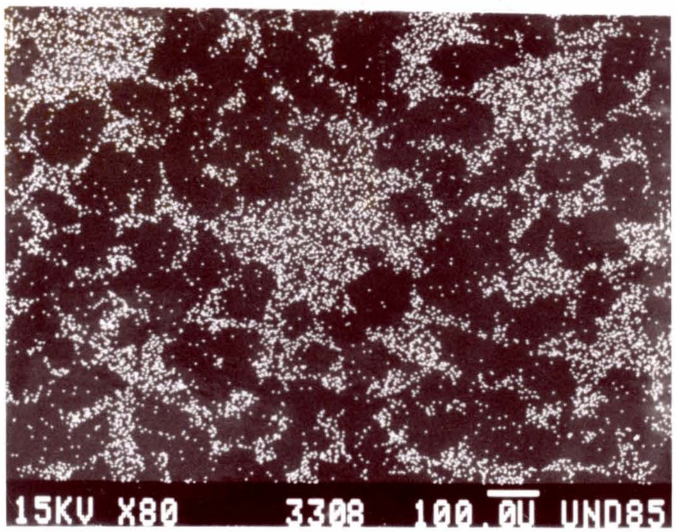
LF-6 has a thin (0.75 m - 1.0 m), uniform, sheet-like morphology which can be correlated across the study area. However, on a gamma-ray log, the K-2 marker varies between 8 ft and 19 ft (2.5 m and 5.8 m) in thickness (including LF-6). This variation in thickness occurs because the log response for the K-2 marker includes silts and clays contained within the adjacent LF's 4 and 5. LF-6 generally has a sharp contact with underlying lithofacies (usually LF-5) and a gradational upper contact with LF-5.

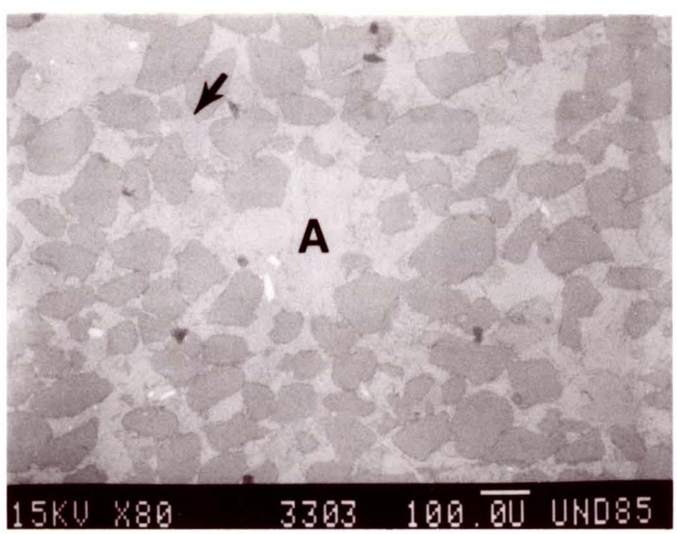
Figure 46: SEM elemental dot map showing the distribution of silicates (quartz and/or feldspar) in the sample. Dark areas do not contain silicates. NDGS# 6333, depth 4102 ft, scale bar = 100 microns.

Figure 47: SEM elemental dot map showing the distribution of sulfur (representing anhydrite, $CaSO_4$) in the sample. Dark areas do not contain sulfur and represent the silicate grains in the figure above. NDGS# 6333, depth 4102 ft, scale bar = 100 microns.

Figure 48: SEM backscatter electron (BSE) image of the same sample shown in the preceeding two figures. Light areas represent minerals containing elements with higher atomic numbers than those in darker areas. Light gray represents anhydrite, note the large crystal (A), medium gray represents potassium feldspar grains (some euhedral, arrow), and dark gray represents detrital quartz grains. Note the angular nature and loose packing of the quartz grains. NDGS# 6333, depth 4102 ft, scale bar = 100 microns.


15KV X80 3310 100.0U UND85


15KV X80 3308 100.0U UND85


A
15KV X80 3303 100.0U UND85

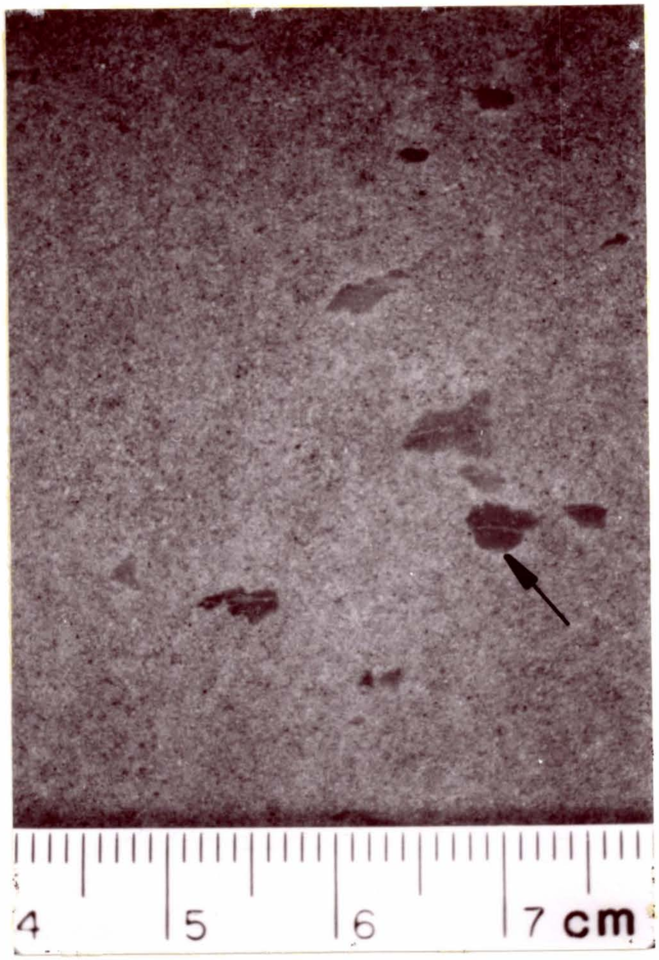
In core, LF-6 appears massive except for anhydrite nodules (Fig. 49), and weak, wavy, nonparallel, thin laminations. In thin section, the thin laminations (Fig. 50) are typically clay and/or fine-grained anhydrite-dominated (Fig. 51), and often separate moderately sorted laminae of different sand size fractions. Sorting of siliciclastic grains is good, although grains are usually loosely packed. No grading or crossbedding is evident within LF-6 in the study area. Locally, LF-6 has a patterned appearance.

Siliciclastic grains range in size from medium sand to very fine silt. They typically have low sphericity and are angular to subrounded (Fig. 48). The siliciclastic grains are predominantly quartz and potassium feldspar; the latter is usually less than 5 percent of the grains. A variety of quartz grain types occur, including monocrystalline, polycrystalline, strained, and grains with linear inclusions. Many of these grains appear to have corroded grain margins. Potassium feldspar grains occur as both anhedral and euhedral forms (Fig. 52). Trace amounts of plagioclase are also present, but rare.

Anhydrite within LF-6 occurs in three major forms, as small nodules (up to 1 cm), large single crystals (up to 0.5 mm) (Fig. 48), and small grains (less than 1 um - 10 um). The small grains typically form matrix between larger quartz grains, and thin laminae which may include very fine silt-clay sized quartz grains and/or clays (Fig. 51).

Figure 49: Massive sandstone from the siliciclastic sandstone-siltstone lithofacies (LF-6) containing small anhydrite nodules (arrow). NDGS# 6727, depth 4098.5 ft.

Figure 50: Photomicrograph showing a thin, wavy lamination separating angular, siliciclastic grains (mostly quartz) of two different size fractions. NDGS# 6333, depth 4102 ft, field of view is 4.3 mm wide, PP.


4
5
6
7 cm

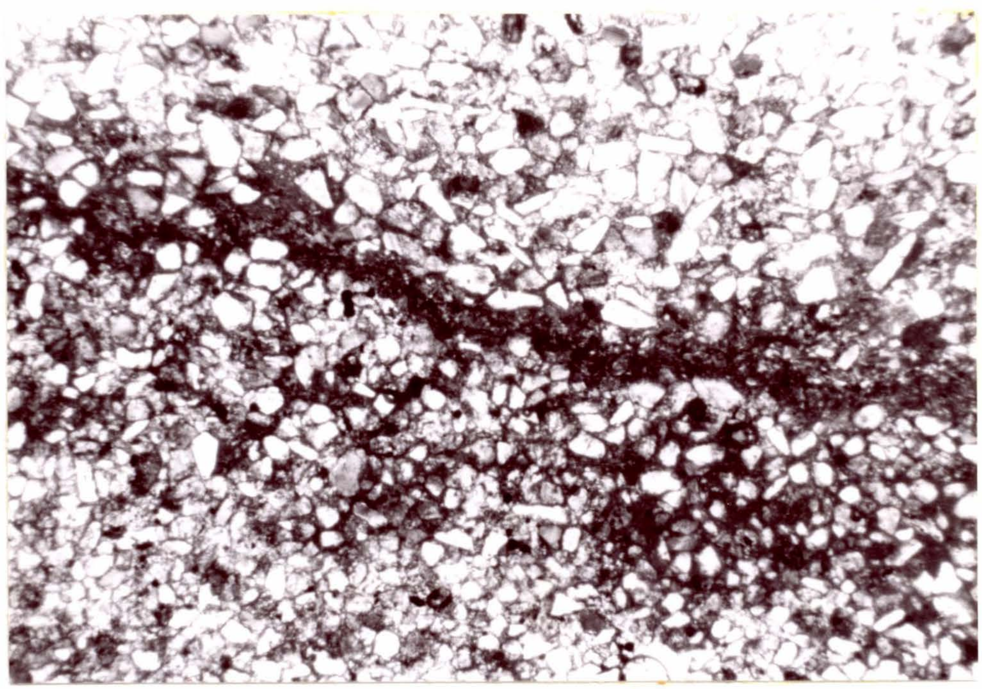
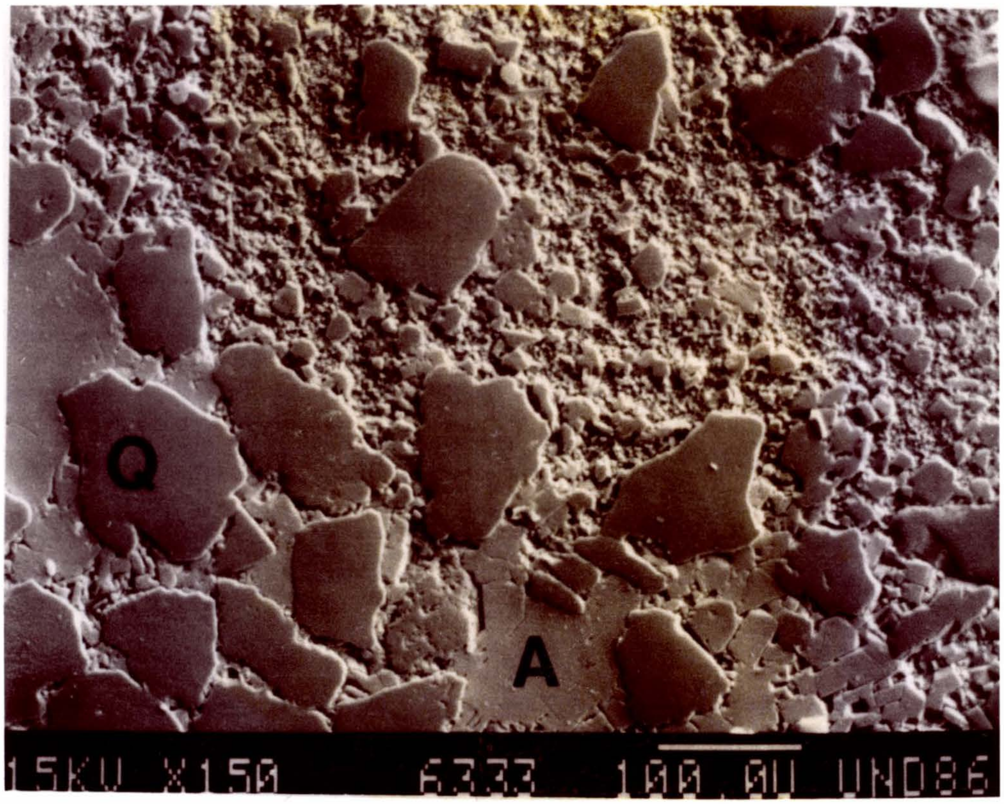
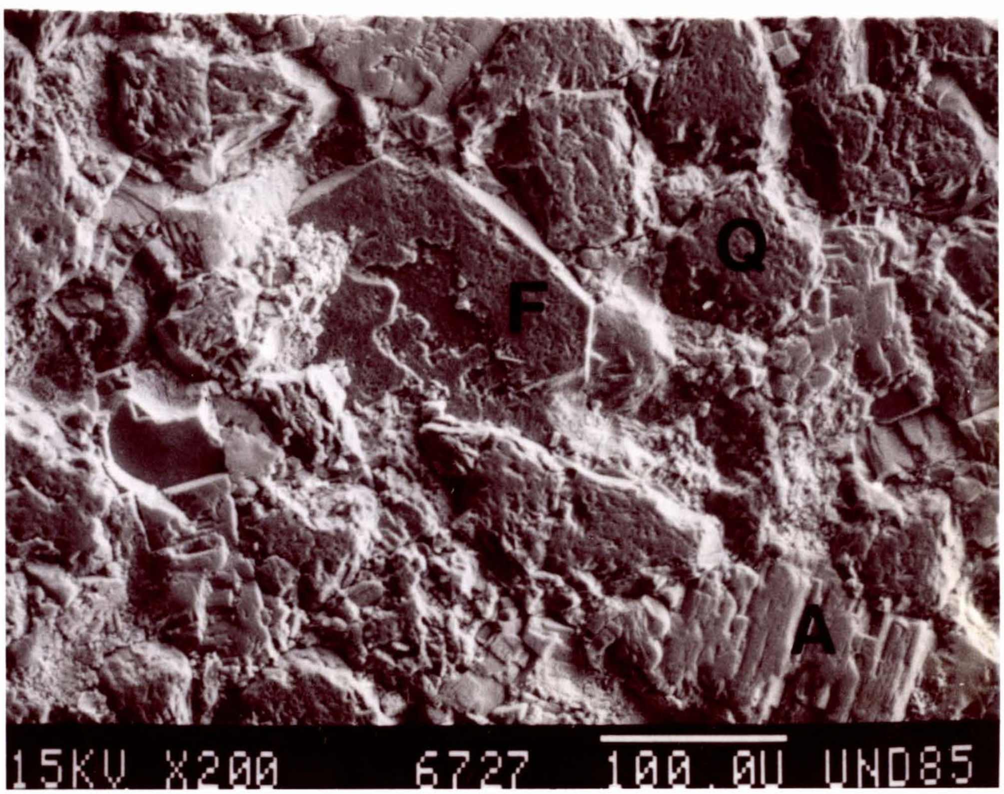


Figure 51: SEM image of the fine-grained lamination shown in the previous figure. The fine-grained lamination consists of small anhydrite crystals and argillaceous material. Also shown underlying the fine-grained lamination, are angular quartz grains (Q) and blocky-anhydrite cement (A). NDGS# 6333, depth 4102 ft, scale bar = 100 microns.

Figure 52: SEM image of a relatively large, euhedral, potassium feldspar grain (F) surrounded by blocky-anhydrite cement (A) and subrounded, quartz grains (Q). NDGS# 6727, depth 4097 ft, scale bar = 100 microns.


Q
A
15KV X150 6333 100.0U UND86


Q
F
A
15KV X200 6727 100.0U UND85

DEPOSITIONAL INTERPRETATIONS

Introduction

Interpretations of the processes and environments which formed the allochems, orthochems and lithofacies found within the study area, are based on shared characteristics with previously documented processes and/or environments observed in modern carbonate environments. Although there is no modern analog for the Mississippian epeiric sea in which the described rocks were deposited, physical and chemical processes observed in modern environments should be essentially the same as those operating during the Mississippian. Likewise, modern environments may be similar to those which formed ancient rocks, but they may be orders of magnitude different in size and rates at which processes acted.

Since there is no modern analog for an epeiric sea, and epeiric seas are hypothesized to have had little or no tidal range (Shaw, 1964), this study will use the terms sublittoral, littoral, and supralittoral (Hedgpeth, 1957) instead of the terms subtidal, intertidal, and supratidal, respectively.

Regional Paleogeography and Paleoclimate

Paleogeographic reconstructions of continental positions during the Mississippian place the Williston Basin between 5 and 15 degrees north latitude (Habicht, 1979; Scotese and others, 1979). Quinn (1986) superimposed modern trade-wind directions on this reconstruction and found that winds would have blown westward across the Williston Basin from the land mass to the east. This is supported by studies done in the southwestern United States (Habicht, 1979).

Due to the proximity of the equator and movement across a land mass, the westward-blowing winds are interpreted to have been warm and dry (Quinn, 1986). This would have enhanced the generally evaporitic conditions, especially for the easternmost portions of the basin.

The key to interpreting the processes which formed the allochems, orthochems, and lithofacies, and their relative positions in the study area, requires an understanding of the setting in which they formed. The Williston Basin, as previously stated, was located just north of the equator and had warm, dry, continental-winds blowing westward across it. This setting could have caused high evaporation-rates (up to several meters of water per year) of the shallow marine-waters in the basin. Water to replace that lost by evaporation in the Williston Basin came from oceans to the west, probably through the constricting Montana Trough, (Smith, 1982), hundreds of kilometers west of the study area. The movements of this inflowing (eastward-flowing) marine-water and those of the dense, saline brines formed by evaporation of marine-waters in more shoreward locales, had a controlling effect on sedimentation in the study area. The types of allochems and orthochems, and the pattern and type of lithofacies found in the study area reflect the movement of more "near-normal" marine-waters from the west that became progressively more saline (due to evaporation) as they flowed east. Increasingly saline marine-waters formed gypsum-precipitating brines in the eastern portion of the Williston Basin.

Allochems

Introduction

The different types of allochems found in the study area were formed in response to a combination of factors including, water composition/salinity, water energy, and possibly water temperature. Areas with factors favoring formation of a particular allochem type should contain the most numerous and largest examples of that allochem type. The factors that are interpreted to have controlled formation of an allochem type and the areal distribution of that allochem type can be used to infer the depositional environment where that allochem occurs.

Peloids

The nongenetic term peloid (McKee and Gutschick, 1969) is used for small (0.03 mm - 0.15 mm), structureless, micritic grains of unknown origin. Peloids can originate as fecal pellets, micritized skeletal or inorganic grains, or by abrasion of larger allochems (Taylor and Illing, 1971; Bathurst, 1975). Other proposed methods of formation include the formation of peloids as Mg-calcite cement (Macintyre, 1985), peloid growth induced by bacterial processes (Chafetz, 1986), and brecciation of carbonate muds by the precipitation and dissolution of evaporite minerals (B. W. Logan, verbal comm., 1987).

In the study area, increased Mg/Ca ratios may have been present in the transitional zone between carbonate and sulfate dominated areas. Increased Mg/Ca ratios may have locally formed peloidal, Mg-calcite cements as described by Macintyre (1985).

Chafetz (1986) studied marine peloids and found that many had nuclei composed of fossil bacterial clumps. Chafetz (1986, p. 813) suggested that marine peloids were "organically induced precipitates; that is, the bacteria helped to establish a favorable microenvironment for the precipitaion of calcium carbonate." He also stated that cavities within rocks and sediments were highly favorable habitats for bacteria and noted that peloids often fill cavities. Pores within rocks in the study area are often totally to partially filled with peloids and in these cases, bacterial processes are favored. Bacteria are tolerant of harsh environments and undoubtedly thrived in the peloid-rich zones adjacent to gypsum-precipitating areas of the study area.

Another method of formation may be by brecciation due to precipitation and subsequent dissolution of evaporite minerals formed within partially lithified carbonate muds (B. W. Logan, verbal comm., 1987). Due to the relatively greater abundance of peloids in rocks adjacent to evaporite-bearing lithofacies (Table 1), the latter method of peloid formation may be responsible for many of the peloids found within the study area. Thus, peloids in the study area appear to have had both an inorganic and an "organically induced," sublittoral origin.

Intraclasts

Intraclasts may be formed by a variety of processes but are usually considered to be eroded, partially to totally lithified sediments (Blatt and others, 1980). The composition of an intraclast is dependent upon its place of origin. Likewise, the size, shape, and sorting of intraclasts is dependent upon their mode of formation, proximity to their place of origin, and local energy systems.

Possible processes which may form intraclasts include: micritization of other grain types; erosion and abrasion of various partially or totally-lithified sediments (Fig. 36); and desiccation cracking or dewatering of sediments. Formation of intraclasts by brecciation of partially lithified sediments due to evaporite precipitation and later dissolution, followed by possible reworking and abrasion of the loose grains may also occur.

Due to the larger average size of intraclasts and the high percentage of thin sections containing them (Table 1), the environment forming LF-3 must have had conditions favorable for intraclast formation. Since LF-3 is adjacent to preserved evaporites, an evaporite-related process is favored, although the other processes mentioned clearly did occur, and may also account for substantial numbers of intraclast grains in the section.

Coated grains

Interpreting the genesis of ancient carbonate-coated grains is difficult, due to the variety of laminae-crystal morphologies, chemistries, sizes and shapes, and environments in which these variations are thought to form. The following interpretations are based on those processes which the writer feels most likely occurred.

Compound-coated grain: Compound-coated grains, with their radially fibrous and micritic laminae morphologies are the most difficult coated-grain type to interpret. Currently, radially-fibrous laminae are thought to occur in normal to hypersaline-marine waters, with low energy, and an above-average concentration of humic acid (Land and others, 1979). Thus the radially-fibrous laminae, while inorganic, may be controlled by organic activity. The humic acids may have come from algal activity which was present throughout much of the study area.

The micritic laminae are more difficult to interpret due to the variety of processes which produce micrite. Two different processes may be used to explain the presence of micritic laminae. In a study of Baffin Bay ooids, Land and others (1979) found that radially-fibrous, Mg-calcite laminae formed when above-average amounts of humic acid were present. When average or below-average amounts of humic acid were present, micritic or tangential laminae of aragonite formed. Thus alternating levels of organic acids may have formed the compound-coated grain type.

One other micritic laminae forming process involves bacterial (Folk and Chafetz, 1983) or algal activity on the grain surface. This would trap sediments on the grain surface and also lead to calcite (micrite) precipitation due to the change in pH and carbonate concentration caused by organic activity (Schneider and others, 1983).

Because the boundary between micritic and radially-fibrous laminae is usually sharp, algal boring and subaerial diagenesis are not thought to have formed the majority of micritic laminae in the rocks of the study area. Since peloids are found within some micritic laminae, bacterial activity may have formed some of the micritic laminae.

The above-mentioned processes in combination could form the compound-coated grains found in the study area. All processes probably occurred in low energy, shallow-water environments with very little grain transport. Variations in grain size and laminae thickness were caused by the length of exposure to a given process.

Radially-fibrous pisoids, ooids, and spherulites: The three radially-fibrous grain types, radially-fibrous pisoids, radially-fibrous ooids, and spherulites, are here interpreted to have formed by the same process. The process favored in this report is that cited by Land and others (1979), who found that radially-fibrous calcite laminae could form in marine waters with above average levels of humic acids, and low energy conditions. Spherulitic aragonite grains in Great Salt Lake, Utah, and elsewhere appear to be directly related to the presence of proteins or their decomposition products (Fabricius, 1977). Differences in grain size and number of laminae present would be dependent upon the size of the core that the laminae nucleated on, and the amount and number of times the grain was exposed to the proper water conditions, respectively.

Micritic-coated grains: Micritic-coated grains are here interpreted to have three possible processes which lead to their formation, two of which require algae. The third process involves the micritization of tangentially-coated grains. Using an SEM, Land and others (1979) found that thinly-laminated micritic-crystal morphologies were very similar to tangential, aragonite crystal morphologies. If micritization of tangential laminae occurred in the study area it might indicate higher energy levels during deposition than the other allochem types do, as tangential-coated grains are thought to require substantial agitation.

Possible algal processes include micritization of previously formed coated grains by endolithic boring algae (Bathurst, 1975), and formation as an oncoid by algal trapping of sediments, but without retention of distinct algal remains or characteristics. The algal processes seem more likely, due to the large percentage of micritic-coated grain occurrences in LF-1 (Table 1), the most fossiliferous lithofacies.

Oncoids: Oncoids are here interpreted to be those coated grains which retain algal remnants or algal characteristics. Oncoids within the study area appear to have been formed by both calcareous blue-green algae and noncalcareous blue-green algae (forming stromatolites). Preserved tubular calcareous filaments tentatively identified as Girvanella (Fig. 18) form coated grains in the study area. Many coated grains do not contain calcareous filaments, but have algal characteristics such as asymmetrical discontinuous laminae, thin dark organic-looking laminae separating thicker micritic laminae, and a fenestral appearance. These are interpreted to have been formed by noncalcareous blue-green algae, the stromatolite form of which was called a spheroidal structure (Type-SS) by Logan and others (1964).

Both calcareous and noncalcareous blue-green algae are unreliable indicators of environments of deposition. Although they are typically found in shallow-marine environments, they may be found in sublittoral (down to 50 m) to supralittoral environments (Wray, 1977). They also inhabit environments with extreme temperature differences, moderate to high pH (Brock, 1976), and fresh to hypersaline water conditions (Park, 1977). Oncoids do appear to require some agitation to form their spheroidal shape (Logan and others, 1964).

Fossils

Calcispheres: Both non-ornamented (smooth-walled) and ornamented (spiny) calcispheres occur throughout the study area. Rupp (1967) noted the similarity of nonornamented fossil calcispheres and reproductive cysts of living dasycladacean algae (chlorophyta) belonging to the subfamily Acetabulariae. Modern Acetabulariae are found in warm, hypersaline to brackish waters of low energy and shallow depth (generally less than 5 m) (Wray, 1977). Ornamented calcispheres may be related, but this has not been definitely established.

Concentrations of calcispheres are usually associated with the cyanophytes Ortonella and/or Girvanella in the study area, and thus may be associated with them in some way. Calcispheres also occur as isolated fossils throughout the study area, possibly floating as unattached cysts to the final point of deposition.

Algae: Both calcareous and noncalcareous blue-green (cyanophyta) algae are present in the study area. Both are generally found in shallow marine waters, although they are not reliable indicators of such an environment (Wray, 1977). Delicate branching tubiform cyanophytes such as Ortonella indicate low-energy, sublittoral environments (Jamieson, 1971). Horizontally laminated algal mats formed by Girvanella or noncalcareous cyanophytes (stromatolites) also indicate shallow, low-energy environments (Logan and others, 1964). These various algal types are probably responsible for many of the chaotic/nodular and laminated rock fabrics found throughout the study area.

Ostracods: Ostracods vary greatly in size, but commonly measure 0.8 mm in length (Scott, 1961). They periodically molt their hard, calcareous carapaces (Scott, 1961), which may contribute to their relative abundance in the fossil record. Some ostracod forms are thought to swim for short distances just above the bottom, but their prevailing benthonic habit makes them intimately associated with the environment of deposition of the bottom sediments (Benson, 1961). Swimming varieties are usually thin-carapaced forms, while crawling and burrowing varieties have thick carapaces (Benson, 1961).

Ostracods are presently found in waters ranging from fresh to hypersaline, in excess of 55 ppt, and seem attracted to cover such as salt-marsh grasses because of the protection they afford (Benson, 1961). Ostracods are often associated with "dwarfed" faunas, but are not themselves dwarfed (Benson, 1961), probably due to their toleration of salinities higher, or oxygen levels lower, than other faunas are able to tolerate. Because of their benthonic habit, however, ostracods might be excluded from areas of dense brine concentration because the brines would tend to accumulate along the bottom and in topographic lows.

Within the study area, virtually all ostracods found in lithofacies other than LF-1 are disarticulated, indicating that ostracods were transported into, rather than living in, lithofacies shoreward of LF-1. Even within LF-1 there is no great abundance of ostracods, which indicates that conditions for ostracod growth during formation of LF-1 were marginal. Thus, during formation, LF-1 was probably on the shoreward or the salinity edge of ostracod production.

Orthochems

Microcrystalline Matrix

Microcrystalline calcite: Microcrystalline calcite or micrite (Folk, 1980) consists of calcite crystals generally between 1 and 4 um in size. Three general sources for micrite are possible: 1) mechanical or biological abrasion of larger carbonate particles; 2) direct inorganic precipitation and; 3) production by algal activity (Blatt and others, 1980).

Although all three processes probably contributed micrite to the study area, they may not have contributed equally. Due to the relative lack of crossbedding, grainstones, or well-sorted deposits, mechanical abrasion probably produced insignificant quantities of micrite. The relatively low number of fossils which may have ingested carbonate grains (producing micrite) also reduces the probable contribution by this process. Production of micrite within the tissue of calcareous algae probably contributed some micrite to the study area, but changing conditions within the non-calcareous algal micro-environment raises pH and, therefore, carbonate concentration (Schneider and others, 1983), which may have led to large amounts of inorganic micrite production.

Micrite may also have been produced in significant quantities by purely abiogenic removal of carbon dioxide from the water column. Removal of carbon dioxide may be caused by several variables, including increasing water temperatures and salinities, or consumption by bacterial activity which rises with increasing salinity (Sonnenfeld, 1984, p.163). Calcium carbonate is relatively insoluble in pure water in the pressure-temperature range of the surface of the sea if no carbon dioxide is present. Pobeguin (1954) found that solubilities of calcium carbonates in carbon dioxide-free waters are 14.3 mg/l for calcite and 15.3 mg/l for aragonite. However, with the addition of carbon dioxide to the water, calcium carbonate solubilities can reach hundreds of mg/l (Bathurst, 1975, p.231).

Thus, if carbon dioxide is removed from the system (Sonnenfeld, 1984, p.163), calcium carbonate solubilities will decrease, leading to precipitation.

A major portion of the carbon dioxide in sea water is held in the bicarbonate ion (Bathurst, 1975, p. 232), although the carbonate ion may have that distinction at elevated salinities/pH (Sonnenfeld, 1984, p. 163). Since both the bicarbonate (Wattenberg, 1936) and carbonate ions (Hardie and Eugster, 1970) are virtually absent in waters near the concentration at which a brine is saturated for gypsum, most of the carbon dioxide should have been removed and calcium carbonate precipitated from waters nearing gypsum saturation.

Due both to the proximity of evaporite deposition and the interpreted warm, shallow-water conditions, inorganic precipitation is interpreted to account for most of the micrite found in the study area. Secondary amounts were probably produced by organic activity.

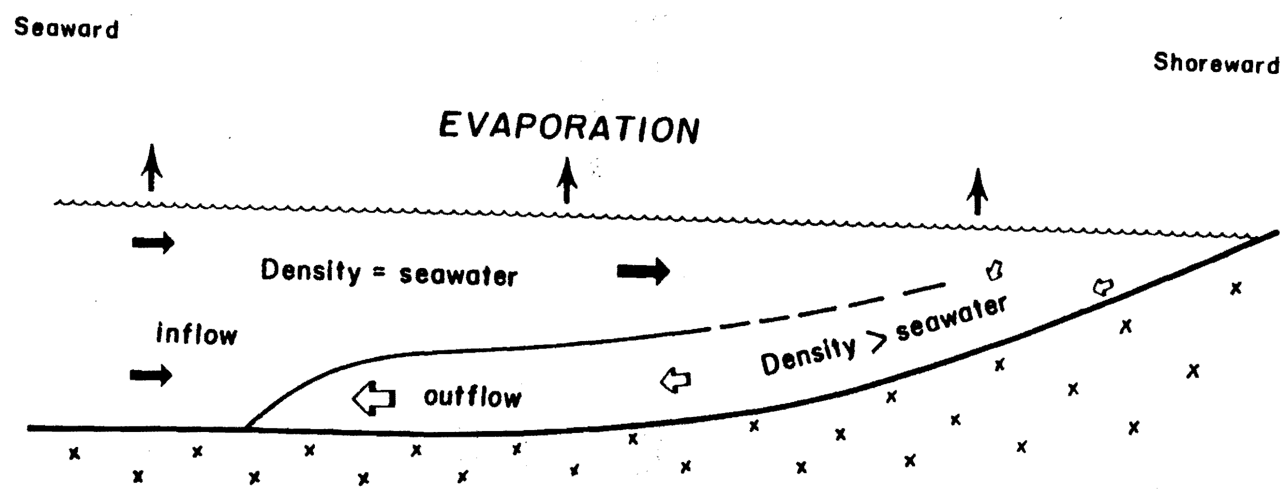
Microcrystalline dolomite: Microcrystalline dolomite (dolomicrite), as used in this study, is that portion of dolomite (generally less than 5 um size) which is interpreted to be of primary or near-surface origin due to crystal size, lack of allochems, and/or well-preserved sedimentary structures. It is typically associated with evaporites or occurs as thin, laterally extensive, argillaceous dolomudstone beds that often exhibit well-preserved crossbedding. Well-preserved crossbedding may indicate precipitation of dolomite before deposition by currents.

Several writers have suggested that dolomite can be formed as a primary or evaporite mineral from hypersaline brines (Edie, 1958; Behrens and Land, 1972; and Friedman, 1980), although this appears to be based on its common occurrence with other evaporites. Since dolomite, as opposed to calcite, is commonly associated with evaporites, it is not surprising that dolomite is more stable than calcite at pH values which favor gypsum precipitation (Sonnenfeld, 1984, p.169).

Because of its occurrence between micrite and evaporite-dominated lithofacies in the study area, dolomicrite is thought to have formed due to the relatively greater Mg/Ca ratio which must have existed in the environment. Mg/Ca ratios would have been elevated due to increasing salinity (ionic concentration) in waters being drawn toward the evaporite-dominated areas (shoreward) by evaporative head.

Mg-rich, dense, saline-brines formed in areas of gypsum precipitation (generally shoreward), and most likely flowed basinward as bottom-hugging brines (Fig. 53) (Fischer and others, 1987; Appendix E, this paper). As the Mg-rich brine came in contact with carbonate ions in the water-column basinward of the gypsum precipitating areas, it would probably form primary dolomite at or above the sediment/water interface. Additionally, previously formed micrite (calcium carbonate) could be dolomitized by this brine in a manner similar to reflux-dolomitization (Adams and Rhodes, 1960; Sears and Lucia, 1980) except that it appears to have dolomitized only at, or a short distance below, the sediment-water interface (Luther and others, 1987; Appendix D, this paper). Thus, both primary dolomite formation and near- surface dolomitization are possible within the environmental configuration suggested for the study area, and are the probable sources of dolomicrite in the study area.

Figure 53: A schematic diagram that illustrates possible fluid movements affecting sedimentation in the study area. Continuous evaporation of marine water in the Basin would require the inflow of marine water (solid arrows) to replace that water lost by evaporation. Evaporation of marine waters would form dense, concentrated brines that would settle to the sea bottom and displace less dense waters (light arrows). Micritic dolomite might form near the seaward margin of the outflowing brine. No scale intended; vertical scale and slope greatly exaggerated. Modified from Sonnenfeld (1984).



Modified from Sonnenfeld (1984)

Microcrystalline calcium sulfate: Microcrystalline calcium sulfate (micritic gypsum) as used in this study is calcium sulfate (generally fine-grained anhydrite now) which is interpreted to have precipitated from surface waters, although some may have been redeposited by eolian processes. Micritic gypsum is most common in the most shoreward portions of the study area. It usually occurs as massive to weakly laminated anhydrite with rare, thin crossbedding, or forms the matrix between siliciclastic grains in LF-6. Micritic gypsum crystals may be lath-like or equigranular and are generally less than 5 um in size.

Precipitation of calcium sulfate occurs when the partial pressure of carbon dioxide drops below $10^{-3.7}$ atmospheres (Stumm and Morgan, 1970). Calcium sulfate precipitation often starts only after salinities of 117 ppt (Elderfield, 1976) are reached, at which time approximately 80% of a given volume of seawater has evaporated.

Crystal shape may be affected by several variables, of which two are most important. First, high-pH solutions produce equigranular crystals, whereas acicular crystals are restricted to acidic environments (Barta and others, 1971). Secondly, partial dehydration of gypsum produces bassanite, a powdery calcium sulfate (Sonnenfeld, 1984; Kinsman, 1974). Either or both of these variables may have affected micritic gypsum crystal size and shape in the study area.

The presence of humic acids may have controlled the crystal shape of calcium sulfates precipitated in areas containing abundant dolomicrite or stromatolites. Massive-bedded calcium sulfates generally consist of equigranular crystals, which may be a result of precipitation in a high pH solution or periodic subareal exposure and dehydration of pre-existing calcium sulfates. Pitted surfaces on some quartz grains in the study area and higher up in the section (Quinn, 1986) may be due to high pH conditions. Since no evidence was found to support periodic, large-scale exposure and dehydration of large bodies of calcium sulfate, the dominantly equigranular calcium sulfate crystals in the study area must be due to precipitation from a high pH fluid.

Lithofacies

Introduction

The distribution of different minerals and allochems (including fossils) in non-detrital settings is controlled by the presence of a depositional (or chemical) environment that favors formation of a particular mineral or allochem type. Thus the distribution of described minerals and allochems in the study area may be used to infer the depositional environment.

In a southwest (seaward) to northeast (shoreward) cross section of the study area, several relations are apparent, including: 1) both the number and variety of fossils decrease in a northeast direction; 2) calcite grades laterally into dolomite, that in turn grades laterally into anhydrite in a northeast direction; and, 3) calcite cement dominates in the southwest while anhydrite cement is dominant in the northeast. These three relations appear to be controlled by a single factor, specifically, increasing salinity of the waters in which fossil organisms lived and from which the minerals precipitated in a northeast (shoreward) direction.

Water salinities progressively increased in a northeast direction, forming a salinity gradient across the study area. Due to the vertical stacking of lithologies in the studied section, the salinity gradient appears to have been relatively static during deposition of the sediments forming the Glenburn bed and the lithofacies defined in the study area. A depositional scenario in which salinity increases from the southwest to the northeast or shoreward across the study area is described in the following section.

Marine waters entered the study area from the southwest (seaward) to replace water lost by evaporation. Marine waters entering the study area became increasingly saline due to evaporation as they flowed northeast (shoreward), forming a water body containing a "horizontal salinity gradient". The horizontal gradient is defined by progressively higher salinities laterally grading into one another in the shoreward direction (Fig. 54). Salinities in the most northeastern (shoreward) parts of the study area became high enough to initiate gypsum precipi-tation. Thus fossil types, other allochems, and major minerals, should and do reflect the increasing salinity, in a northeast direction, of the marine waters from which they formed.

Discussion

Scruton (1953) hypothesized a horizontal salinity gradient within the water column in a marine estuary (Fig. 55), and suggested that increasingly soluble minerals would precipitate from marine waters as they became progressively more saline. If the relative positions of salinities within a horizontal salinity gradient were static, Scruton (1953) suggested that salts (minerals) would be precipitated primarily where the salinity and fluid densities were conducive to precipitation of a particular salt, leading to laterally adjacent bodies of

Figure 54: A schematic drawing illustrating the laterally increasing salinity in the water column and its affect on fossil and mineral varieties and distribution. Also shown are the positions of the lithofacies defined in this study relative to the position of the horizontal salinity gradient.

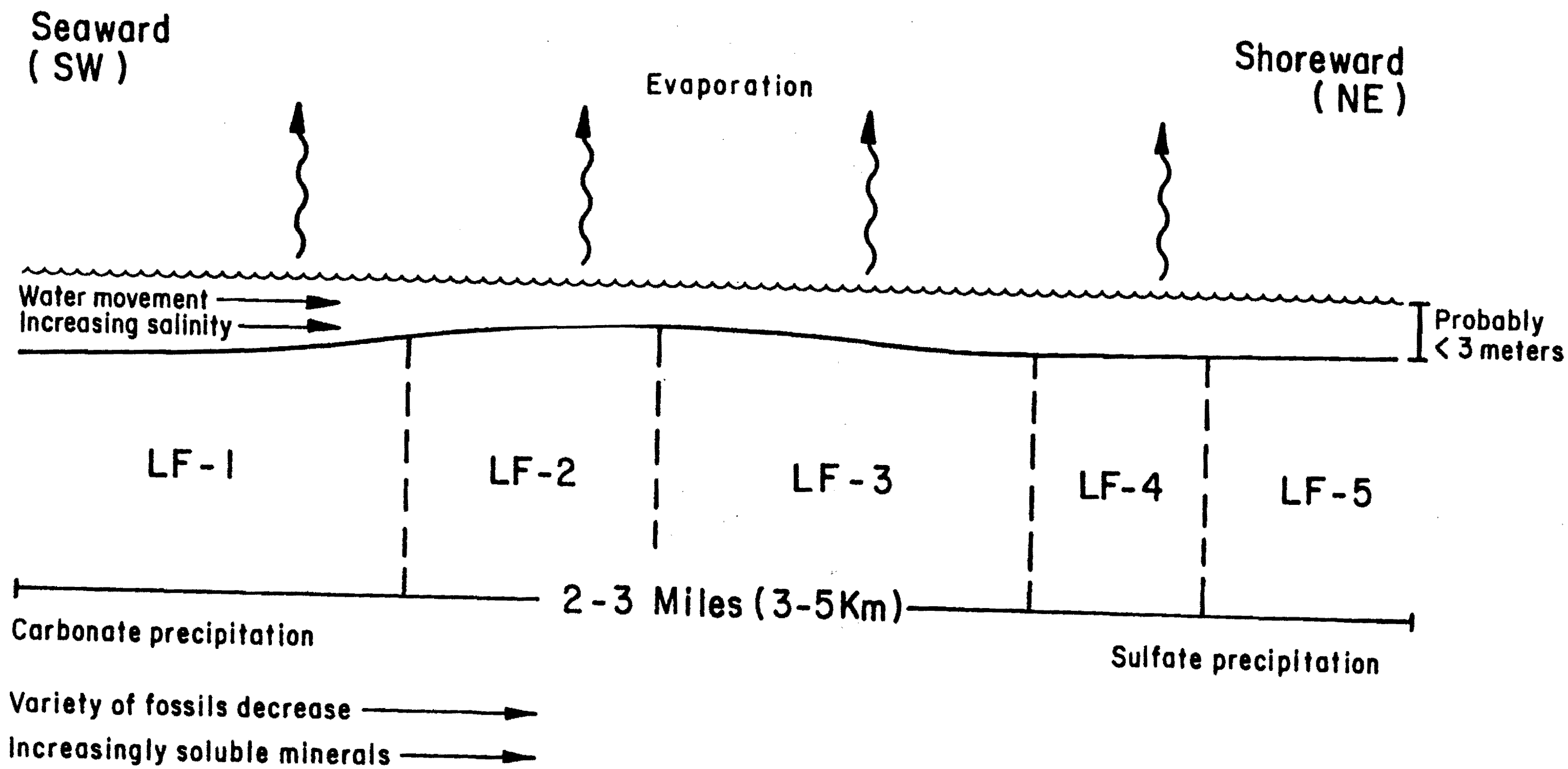
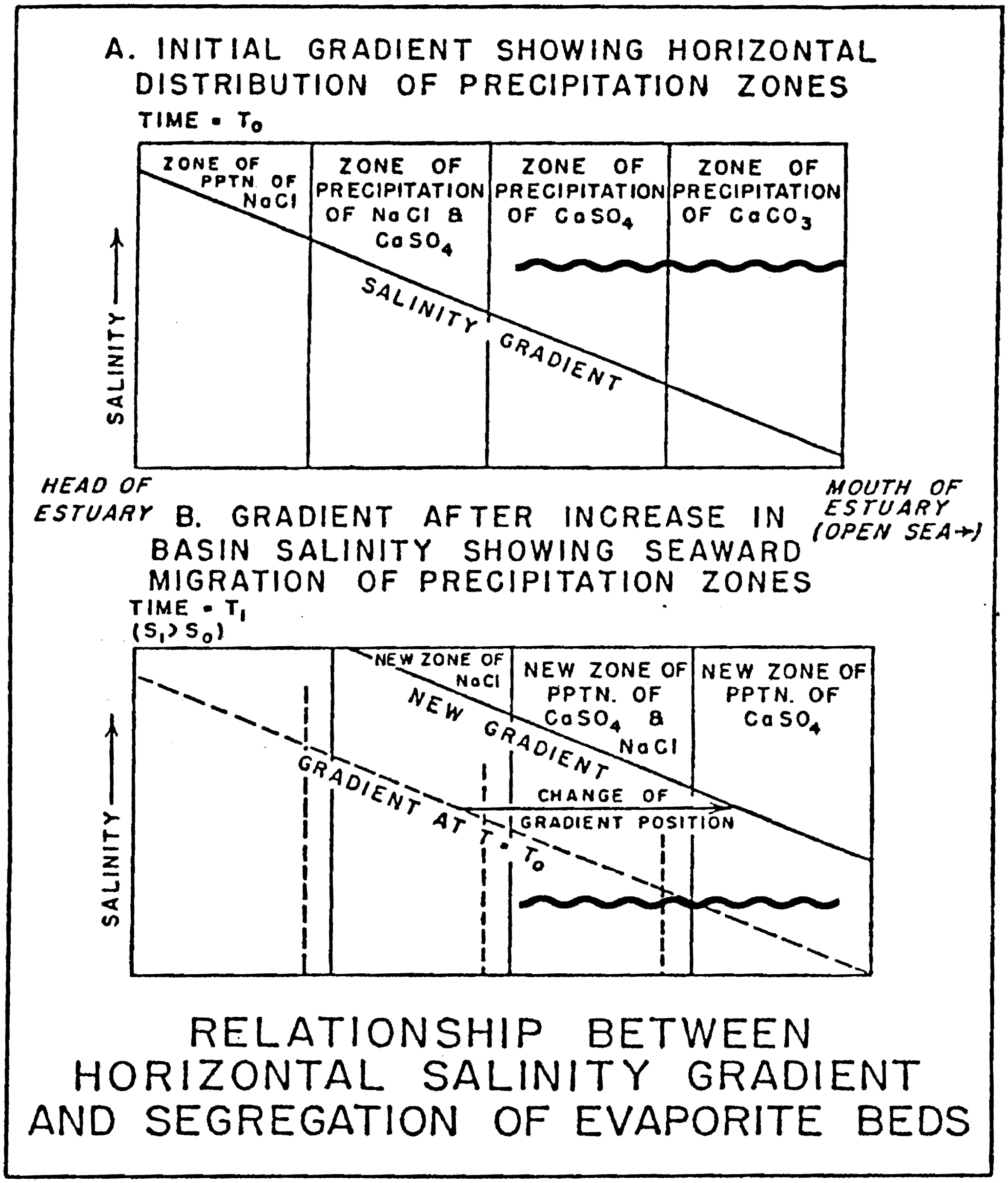

Seaward
(SW)
Evaporation
Shoreward
(NE)
Water movement
Increasing salinity
Probably
< 3 meters
LF-1
LF-2
LF-3
LF-4
LF-5
2-3 Miles (3-5Km)
Carbonate precipitation
Sulfate precipitation
Variety of fossils decrease
Increasingly soluble minerals

Figure 55: A diagram illustrating Scruton's (1953) horizontal salinity gradient model and the probable position of the study area (heavy, wavy line) relative to such a salinity gradient. Modified from Scruton (1953).


A. INITIAL GRADIENT SHOWING HORIZONTAL DISTRIBUTION OF PRECIPITATION ZONES
TIME = T_0
ZONE OF PPTN. OF NaCl
ZONE OF PRECIPITATION OF NaCl & $CaSO_4$
ZONE OF PRECIPITATION OF $CaSO_4$
ZONE OF PRECIPITATION OF $CaCO_3$
SALINITY GRADIENT
SALINITY
HEAD OF ESTUARY
MOUTH OF ESTUARY (OPEN SEA→)
B. GRADIENT AFTER INCREASE IN BASIN SALINITY SHOWING SEAWARD MIGRATION OF PRECIPITATION ZONES
TIME = T_1
($S_1 > S_0$)
NEW ZONE OF NaCl
NEW ZONE OF PPTN. OF $CaSO_4$ & NaCl
NEW ZONE OF PPTN. OF $CaSO_4$
NEW GRADIENT
GRADIENT AT T = T_0
CHANGE OF GRADIENT POSITION
SALINITY
RELATIONSHIP BETWEEN HORIZONTAL SALINITY GRADIENT AND SEGREGATION OF EVAPORITE BEDS

increasingly soluble salts in the direction of higher salinities. As salinity increases, minerals precipitate in order of increasing solubilities, i.e., calcium carbonates, followed by calcium sulfate, followed by sodium chloride.

The presence of a horizontal salinity gradient, and the order of salt (mineral) precipitation hypothesized by Scruton (1953), has been described in a modern environment. Brantley and others (1984) in a study of a Peruvian estuary, the Bocana de Virril , described a setting in which marine waters flow into the estuary to replace water lost by evaporation. Normal marine water entering the mouth of the estuary becomes increasingly saline as it flows to the estuary head. Brantley and others (1984) also noted the precipitation of increasingly soluble minerals as they got farther away from the mouth of the estuary (source of normal marine water). They noted that there was a lateral zonation of evaporite minerals toward the estuary head with calcite followed by gypsum and ending with halite.

The effect of a horizontal salinity gradient on the number and variety of organisms present in a marine water body has also been documented. Logan and Cebulski (1970), in a study of Shark Bay, Western Australia, found that biotic zones were limited by water types. They noted that the variety of organisms (though not necessarily the numbers) decreased in the direction of increasing salinity.

Thus, it can be shown that a horizontal salinity gradient can affect the distribution of minerals and organisms in a predictable way. The interpretation that the various lithofacies found in the study area formed as a result of their position in marine waters that contained a horizontal salinity gradient, is supported by the distribution of major minerals and allochems, including fossil organisms (Fig. 56), in the study area. The lowest salinities were in the area containing LF-1, and salinities increased progressively in a northeast direction from LF-1 toward LF-5 (Fig. 54).

Fossiliferous grainy mudstone-packstone (LF-1)

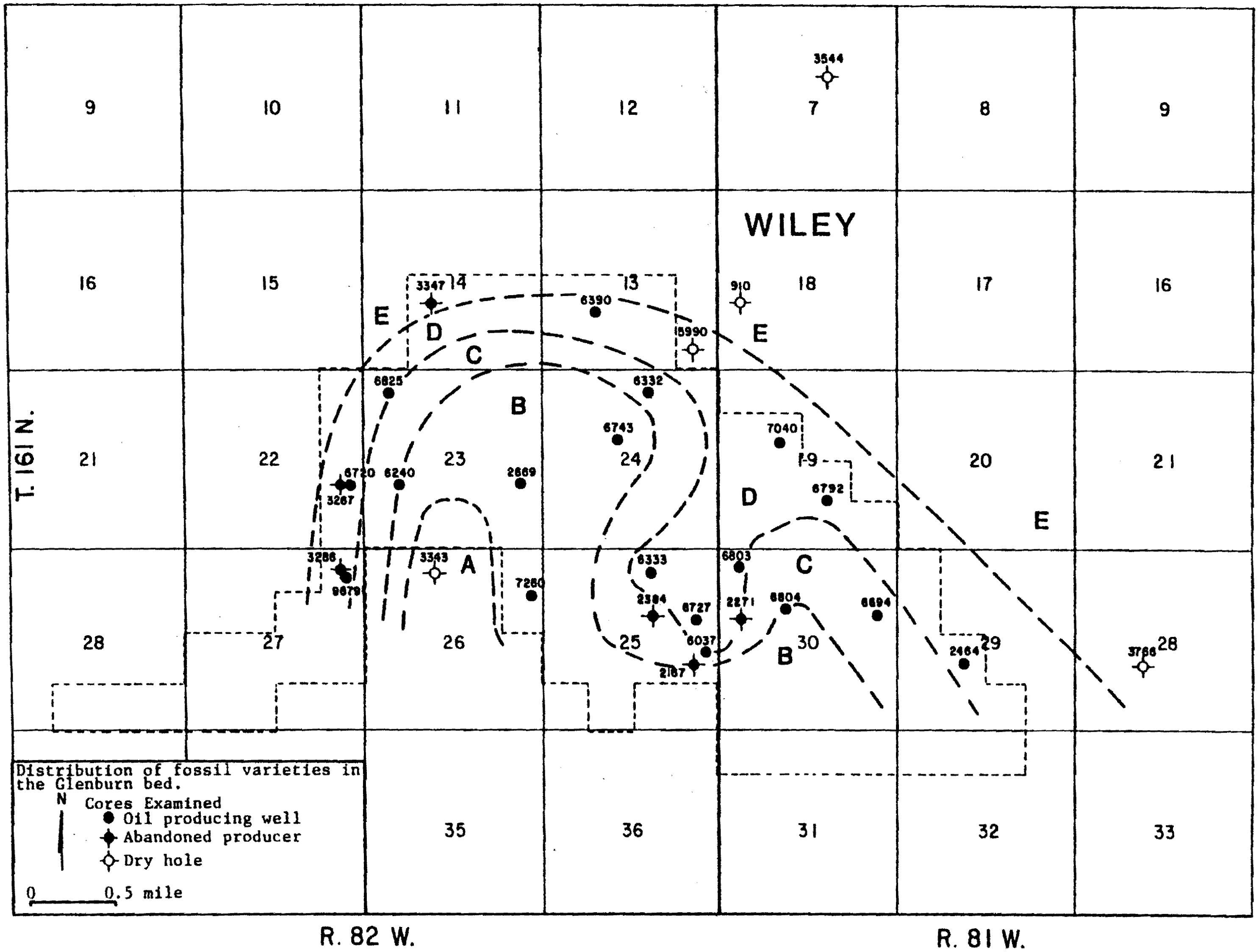
Deposition of the sediments forming LF-1 was in water conditions nearer to normal marine than that in which other lithofacies in the study area were deposited. Evidence supporting this includes a much greater diversity and number of fossils as well as cementation by calcite rather than anhydrite. Deposition was in a shallow-sublittoral setting; the sediments forming LF-1 were deposited in the topographically lowest portions of the study area.

Evidence for shallow-water conditions comes from isopach maps of rocks overlying carbonates of the Glenburn bed (Fig. 13) and measurements of the thickness of the Glenburn bed in the study area. These illustrate that there was no great change in slope (and thus depth) between the area where the sediments forming LF-1 were deposited and areas (shoreward) where the described lithofacies are inferred to have been deposited in shallow-water and possibly subaerially-exposed settings. Additional evidence for shallow-water deposition consists of the presence of light-colored rocks and fenestral fabrics in LF-1. The presence of scolecodonts is also indicative of warm, shallow marine conditions (F. W. Hueber, personal comm. 1986).

Within the Wayne bed, LF-1 is characterized by fossils indicative of near-normal marine conditions such as echinoderms, bryozoans,

Figure 56: The areal distribution of fossil varieties in the Glenburn bed. Boundaries are transitional and their positions are based on descriptions of the cored wells shown.

A = Common: calcisphere, calcareous and noncalcareous blue-green algae, ostracod, plant material, scolecodont.
Less common: coral, bivalve, gastropod, echinoderm, foraminifera.
B = Common: calcisphere, noncalcareous blue-green algae.
Less common: ostracod, calcareous blue-green algae, gastropod.
C = Isolated: calcisphere, ostracod, calcareous and noncalcareous blue-green algae.
D = Isolated: noncalcareous blue-green algae, ostracod.
E = No fossils detected.



Distribution of fossil varieties in the Glenburn bed.

brachiopods, and corals (Heckel, 1972). In cores from more basinward wells, fossils become slightly more abraded and disarticulated, and the rocks become moderately to well-sorted and nearly mud-free, and may contain weak, low-angle crossbedding. More shoreward cores contain the same varieties of fossils, although in lower numbers and with more fine-grained matrix. Higher energy conditions basinward are indicated by the relative lack of mud in those cores. This may be due to an abrupt change in basinal slope or to low-relief shoals which received more wave action than that in more shoreward areas. LF-1 within the Wayne bed is very similar to Obelenus' (1985) skeletal grainstone lithofacies.

Within the Glenburn bed, LF-1 is characterized by a relative lack of stenohaline fossils and a great abundance of micritic matrix. The most common fossils include calcispheres, ostracods, and calcareous blue-green algae, although gastropods, brachiopods, corals, and foraminifera are also found in smaller numbers. The relative absence and/or presence of these fossils types indicates formation in a sublittoral, transitional-restricted to hypersaline marine environment (Heckel, 1972). Low to moderate energy is indicated by the abundance of micrite found in the rocks. LF-1 within the Glenburn bed is somewhat similar to Obelenus' (1985) calcisphere wackestone and packstone lithofacies, although it probably grades basinward into facies formed in more normal marine conditions.

Some fossils within the Glenburn bed section of LF-1 are problematical, due both to their origin and excellent preservation. Plant fragments and megaspores (arborescent lycopods) preserved in nonbioturbated marine carbonates of LF-1 show no evidence of transport, yet they are thought to be from freshwater land plants (Luther and others, 1987; Appendix D, this paper). A mechanism responsible for the incredible preservation of these organic fossil fragments is also difficult to envision, given the shallow, carbonate-producing marine setting indicated by all other characteristics of the lithofacies. Preservation by nearly anoxic, dense, saline brines is proposed for the fossil plant fragments found in LF-1 (Luther and others, 1987; Appendix D, this paper).

LF-1 was thus deposited in a shallow, low to moderate energy, sublittoral setting with salinities ranging from greater than 35 parts per thousand (ppt) to periodically greater than 100 ppt. Based on the types of fossil organisms found and their salinity tolerances (Heckel, 1972), deposition of the sediments forming LF-1 in the Wayne bed probably occurred in salinities of 35-45 ppt whereas deposition in the Glenburn bed may have occurred in salinities averaging between 45 ppt and 60 ppt.

Coated-grain wackestone-grainstone (LF-2)

LF-2 was deposited in a shallow, moderate-energy, sublittoral setting with probable hypersaline conditions. Deposition on low relief, topographic highs or shoals is indicated.

Several characteristics aid in determining the depositional environment of LF-2: 1) the paucity and type of fossils; 2) the predominance of coated grains, most with radially-fibrous laminations; 3) the greater frequency of occurrence of grainstones; 4) the common occurrence of fenestral fabrics and fine-grained crusts or laminations; 5) predominantly calcite cements; and 6) the areal distribution of LF-2.

Although water energy conditions appear to have been higher during the deposition of LF-2 than in other lithofacies, energy was still relatively low. The abundance of micrite supports both the low energy conditions, and that substrate movement was not a major control on the abundance of organisms as would be the case in a high energy, grain-rich environment. The relative lack of fossils, and the types of the fossils that are present (mostly blue-green algae, calcispheres, and ostracods), indicate water conditions which were usually too extreme (saline) for most organisms other than blue-green algae and/or bacteria. Water temperature may have had some effect on organisms, but other than contributing some control on dissolved-oxygen content, temperature effects are not known. If the paucity of fossils was caused by salinity, very hypersaline conditions must have been present to exclude all organisms except for the most euryhaline types (Heckel, 1972).

Water-energy conditions which formed LF-2 appear to have been slightly higher than in the other lithofacies, and fairly uniform through time. Evidence supporting greater energy conditions includes radially-fibrous coated grains which imply gentle agitation (see coated grain interpretive section) and the occasional presence of grainstones (some crossbedded) which require higher energy levels to remove the mud. The balance of these two characteristics would require fluctuations of generally low to moderate energy levels in the deposition of sediments forming LF-2.

Fenestral fabrics which are common in LF-2 often indicate deposition in intertidal areas in modern environments, but are not restricted to that environment. Shinn (1983) found cemented pelletal and oolitic sediments which contained fenestrae (very similar to those found in LF-2) formed and cemented in a subtidal setting. Shinn (1983) suggested that the fenestrae were primary voids, the result of resedimentation of irregularly shaped cemented aggregates or lithoclasts. Most of the fenestral fabric in LF-2 appears to be a result of algal and/or bacterial mat growth, although the process described by Shinn (1983), may have contributed. These algal and/or bacterial mats would tend to stabilize the substrate in the area of LF-2 as well as trap and bind a variety of grain sizes, forming the poorly sorted, weakly to well laminated, thin beds found. Dill and Shinn (1986) found a similar relation between algal mat occurrence and substrate stabilization/grain entrapment in a modern, high-energy environment in the Bahamas.

Thin micritic laminations or crusts which are often found draping over grains or separating different size fractions of grains, are very similar in appearance to bacterial mats described by Folk and Chafetz (1983). These crusts have been considered to be of vadose origin in nearby areas by several writers (Elliot, 1982; Gerhard, 1985), but there does not appear to be indisputable evidence supporting subaerial exposure of sediments forming LF-2. Evidence, such as numerous occurrences of gravity or meniscus cements, was not found during this study. Radially-fibrous crusts which are formed inorganically and subaqueously are also present, and are here considered to have formed similarly to radially-fibrous coated grains (see coated grain interpretive section).

The cements found in LF-2 are predominantly calcite, and occur in several different forms. The restricted distribution of calcite cement in areas including and basinward of LF-2, rather than the dominantly anhydrite cements of more shoreward lithofacies (LF's 3-6), is suggestive of an origin that was controlled by surface fluid movements.

Another characteristic that aids in determining the depositional environment of LF-2, is the areal distribution of LF-2 relative to the other described lithofacies. The roughly parallel, banded nature of the lithofacies (Fig. 27), along with LF-2's position between the relatively fossiliferous LF-1 (seaward) and bedded anhydrites of LF-5 (shoreward), suggests deposition in water of greater salinity than for LF-1, and lesser salinity than for LF-5.

Therefore, sediments forming LF-2 appear to have been deposited in shallow, hypersaline waters of low to moderate energy. Deposition was in a sublittoral setting which may have been rarely subaerially exposed. The sediments that formed LF-2 were deposited on low-relief topographic highs or shoals, where wave energy would be high relative to areas of adjacent lithofacies. Near surface flow of calcite precipitating fluids through sediments was probable.

Peloidal/intraclastic wackestone-packstone (LF-3)

LF-3 was deposited in a shallow, low-energy, sublittoral setting with hypersaline water conditions. Infrequent deposition by storms may have occurred.

Several characteristics aid in determining the depositional environment of LF-3: 1) the paucity and type of fossils; 2) the predominance of peloids and intraclasts; 3) the abundance of micrite and dolomicrite; 4) the thin bedded to laminated deposits; 5) the predominantly anhydrite cement; and 6) the great variety of diagenetic minerals.

Fossils found within LF-3 consist of low numbers of calcispheres, ostracods (generally disarticulated), and blue-green algae (stromatolites). The calcispheres and ostracods were probably transported into the location of LF-3 while the blue-green algae (stromatolites), that are highly tolerant of saline conditions (Heckel, 1972; Wray, 1977), grew where the sediments which formed LF-3 were deposited. The lack of fossil types other than those tolerant of hypersaline conditions, along with preserved primary evaporites in the adjacent LF-4, indicate very hypersaline conditions.

As indicated previously in the section on allochems, peloids and intraclasts may have formed in LF-3 as a result of evaporite precipitation and later dissolution, the presence of Mg-rich, saline brines, or bacterial processes, all of which require or could take place in hypersaline environments.

The abundance of micrite and dolomicrite, as well as the relative lack of coated grain types which require some agitation, indicate low energy conditions. Infrequent rip-up of partially lithified, laminated sediments (Fig. 36) was probably caused by storms. The lack of features indicative of subaerial exposure suggests deposition in a shallow, but generally sublittoral, setting.

The generally thin-bedded, fine-grained material (micrite and dolomicrite) in LF-3 may be from primary precipitation (see orthochem interpretive section) or may be from the settling out in low-energy waters of material washed from adjacent higher-energy environments. Laminar stromatolites very likely contributed to the laminated nature of the lithofacies. Infrequent, thin, patterned dolostones appear to be basinward extensions of more argillaceous types found shoreward (updip) in LF-4. The thin, relatively widespread nature of the patterned dolostones may be due to sea level drop, increased salinities, and eolian deposition in the Haas Field (Elliot, 1982), but is likely due to a sudden change in salinities by the introduction of continentally-derived waters in updip (shoreward) portions of the study area. The infrequent dispersion of less dense continental derived waters and suspended silts and clays across the surface of dense, hypersaline marine brines (interpreted in LF-4) may have formed the patterned and argillaceous dolostones, and is favored by this writer.

The distribution of predominantly sulfate (mostly anhydrite) cements in LF-3, which is located between basinward calcite precipitating areas (LF's 1 and 2) and shoreward evaporite precipitating areas (LF's 4 and 5), is suggestive of early, near-surface formation of sulfate cements.

The occurrence and estimated time of formation of diagenetic and/or primary precipitated minerals such as fluorite, celestite and cryptocrystalline quartz within LF-3, supports the presence of evaporite-precipitating brines in a surface or shallow-subsurface setting. The presence of fluorite within apparently noncompacted silicified zones, concentrated in stylolite seams, within carbonates, and within carbonates replaced by anhydrite, indicates that fluorite was formed along with or shortly after the carbonates and before the occurrence of anhydrite replacement, pressure solution, silicification, and substantial compaction of carbonates. Fluorite will precipitate directly from evaporating marine brines and is frequently found as traces in limestones surrounding an evaporite pan (Sonnenfeld, 1984, p.226-227).

The presence of celestite as clastic grains and/or displacive crystals, which indicates formation at the surface or in the shallow subsurface prior to carbonate lithification, is evidence for the presence of evaporite-precipitating brines in LF-3 during or shortly after deposition. Celestite (strontium sulfate) has a lower solubility than gypsum (calcium sulfate) (Sonnenfeld, 1984, p. 186) and thus is already precipitating at the onset of gypsum precipitation. Additionally, celestite solubility decreases with increasing temperatures (Sonnenfeld, 1984, p.186-187). Thus celestite precipitation may be a result of increasing brine concentration (salinity), increasing water temperature, or both.

The paucity and types of fossils, the increased frequency of sulfates and associated diagenetic minerals, and the abundance of micrite and dolomicrite, may all be used to infer the depositional environment for LF-3. The evidence indicates lower energy levels and much greater restriction and/or increasing temperature of waters forming LF-3 than for the more basinward LF's 1 and 2, and is consistent with overall salinity increasing to the northeast.

Dolowackestone-mudstone and nodular anhydrite (LF-4)

LF-4 was deposited on a very low relief surface in a low-energy, hypersaline, shallow-sublittoral to possibly supralittoral setting. Alternating water conditions favoring dolomite or calcium sulfate formation resulted in a mixture of the two within LF-4, and an interfingering with adjacent lithofacies. Due to LF-4's position adjacent to the evaporite-precipitating brines which formed LF-5, it facies in the study

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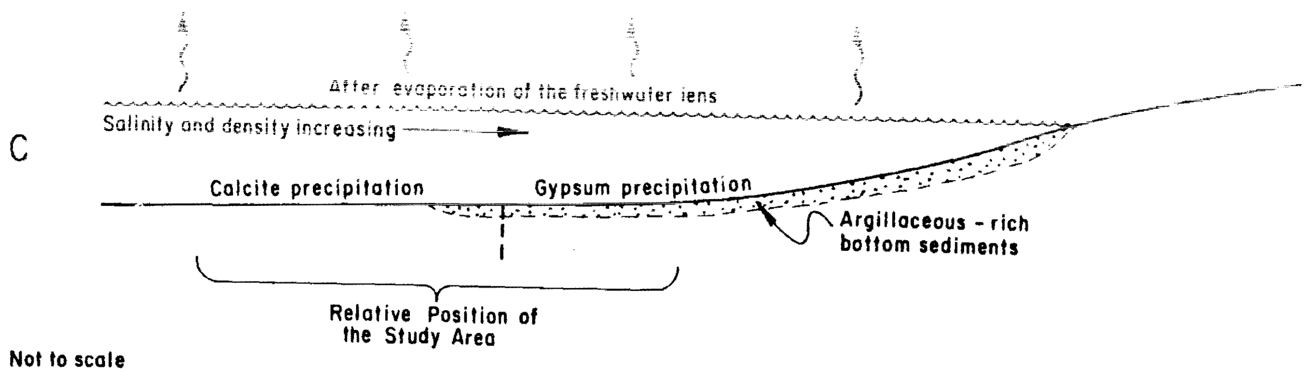
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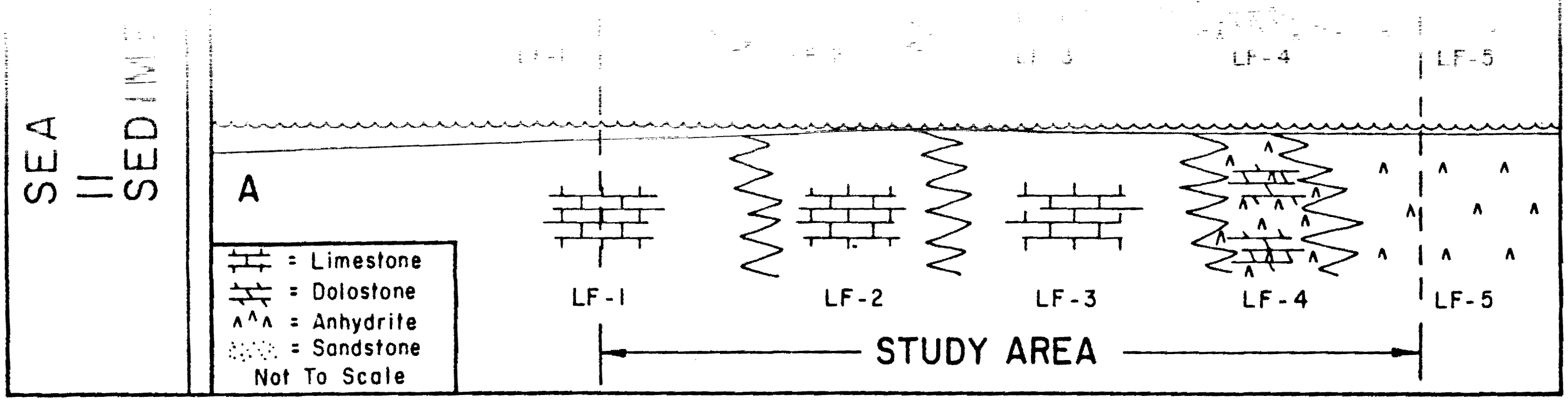
SEA
SEDIM
A
LF-1
LF-2
LF-3
LF-4
LF-5
STUDY AREA
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= Dolostone
= Anhydrite
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...ed and formed a sand
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...nner of deposition of
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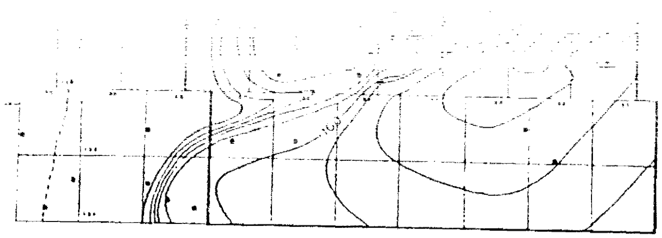
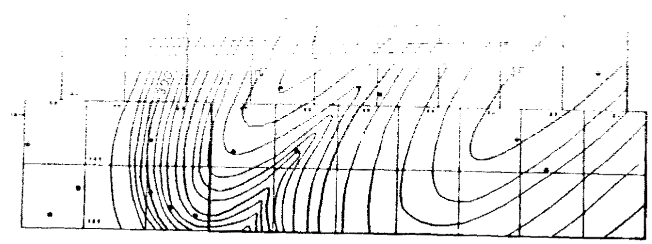
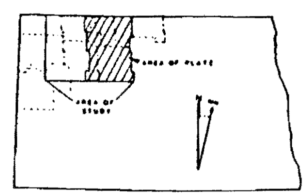


ANHYDRITE ISOPACH



CARBONATE ISOPACH



CONTOUR INTERVAL 10 FT

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...or thick halite bodies in
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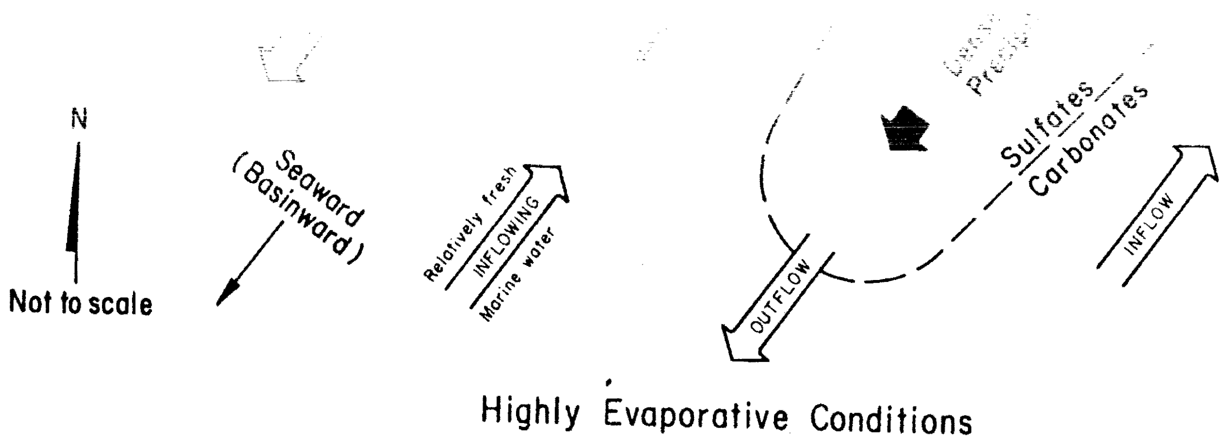
N
Not to scale
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Relatively fresh
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INFLOW
Highly Evaporative Conditions

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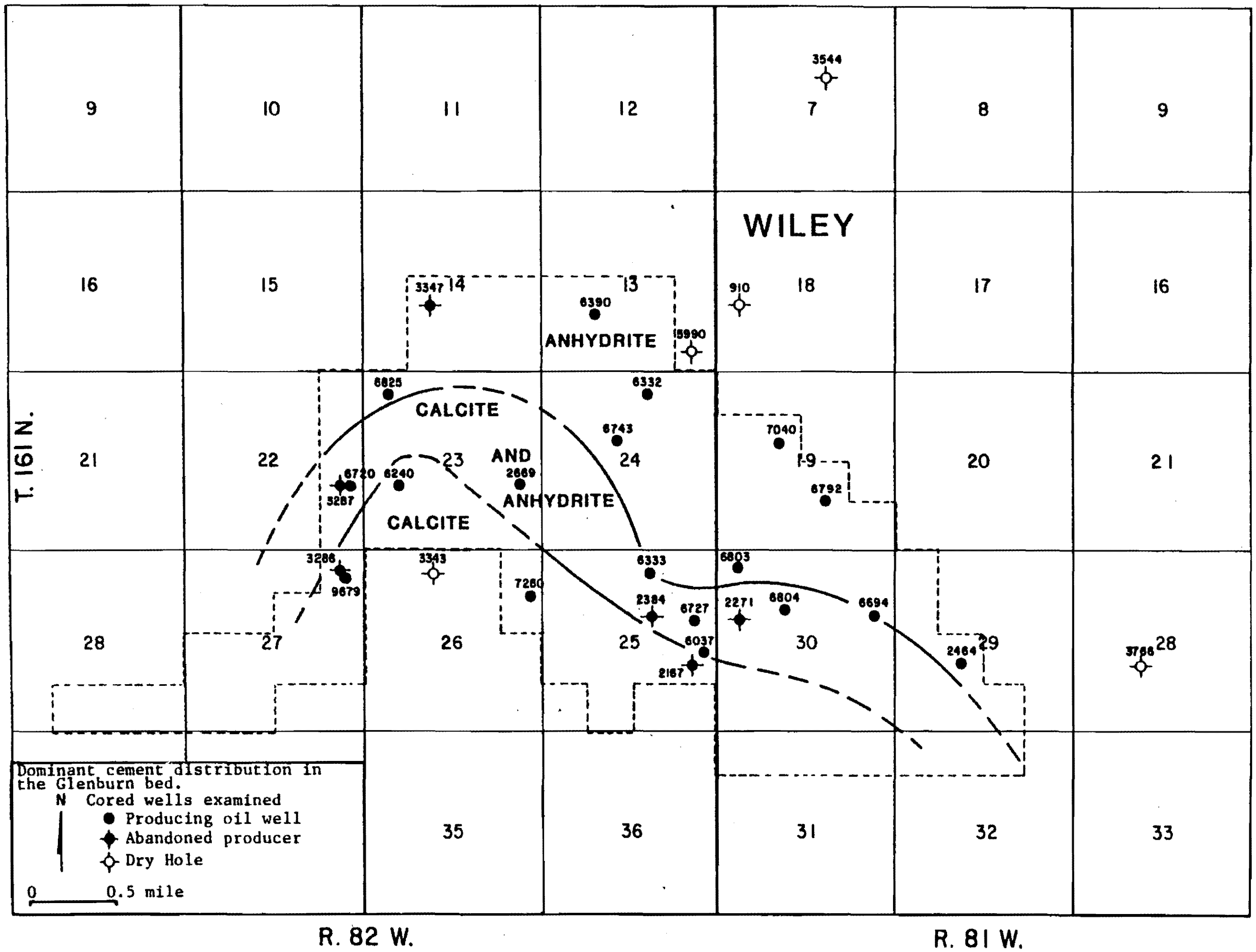
Figure 62: A figure illustrating the approximate distribution of the two dominant cement types (calcite and anhydrite) in the study area.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6240
2669
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Dominant cement distribution in the Glenburn bed.
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Cored wells examined
Producing oil well
Abandoned producer
Dry Hole
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0.5 mile

(equant, 2/1 to 1/1: Length/Width), bladed (6/1 to 2/1: L/W), and fibrous (greater than 6/1: L/W). Minor amounts of syntaxial cements occur locally in fossil-rich zones. Microprobe analyses indicate that low-Mg calcite is the mineral phase in all crystal forms.

Blocky Calcite: Blocky calcite is the most common calcite cement morphology in the study area (Fig. 63). It is found predominantly in LF-2 and in lesser amounts in LF's 1 and 3. Crystals with a blocky habit typically line or occlude pores and infrequently share pore space with anhydrite. Crystal size varies from less than 50 um to greater than 1 mm. Blocky calcite most commonly occurs in secondary or enlarged pores and may fill pores which are lined with fibrous or bladed spar cement.

Where they occur together, precipitation of blocky calcite appears to have occurred later than fibrous or bladed calcite. Relative timing of blocky-spar precipitation in pores which also contain sulfate cement is not obvious, but calcite appears to have precipitated first.

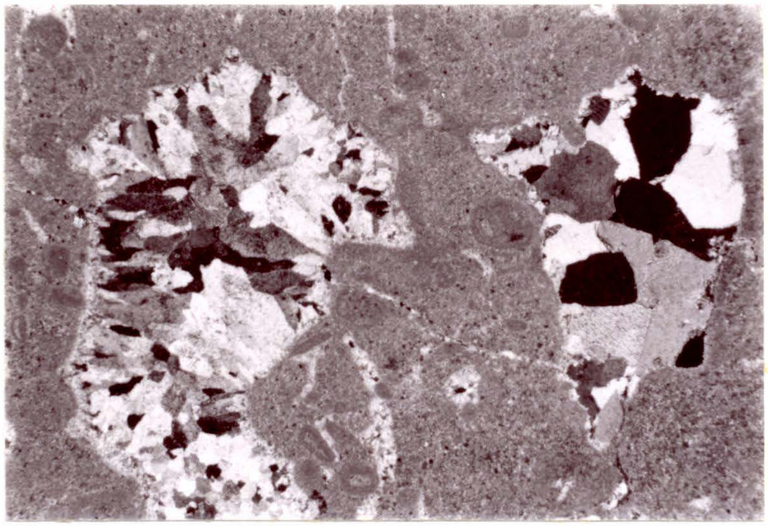
Bladed Calcite: Bladed calcite is much less common in the study area than blocky calcite, and occurs predominantly in LF-1, and in lesser amounts in LF-2. Crystals with a bladed habit typically line or occlude pores (Fig. 63) and share pore space with blocky calcite. Precipitation of bladed calcite appears to have preceded that of blocky calcite in every observed occurrence. Crystal size is generally less than 1 mm in the longest dimension. Bladed calcite most commonly occurs in primary voids such as sheet cracks and fenestrae, and may fill secondarily enlarged pores.

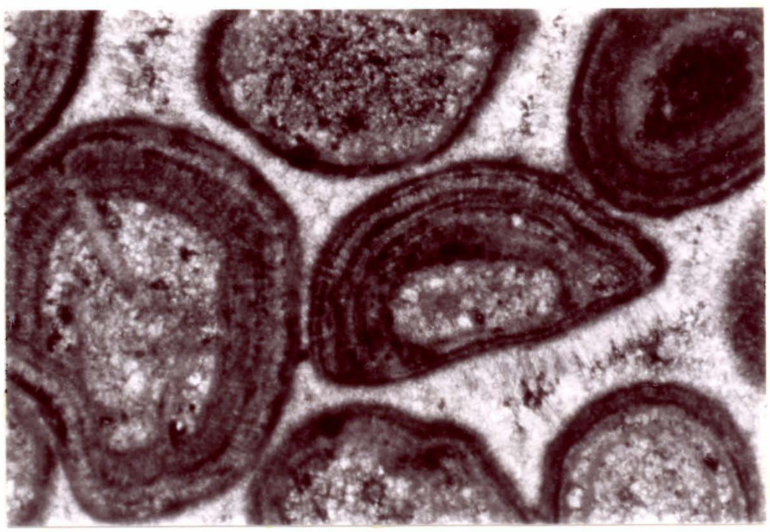
Fibrous Calcite: Fibrous calcite is the least common calcite

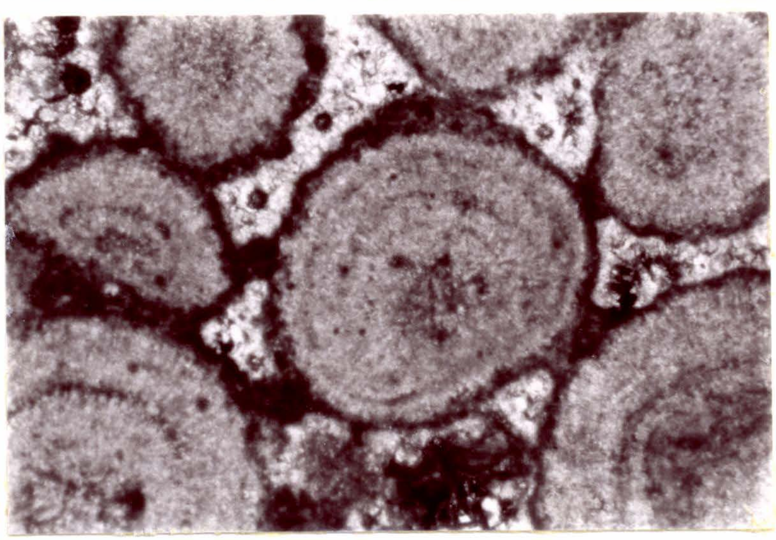
Figure 63: Photomicrograph showing blocky- (bottom) and bladed- (top) calcite cement occluding vugs. NDGS# 3343, depth 4173.1 ft, field of view 4.3 mm wide, XP. Up is left (toward binding).

Figure 64: Fibrous-calcite cement occluding interparticle pores in an ooid grainstone. NDGS# 7260, depth 4153 ft, field of view 1 mm wide, XP.

Figure 65: Rare, micritic, meniscus cements (dark) forming at grain contacts. Grain (ooid) margins are also micritic. NDGS# 6720, depth 4170.4 ft, field of view 1.3 mm, XP.







cement found in the study area, and occurs predominantly in LF-2 and much less frequently in LF-1. Crystals with a fibrous habit have an isopachous morphology, and typically line and/or fill interparticle pores in grainstones and intraparticle pores in fossils. Crystal size is generally less than 0.5 mm in the longest dimension. Fibrous calcite nearly always occurs in primary voids such as interparticle pores in ooid grainstones (Fig. 64).

Although micritic cement (blocky crystals less than 10 um and generally opaque (Folk, 1980)) is present within the study area, it is difficult to differentiate it from the micritic matrix discussed in the orthochems section. The only indisputable micritic cements recognized during the study were very rare meniscus (pore rounding) cements (Fig. 65) in a single sample of an ooid grainstone. Micritic pendant (gravitational) cements may also be present rarely. However, due to the presence of internal laminations, often formed by alternating radially-fibrous and micritic laminae, these pendants may be some type of algal or bacterial structure rather than true pendant cements.

Discussion:

Calcite cement of various crystal morphologies has been attributed to formation in a variety of physical settings and chemical environments. Suspected controls on calcite crystal morphology have included salinity (Friedman, 1968), the Mg/Ca ratio of the precipitating fluid (Folk, 1974), and numerous depositional settings in which the various cement morphologies occur (Harris and others, 1985).

A more satisfying explanation for calcite crystal habits was given by Given and Wilkinson (1985) who suggested that crystal morphology is controlled by the rate of reactant supply to a growing crystal surface. Greater amounts of reactants produce more elongate (fibrous) morphologies while lesser amounts of reactants produce equant (blocky) crystal morphologies.

The amount of reactant (Ca^{2+} and/or CO_3^{2-}) supplied to the site of cement precipitation may be controlled by the amount of fluid passing by (if reactant content of fluids are equal) or by differences in the amount of reactant in the fluid. Both factors may have controlled the formation of blocky spar within the study area.

Pores which contain both fibrous or bladed, and equant spar are typically found in basinward portions of the study area and were probably filled with changing crystal morphologies due to the reduction of fluid flow (reducing permeabilities) as the pore was filled. Evidence supporting this interpretation includes the common occurrence of calcite of different crystal habits in adjacent pores (Fig. 63). Since the concentration of reactants in the fluids filling such closely spaced pores most likely was similar, the difference in crystal habit must have been due to the rate at which reactant was supplied to each pore (fluid flow). Additional evidence supporting control of crystal morphology by fluid flow includes fibrous calcite occurrence generally restricted to rocks that apparently had high primary porosities and permeabilities, such as ooid grainstones (Fig. 64).

In more shoreward portions of the study area, adjacent to dominantly anhydrite-cemented areas, fibrous and bladed spar are rare or absent, and blocky spar alone dominates. As pore sizes and types appear similar to those found in the more basinward rocks, reactant concentrations rather than the amount of fluid flow may have become the dominant factor affecting crystal morphology in those areas. Since carbonate solubility is lower than sulfate solubility (carbonates precipitate first), it is reasonable to expect that the relative amount of CO_3^{2-} ions would be reduced in marginal areas where sulfate precipitation becomes more dominant. This might lead to precipitation of equant rather than bladed or fibrous calcite morphologies due to a lowering in the rate of reactant supply (CO_3^{2-}).

It appears that reactant concentrations rather than the amount of fluid flow may have been the dominant factor controlling calcite crystal habit (blocky) in more shoreward lithofacies, and that relative fluid flow was the controlling factor in basinward lithofacies where bladed and fibrous varieties are more common.

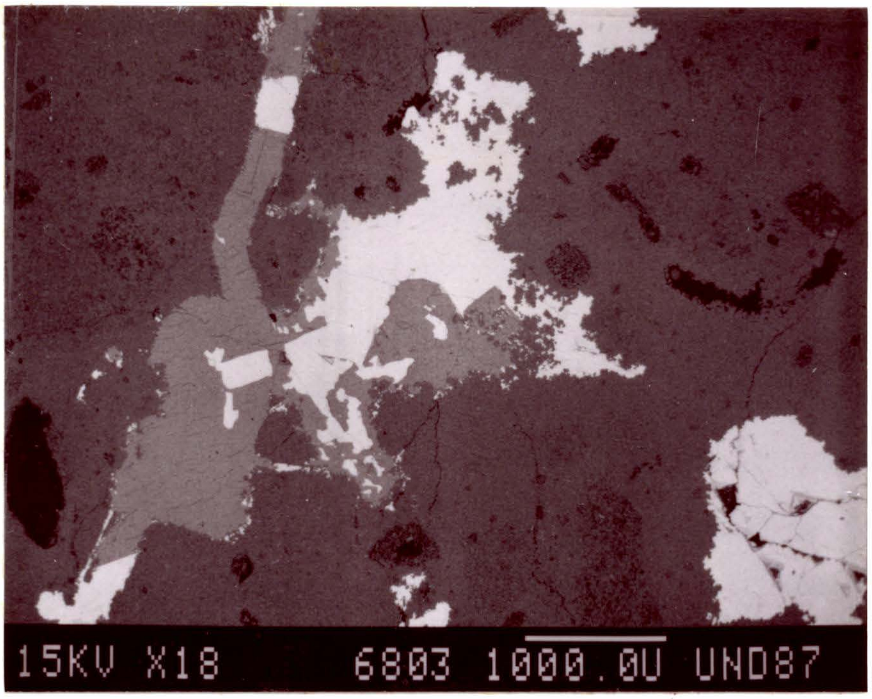
Anhydrite

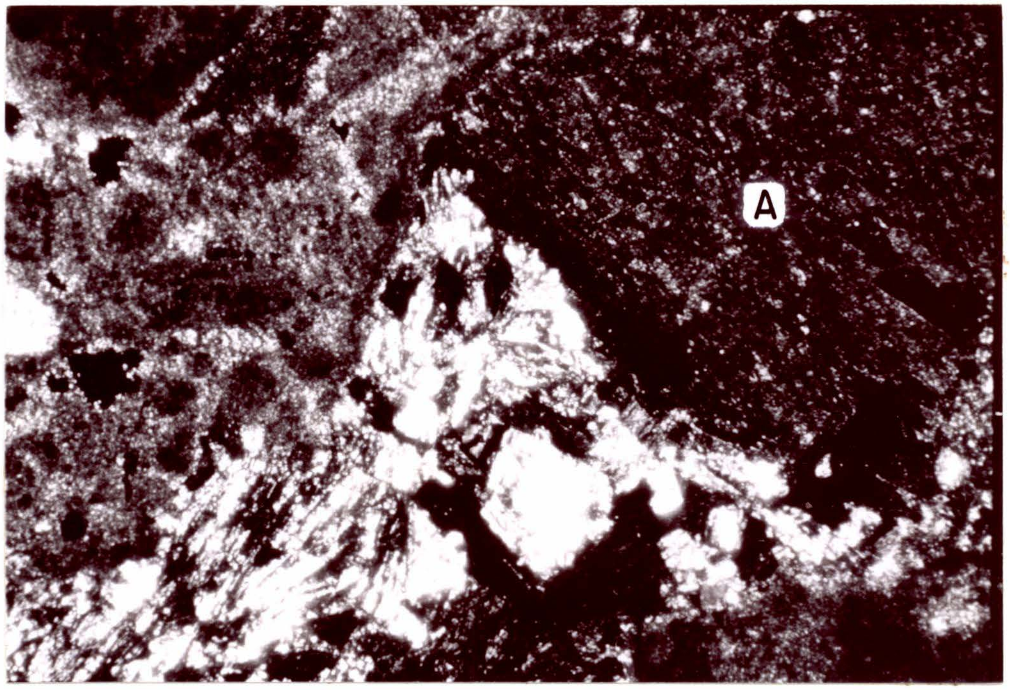
Anhydrite cement is the dominant cement in the most shoreward lithofacies (LF's 3-6) in the study area (Fig. 62). It most commonly occurs as vug occlusions. Infrequently, anhydrite occurs in association with calcite or celestite (Fig. 66). Anhydrite is the mineral filling virtually all occluded fracture and stylolitic pores, and it frequently has replaced limestone adjacent to the occluded pore. Anhydrite crystal size varies widely depending on pore size and crystal habit. Both blocky and lath-like crystal fabrics are common, and often occur in the same pore (Fig. 67).

Anhydrite cementation and replacement of carbonates usually occurred basinward of, or directly below, the bedded evaporites of LF-5 (located on the shoreward edge of the study area). In most instances, the distribution of anhydrite cement in the transition zone

Figure 66: SEM image (back-scatter) showing both anhydrite (medium gray) and celestite (light gray) occluding the same pores in a dolostone (dark gray). NDGS# 6803, depth 4099.5 ft, scale bar in microns.

Figure 67: A photomicrograph showing both a large, single, blocky crystal (large dark area, (A)) and small, lath-like crystals (light area) occluding a single pore. NDGS# 6694, depth 4098.1 ft, field of view 1.8 mm wide, XP.


15KV X18 6803 1000.0U UND87


A

between carbonate-dominated and sulfate-dominated areas, implies the early, near-surface flow of dense, increasingly concentrated gypsum-precipitating fluids and is a reflection of increasing salinity in the waters of the depositional environment.

The filling of large vertical fractures (up to 1 cm wide) and stylolitic pores with anhydrite appears to have occurred later than the precipitation of other pore-filling anhydrite cements. Late-stage anhydrite cement (possibly early mesogenetic) may be due to either the downward-flow (from overlying sulfate deposits) of dense, calcium sulfate-precipitating fluids and/or the reprecipitation of evaporites dissolved by pressure solution or calcium sulfate-undersaturated fluids.

Calcium sulfate-rich fluids may also be introduced into sediments adjacent to large evaporite bodies during the compaction and recrystallization of gypsum ($CaSO_4 \cdot 2H_2O$) to anhydrite ($CaSO_4$). Lee Roark and Jordan (1987) found that 38% of the volume, or 29% of the density is removed from gypsum during its compaction dewatering and recrystallization to anhydrite. It is very likely that fluids driven off during this dewatering event would carry calcium sulfates into adjacent carbonates, and possibly precipitate in pores. Crystal habit (blocky or felted-acicular) of the anhydrite cement may be due to differences in pH in the fluid from which it precipitated (Barta and others, 1971), or the rate at which reactants were supplied to the site of crystal growth.

<u>Celestite</u>

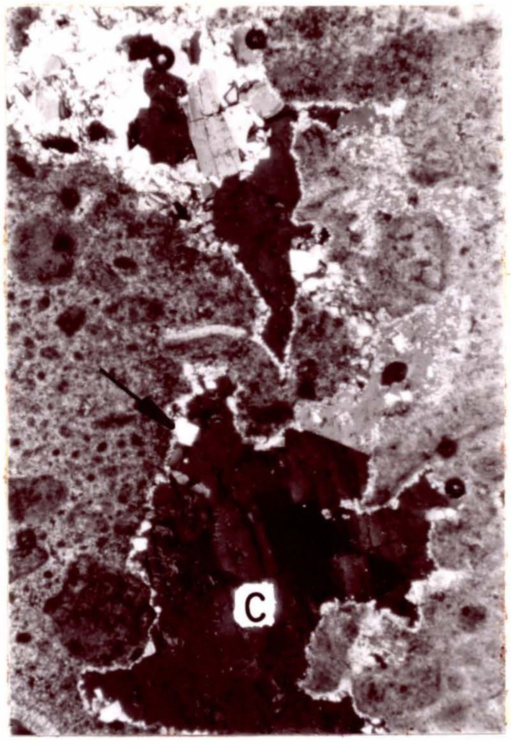
Celestite ($SrSO_4$) is a minor mineral constituent in the study area, and occurs both as euhedral crystals within carbonate matrix and as pore-filling cements. The pore-filling celestite is considered here. Pore-filling celestite commonly occurs in vugs or fractures, predominantly in LF's 3-4. Celestite cement usually consists of blocky, clear, single crystals filling or partially filling secondary pores (Fig. 68). In thin section, viewed with polarized light, celestite cement usually has low birefringence with colors consisting of first order cremes and grays. It closely resembles low birefringence crystals of gypsum and differentiation of the two was usually accomplished with the use of an SEM/Microprobe. Celestite often fills pores along with anhydrite (Fig. 66) and may occasionally be replaced by anhydrite (Fig. 69). Since a pore may be filled with a single celestite crystal, crystal size often varies depending on the size of available pores.

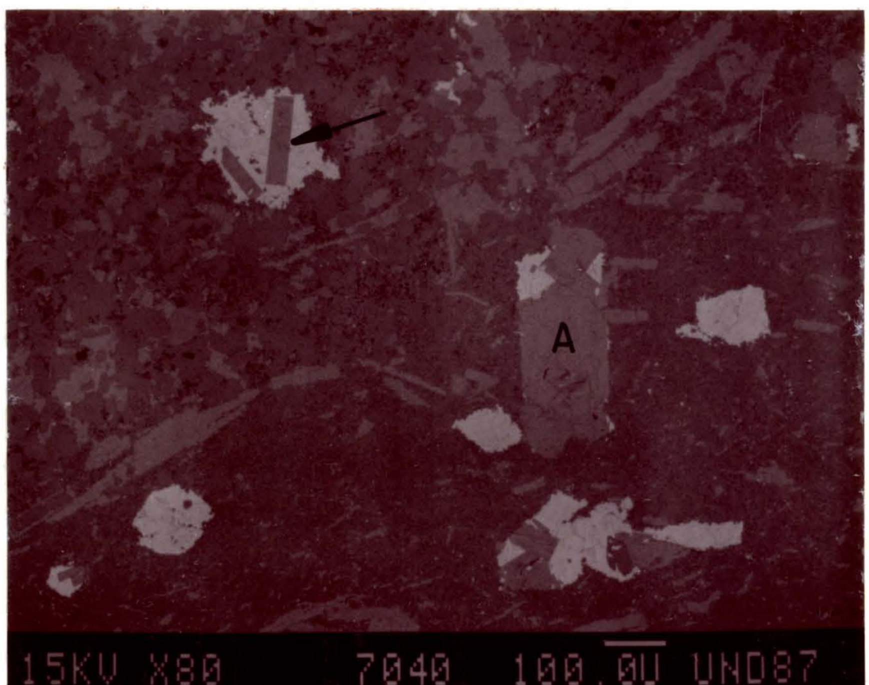
Celestite solubility is considerably lower than calcium sulfate solubility (Sonnenfeld, 1984, p. 186) and higher than calcite solubility. Therefore, it might be expected that celestite ($SrSO_4$) would precipitate between calcite- and calcium sulfate-dominated areas. Since most of the celestite cement in the study area is located in the transition zone between calcite-dominated (basinward) and anhydrite- (calcium sulfate) dominated (shoreward) areas, this suggests celestite formation in a near-surface (eogenetic) setting.

The occurrence of minor amounts of celestite cement in fractures and other pores, which may not have existed in near-surface environments, requires the introduction of strontium-rich fluids at greater depths. This second generation of strontium-rich fluids might have originated from the conversion of strontium-rich aragonite to either strontium-poor calcite or dolomite. Liberation of strontium ions by

Figure 68: A photomicrograph showing a large, single, blocky-celestite crystal (C) occluding a vug. Note the large dolomite crystals (light colored, arrow) lining the vug in this peloidal-intraclastic packstone. NDGS# 6332, depth 4095.4 ft, field of view 2.1 mm high.

Figure 69: An SEM image (back-scatter) showing probable replacement of celestite (light gray) by anhydrite (medium gray). Dolomudstone is dark gray. Anhydrite, lath-like crystals (arrow) within a celestite crystal, and nearly total replacement of a celestite crystal by anhydrite (A) is shown. NDGS# 7040, depth 4050.2 ft, scale bar = 100 microns.


C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such a conversion are discussed by Sonnenfeld (1984, p. 186).

Silica

Cryptocrystalline quartz, which has replaced carbonate and partially filled pores, occurs in one major zone a few centimeters thick (Fig. 70), that appears to be correlative between several wells. An additional occurrence of cryptocrystalline quartz is in well #5990 (LF-4), where it fills small vertical fractures and moldic pores. Silica cement is present only in wells penetrating LF's 3 and 4. Silicified zones often have sharp upper and lower boundaries (Fig. 70) and the boundary between silicified and nonsilicified carbonates often cuts across individual allochems (Fig. 71). Due to the noncompacted appearance of the former carbonate allochems, silicification appears to have taken place before significant compaction or pressure solution occurred. Pressure solution features often occur adjacent to (above or below) the silicified zone. Larger pores are often lined with small euhedral quartz crystals, but the size of the pore does not appear to have been greatly reduced by silica cementation.

Silicification of rocks situated downdip from evaporite deposits is frequent (Hite, 1970). A similar situation occurs in the study area, where locally silicified carbonates of LF's 3 and 4 are situated downdip (basinward) of large deposits of bedded anhydrite. The most likely source of the silica required for the thin zones of silicified carbonates would be the dissolution of clastic silicate grains by high-pH fluids.

In an oxygenated, acidic environment, both quartz and aluminum silicates are stable; however, in an anaerobic, alkaline environment they are not (Sonnenfeld, 1984, p. 244). Updip (shoreward) of the silicified zones in the study area are massive anhydrite deposits. During deposition, the brines forming the anhydrites most likely would have been basic and nearly anaerobic (Sonnenfeld, 1984, p. 119). Quartz or feldspar grains blown from shoreward areas into these evaporite-precipitating brines would have probably been subject to partial to total dissolution. The resulting silica-enriched, dense brine might then have flowed basinward (downdip) along the sediment surface or within the sediments until it reached an area where silica precipitated, possibly due to lower pH.

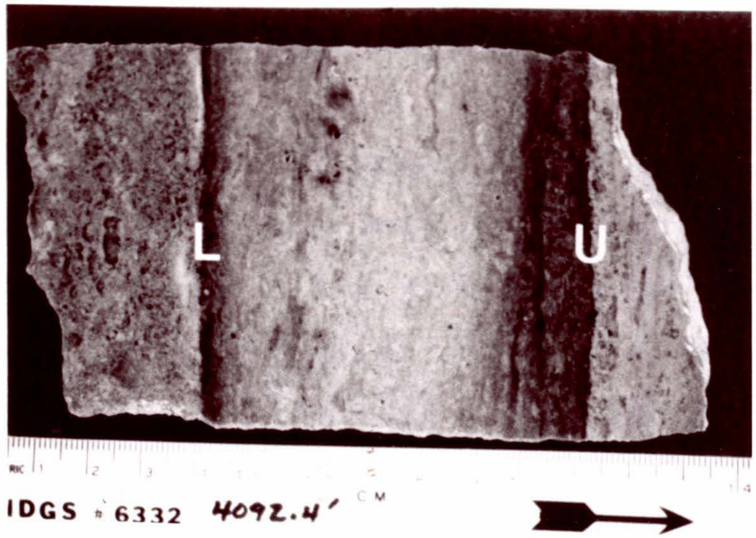
Evidence supporting silica availability due to dissolution of clastic silicates includes the presence within the study area of anhydrite cements containing quartz grains (Fig. 72) whose surfaces resemble irregular, solution-precipitation surfaces described by Baker (1976), and the quartz grains etched by NaCl solutions described by Young (1987). Similar dissolution of clastic quartz grains was also noted by Quinn (1986), who interpreted this as the silica source for silicified carbonates in his study area.

In addition to the four cement-forming minerals previously discussed, halite may also have formed cements within carbonates in the study area. Harrison (1975), in a reservoir study of the Wiley Field, noted an apparent lack of pressure continuity between adjacent wells in the Glenburn reservoir at the Wiley Field. Harrison also noted that the amounts of both oil and water produced often declined during the producing life of a well. This would indicate that there is little or no fluid communication between the Wiley Field and the Madison aquifer discussed by Downey (1984). The present lack of fluid communication has many implications including direction and timing of

Figure 70: A core photograph of a silicified zone showing the sharp upper (U) and lower (L) boundaries of the zone. Dolomitic limestone above and below the silicified zone. NDGS# 6332, depth 4092.4 ft.

Figure 71: A photomicrograph showing the boundary between the siliceous zone (bottom) and limestone (top). Note the open pore (P) and the partially silicified intraclast (I). NDGS# 6332, depth 4092.4 ft, field of view 2.6 mm wide, PP.

Figure 72: An SEM image (SEI) showing the corroded surface of a quartz sand grain (Q) within blocky, anhydrite cement (A). NDGS# 6333, depth 4102 ft, scale bar = 10 microns.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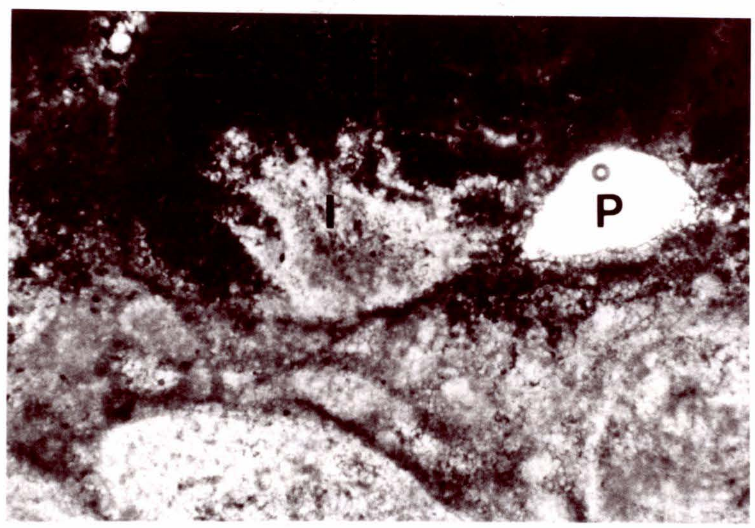
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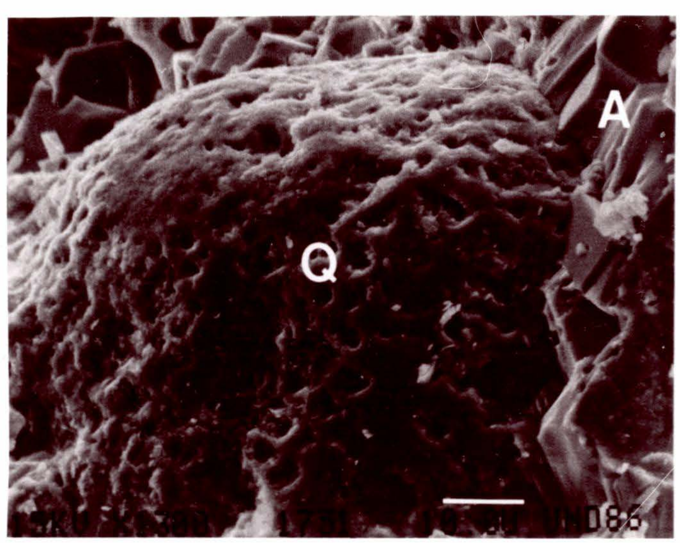
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hydrocarbon migration into the study area, and the possibility of a late-stage cement.

Although recent works (Brooks and others, 1987) dispute the source of hydrocarbons in the Mission Canyon Formation, it is generally accepted that hydrocarbons produced from the Mission Canyon Formation are derived from the organic-rich shales of the stratigraphically lower Bakken Formation. Due to the initiation in the late Cretaceous of the Madison aquifer (Downey, 1984), these hydrocarbons, after reaching the Madison Group, may have then migrated in a generally northeast direction (Fig. 3) until they were trapped in areas such as the stratigraphic trap at the Wiley Field. Since it presently appears that there is little or no communication between hydrocarbon producing wells within the Wiley Field or with the Madison aquifer (Harrison, 1975), this would indicate a cementation event later than hydrocarbon emplacement (post-Cretaceous).

Since it is difficult to explain the areal distribution of the four previously mentioned cements in other than a near surface setting, some other cement type may have precipitated later than hydrocarbon emplacement. Although halite is present in only trace amounts in core samples (Fig. 73), it may have been a late-stage cement in the study area. The relative scarcity of halite in core may be due to dissolution of halite by drilling fluids that typically were saturated only for gypsum.

Downey (1984) noted that the highest salinities in the Madison aquifer were found in the deepest areas, where temperatures were greatest and the solution of halite enhanced. Conversely, salinities decreased away from the deepest areas and in the direction of aquifer

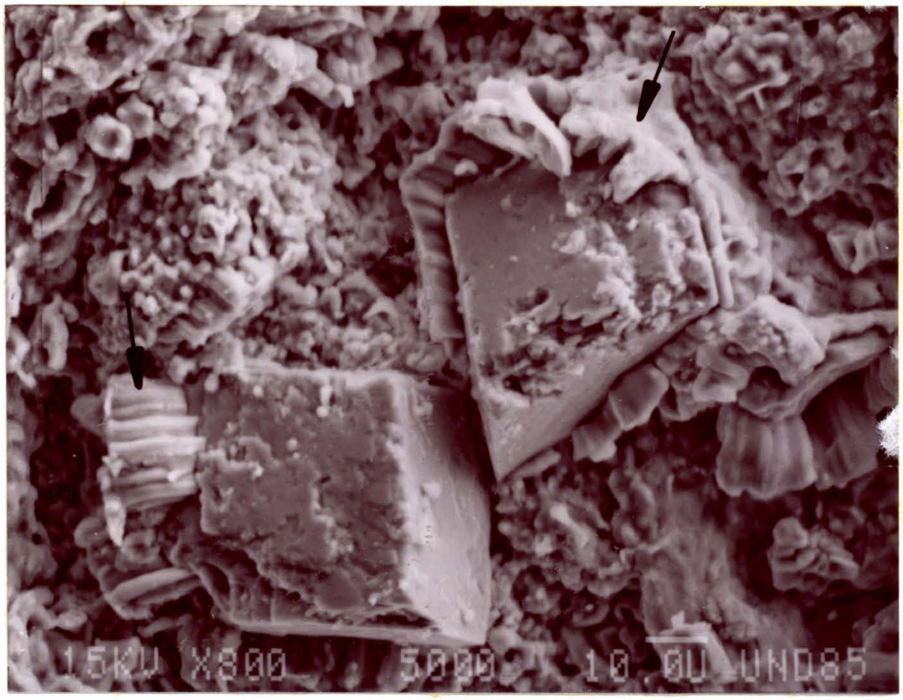


Figure 73: An SEM image (SEI) showing halite (arrow) that has precipitated around two dolomite grains. NDGS# 6037, depth 4112.5 ft, scale bar = 10 microns.

flow. The aquifer flow is generally northeast (Fig. 3) and updip in direction, leading to cooler water temperatures and lowered salinities (Fig. 3). These reduced salinities may be due at least in part to the precipitation of halite in the cooler, updip sections of the Madison aquifer (Downey, 1984).

The Wiley Field's position on the eastern flank of the Williston Basin, updip of the most saline portions of the Madison aquifer, make it likely that halite precipitation would have taken place there after initiation of the Madison aquifer (post-Cretaceous). This could have provided the apparent late cements affecting reservoir properties at the Wiley Field.

Summary

The distribution of the major pore filling cements in the study area occurs in a pattern illustrating precipitation from fluids that became increasingly concentrated (saline) in a shoreward (northeast) direction. The increasingly higher salinities (shoreward) represented by the major cements provides evidence of the horizontal salinity gradient discussed throughout this paper. Because the salinity gradient is most easily formed in surface or near-surface waters, cementation by the major cements is likely a near surface (eogenetic) event.

It is interesting to note that saddle (or baroque) dolomite, a cement that was reported in every other Mission Canyon Formation oil field study completed by students at the University of North Dakota (Stephens, 1986; Quinn, 1986; Durall, 1987; and Schwartz, 1987), is not present in the Wiley Field. The other studies dealt with rocks from depths greater than approximately 5000 ft. The lack of saddle dolomite in rocks from depths of approximately 4100 ft, described from the Wiley Field, may indicate an upper limit for saddle dolomite formation in the Williston Basin.

Replacement

Mineral replacement has altered the limestone lithologies of LF's 1 through 4 to some degree. Calcium carbonate minerals are replaced predominantly by dolomite and anhydrite, and to a much lesser degree by fluorite and celestite.

Dolomitization

This section covers that fraction of dolomite that is not interpreted to be of primary origin (micritic dolomite). The replacement dolomite ranges in size from greater than 5 um to nearly 100 um, averaging 20-30 um. It is generally clear and euhedral, and occurs as vug and allochem linings (Fig. 74). Isolated crystals within limestone allochems, associated with stylolites (Fig. 75), and as complete replacement of limestone matrix and allochems (Fig. 76) is also found. Dolomitization such as this is generally restricted to LF's 2 and 3. Replacement of calcium carbonate by dolomite in LF's 2 and 3 is minor by volume, although it may dominate thin zones (less than 0.5 m) locally.

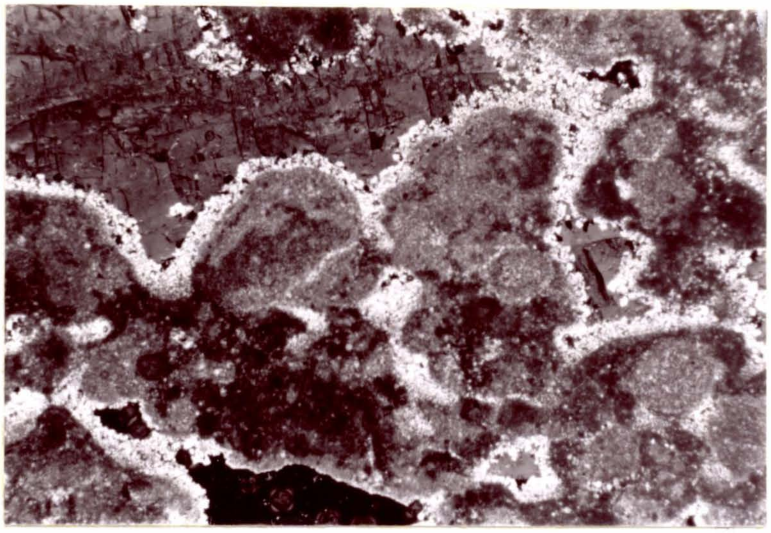
Replacement dolomite in the Wiley Field is probably formed by the interaction of previously precipitated calcium carbonate and magnesium-rich fluids derived from three sources: dewatering of sediments and the expulsion of magnesium-rich fluids during mechanical compaction; magnesium-rich fluids liberated during pressure solution; and the presence in the eogenetic realm of magnesium-rich, hypersaline brines derived from evaporite-precipitating areas.

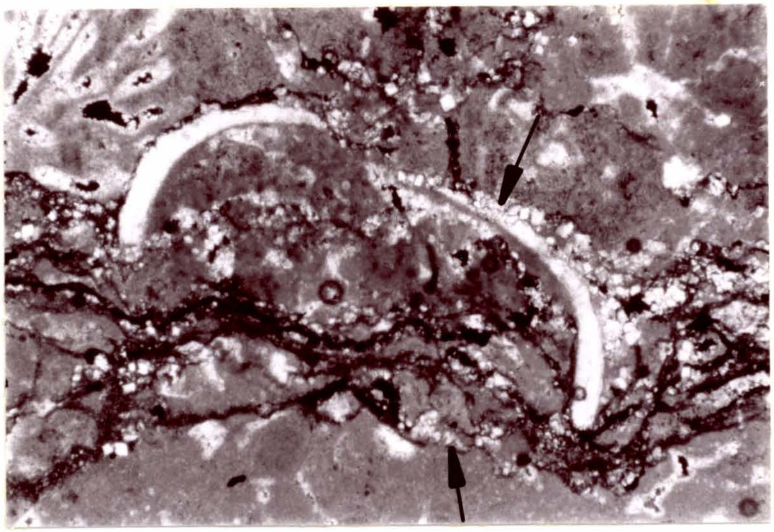
The expulsion of hypersaline brines from the dewatering of sediments in LF's 4 and 5 may have led to the introduction of these magnesium-rich, hypersaline brines into the calcium carbonate sediments forming the laterally adjacent LF's 2 and 3. The amount of magnesium supplied in this way would be relatively low, and would limit the amount of dolomitization that could take place and the rate at which it might proceed. As the amount of dolomitization decreases, the dolomite crystal size generally increases. A similar relation was observed northwest of the Wiley Field by Hartling and others (1982), who suggested that a decreasing supply of magnesium ions might lead to slower nucleation (larger crystals) at fewer sites. This process of dolomitization would most likely be responsible for dolomitization of existing pore walls or allochem margins because sufficient magnesium

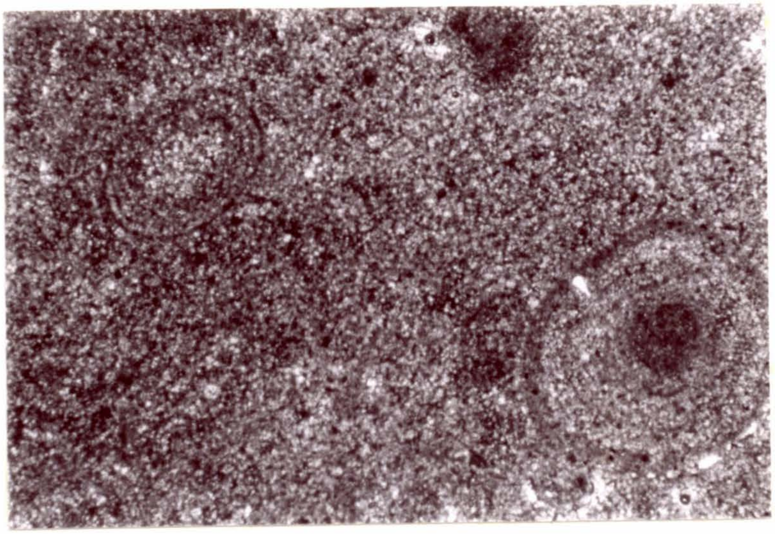
Figure 74: Dolomite crystals (light color) lining celestite occluded vugs and allochems. NDGS# 6332, depth 4108 ft, field of view 4.3 mm wide, XP.

Figure 75: Dolomite crystals (light color) concentrated along stylolites (arrows). Pores and insoluble residue along stylolites are dark colored. NDGS# 7260, depth 4138.9 ft, field of view 2.2 mm wide, XP.

Figure 76: Dolomitized ooids (grain ghosts) in a dolowackestone. NDGS# 6037, depth 4116.5 ft, field of view 2.6 mm wide, PP.







ions would not be available for more extensive dolomitization. Lindsay and Roth (1982), in a study of the Little Knife Field, suggested that such an expulsion of dolomitizing fluids by mechanical compaction of sediments may be an alternative model to Adams and Rhodes' (1960) reflux model.

Dolomite is nearly always associated with pressure-solution features in the study area. Although some of this dolomite appears to be insoluble residue concentrated by the dissolution of surrounding limestones, much of the dolomite appears to have originated or become enlarged at the site of limestone pressure solution.

Wanless (1979) stated that pressure solution-dolomitization must be considered as a common and expected result of stress response in limestones. The process by which dolomite forms along stylolites probably involves the dissolution of magnesium-rich calcite followed by the removal and later precipitation of low-magnesium calcite; leaving a concentration of magnesium ions along the stylolite and leading to dolomite formation or crystal growth. Limestones which contain low to negligible amounts of magnesium calcite contain little or no dolomite along pressure solution seams (Wanless, 1979). Although all calcite in the study area is now low-magnesium calcite, the abundance of dolomite associated with nearly every pressure solution feature suggests that the calcite originally contained significant amounts of magnesium. Also, high-magnesium calcite would be expected in the vicinity of the study area due to the shallow water depths and position of the study area near the equator, both of which should lead to elevated water temperatures. A positive correlation between increasing magnesium content in calcite skeletal parts and increasing water temperature was noted by Chave (1954). This relation may also apply to abiogenic calcite.

Zones which are extensively dolomitized were probably produced in the eogenetic realm by the passage of large quantities of magnesium rich-brines through the calcium carbonate sediments. These brines were probably derived from evaporite-precipitating areas located in shoreward (updip) portions of the study area. This possible scenario is discussed in Luther and others (1987), Appendix D, this paper. Additional support for a scenario of near-surface dolomitization comes from Given and Wilkinson (1987), who recently proposed that extensively dolomitized sections formed most easily from seawater in a near-surface (eogenetic) setting.

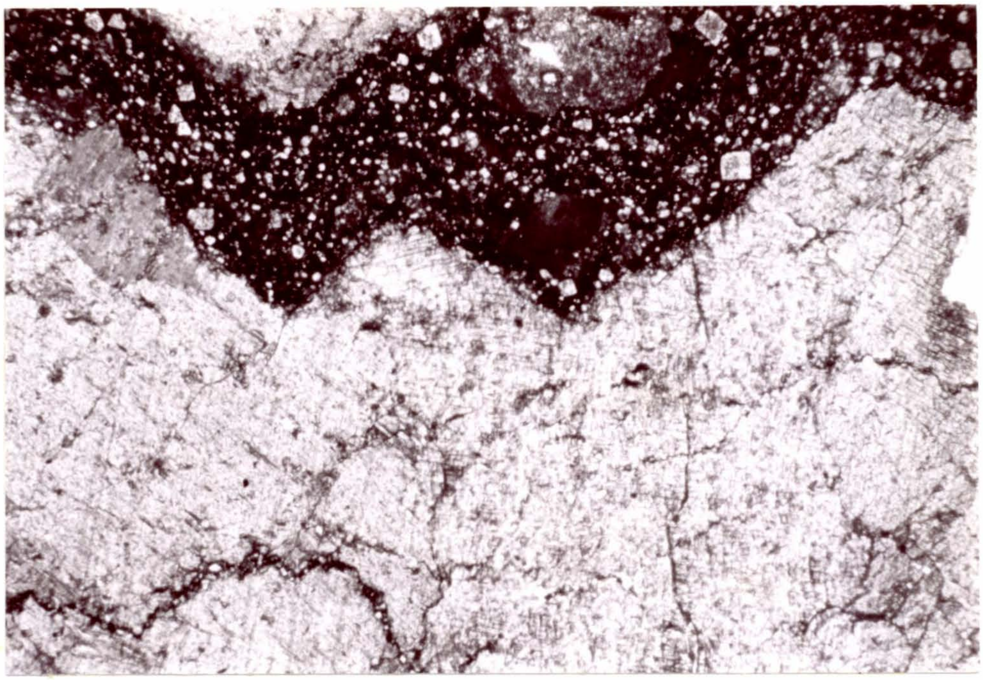
Replacement anhydrite

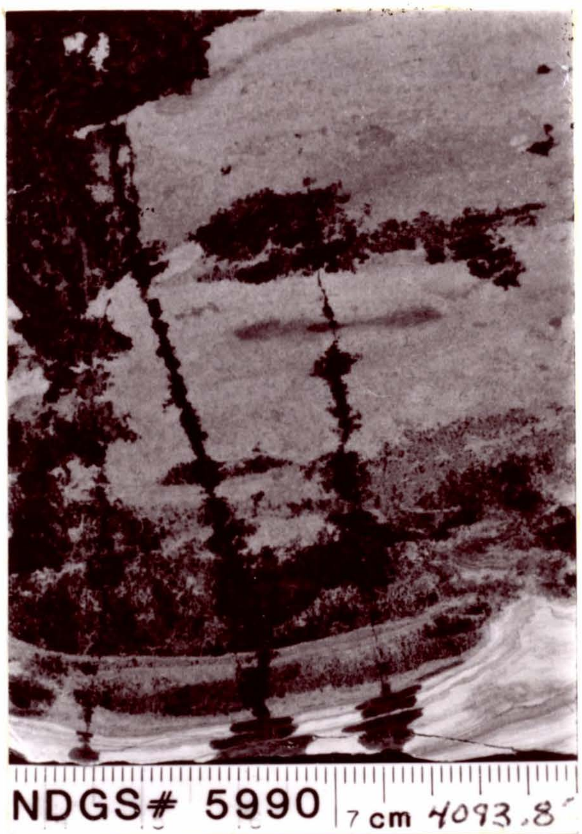
Anhydrite has frequently replaced limestone within the study area. It is generally clear and has replaced limestone adjacent to anhydrite-filled fractures (usually vertical) or along stylolites (Fig. 77). It is found less frequently as total to partial replacement of thin zones not visibly associated with fractures or stylolites (Fig. 78). These thin zones are often laterally adjacent to, or overlain by, massive evaporite deposits.

Less common than the clear, replacement anhydrite is a brown anhydrite. This occurs associated with fractures, small stylolites, and as pervasive replacement of limestone. Brown replacement anhydrite appears to occur predominantly in lithofacies which are laterally adjacent to massive evaporite deposits. Dolomite appears to be resistant to replacement by either brown or clear anhydrite, and primary textures are often preserved by dolomite crystals which

Figure 77: A photomicrograph showing anhydrite (light color) that has replaced limestone adjacent to stylolites (dark). Light-colored, small cubes within the stylolite (dark band) are fluorite and the remainder of the light-colored crystals are dolomite. NDGS# 3347, depth 4134 ft, field of view 4.3 mm wide, PP.

Figure 78: A core photograph showing anhydrite (dark) replacement of a peloidal packstone. Anhydrite appears to have replaced limestone along bedding planes and possible very small vertical fractures. NDGS# 5990, depth 4093.8 ft.




NDGS# 5990
7 cm 4093.8

outlined pore walls and calcite allochems prior to anhydrite replacement.

Both the clear and the brown replacement anhydrite are of a late-stage origin as evidenced by their presence in large vertical fractures and association with stylolites. Both types are probably the result of downward or lateral migration of dense, sulfate-saturated brines derived from overlying or adjacent evaporite precipitating areas, or from mechanical compaction and dewatering (anhydritization) of adjacent large bodies containing primary gypsum sediments.

Replacement may occur in limestone rocks/sediments because of the abundance of free sulfate ions compared to the low number of calcium ions available for calcium sulfate precipitation. Sonnenfeld (1984, p. 179) stated that if all calcium ions in inflowing seawater were captured by sulfate ions, only about 36.2 % of the available sulfur would be utilized. Taking into consideration the amount of calcium removed from the system by calcium carbonate precipitation, this could result in some of the excess sulfate ions replacing carbonate ions in previously precipitated calcium carbonates.

Large vertical fractures that are filled with anhydrite are generally restricted to carbonate areas near the contact with adjacent evaporite deposits. These fractures may result from differential compaction or subsidence rates between carbonate- and evaporite-dominated deposits, and thus give some idea of the timing of the event. Relative timing of the anhydritization event is also estimated by its occurrence along stylolites. Since pressure solution responses require substantial burial, the occurrence of anhydrite along stylolites suggests anhydrite formation in relatively deep-burial, mesogenetic conditions.

To explain the presence of both a clear and a brown replacement anhydrite in the study area, one must call upon either anhydritization by different fluids at different times, or the introduction into the anhydritizing fluids of color causing impurities predominantly in those areas where brown anhydrite is concentrated, specifically, near the carbonate/evaporite lateral contact. The brown anhydrite in the study area is similar in appearance as well as occurrence to that described by Kendall and Walters (1978) from Mississippian carbonates in Saskatchewan. In their study, they found that the brown color was caused by bitumen inclusions in the anhydrite and concluded that anhydrite replacement took place during or after hydrocarbon migration into the area. Distribution of the brown anhydrite generally updip of the clear anhydrite suggests that either the clear anhydrite formed before oil migration updip into the study area, or that the bitumen in the brown anhydrite came from a local source, such as the adjacent evaporites. That there may have been local sourcing of hydrocarbons in Mission Canyon rocks, was recently demonstrated by Brooks and others (1987). It will take further research and close examination of the fluids present to resolve this issue.

Fluorite

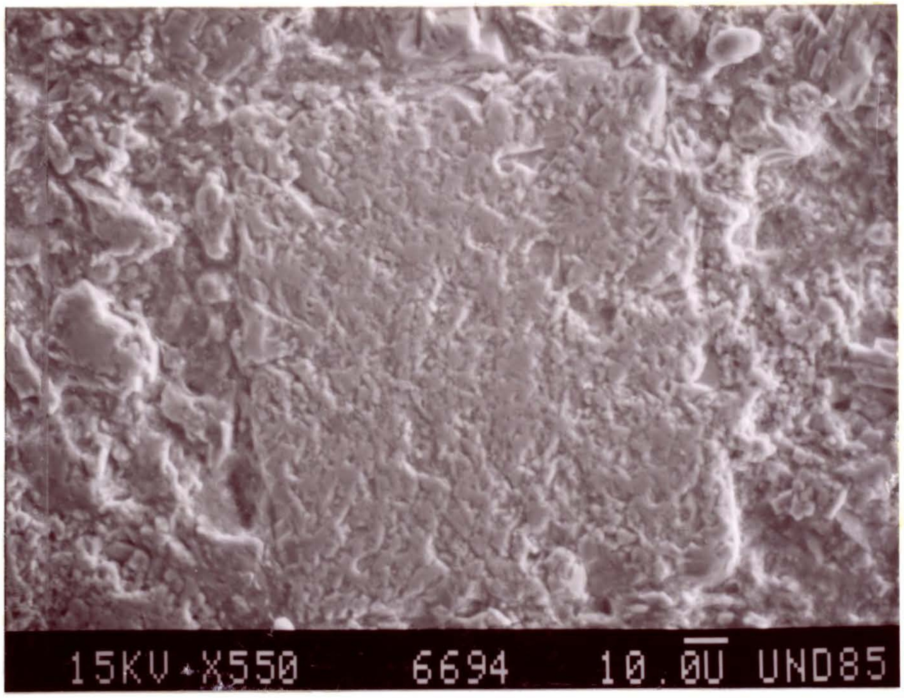
Fluorite occurs in the study area predominantly in LF-4 and much less frequently in LF-3. Fluorite can be distinguished in thin section by its cubic shape and isotropic character. Additionally, SEM/Microprobe and XRD analysis was used in this study to confirm its occurrence. To this writer's knowledge, this is the first reported occurrence of fluorite from the Mission Canyon Formation in the Williston Basin. Fluorite in the study area consists of cubic, euhedral crystals averaging 100 um across (Fig. 79). Because of its occurrence in several types of diagenetically altered zones, fluorite appears to have been an early replacement or precipitated mineral. As such, it may prove useful in the relative timing of other diagenetic events. Fluorite occurs within carbonate allochems, within anhydrite replaced zones, within silicified zones (of relatively uncompacted carbonates), and concentrated by pressure solution features (Fig. 80). Due to the unlikely possibility that fluorite could form with equal ease in such a variety of diagenetically altered zones, it seems more likely that fluorite formed early, penecontemporaneously with calcium carbonates that were later diagenetically altered by anhydritization, silicification, compaction, and pressure solution.

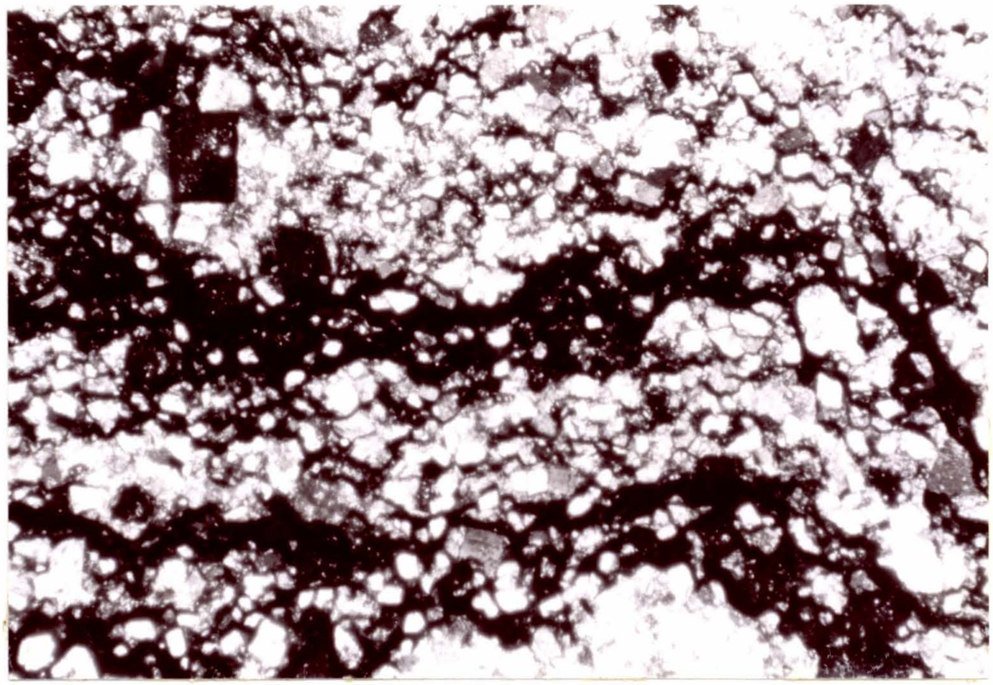
Sonnenfeld (1984, p. 226) stated that fluorides are much more frequent as traces in limestones surrounding evaporite pans than in evaporites precipitated within that pan, but goes on to state (p. 227) that in German Zechstein sediments, fluorite most commonly occurs in dolomites. Within the study area, fluorite is found in the predominantly dolomitic rocks of LF-4 and in the less dolomitic rocks of LF-3, near the contact with LF-4.

Fluorite (CaF_2) solubility decreases as the mole fraction of magnesium fluoride increases in a solution (Sonnenfeld, 1984, p. 227). This implies that, as the Mg/Ca ratio increases, fluorite precipitates; this response is consistent with the observation that dolomite increases in the same areas. An increase in the Mg/Ca ratio may be due to salinity gradients, or to the basinward flow of dense,

Figure 79: An SEM image (SEI) showing a single, cubic, fluorite crystal. NDGS# 6694, depth 4987.2 ft, scale bar = 10 microns.

Figure 80: A photomicrograph showing isotropic, fluorite crystals (black cubes), and dolomite crystals (light color) that have been concentrated by a stylolite (dark, insoluble residue). NDGS# 6332, depth 4099 ft, field of view 1.7 mm, XP.


15KV X550 6694 10.0U UND85



magnesium-rich brines from more shoreward, evaporite precipitating areas (LF-5). In either scenario, Mg/Ca ratios increased in near-surface conditions, and led to the growth of fluorite crystals in carbonate allochems prior to the silicification of these relatively uncompacted carbonates.

Porosity

Several types of pores are present at the Wiley Field including: vugular, fenestral, intercrystalline, interparticle, intraparticle, moldic, stylolitic, and fracture. Of these, inter-crystalline and vugular/enlarged fenestral are the most common. Intercrystalline porosity generally increases near the carbonate/evaporite contact and is dominant in LF-4. Vugular/enlarged fenestral porosity is common throughout most of the Wiley Field basinward of LF-4 and appears to be the dominant pore type in LF's 2 and 3. Nearly all porosity at the Wiley Field appears to be secondary or secondarily enlarged. The timing of this secondary porosity development is difficult to determine.

Several writers have discussed the development of secondary porosity in and around an area including the Wiley Field. Suggestions have included telogenetic dissolution by downward percolation of meteoric waters (Obelenus, 1985), or dissolution by meteoric waters in a vadose setting (Gerhard, 1985), or dissolution of carbonates by acidic-pore waters in a "deep" subsurface environment (Elliot, 1982).

Obelenus' (1985) suggestion that dissolution resulted from the downward percolation of meteoric waters in the telogenetic zone does not seem applicable at the Wiley Field due to the presence of impermeable, bedded anhydrites both overlying and updip of the Wiley

Field. Gerhard's (1985) suggestion that dissolution took place in the vadose zone due to the introduction of meteoric waters has at least two unsettling points. First, there is a scarcity of fabrics clearly of vadose origin in the study area, and in the nearby Haas Field (Elliot, 1982) vadose features were not found to be associated with highly-porous zones. Second, the arid climate represented by the massive evaporite deposits bordering the Wiley Field seem inconsistent with the amount of meteoric water that would be required for the amount of vugular porosity found in the Wiley Field. Elliot (1982) presented convincing evidence that at least a portion of the carbonate dissolution took place in the mesogenetic realm. However, the distribution of the two major cements (calcite and anhydrite) filling pores in the study area are in a pattern consistent with their formation in near surface environments, and indicate a near-surface or eogenetic formation of the pores in which they are precipitated.

One possible way in which the near-surface, subtidal dissolution of carbonates might occur would be the presence of corrosive brines derived from evaporite-precipitating waters located shoreward of the porous carbonates. Paull and Neumann (1987) found that the introduction of pore fluids containing sulfides into oxygenated seawater produced the reaction $HS^- + 2O_2 \rightarrow SO_4^{2-} + H^+$, producing an acid corrosive to limestones. At the Wiley Field, dense, sulfide-rich brines may have formed in evaporite-precipitating areas due to the microbial reduction of sulfates, and then flowed basinward into more oxygenated areas where carbonates were being deposited.

This model for carbonate dissolution in the study area seems reasonable for the following reasons:

1) Waters in the updip, evaporite-precipitating areas would be much less oxygenated (possibly anoxic) than those in carbonate precipitating areas, due to the relation noted by Kinsman and others (1974).

2) In an evaporite-precipitating environment, excessive amounts of sulfate ions are available (Sonnenfeld, 1984, p. 179) for reduction to sulfides by microbial processes.

3) Dissolution of carbonates by these brines could result in pore types morphologically similar to those formed by vadose processes and the pores would have been formed in a near-surface, eogenetic setting.

4) Dissolution by brines could take place utilizing ions that are known to have been present, rather than calling upon sea level changes and the introduction of fresh water into an arid environment.

CONCLUSIONS

Several conclusions are drawn from this study of the Wiley Field, and include:

1) Six lithofacies were described, including: the fossiliferous grainy mudstone-packstone (LF-1); the coated-grain wackestone-grainstone (LF-2); the peloidal/intraclastic wackestone-packstone (LF-3); the dolowackestone-mudstone and nodular anhydrite (LF-4); the massive anhydrite (LF-5); and, the siliciclastic sandstone-siltstone (LF-6) lithofacies.

2) All lithofacies, with the exception of LF-6, were deposited in a predominantly low-energy, shallow-sublittoral setting.

3) The siliciclastic sandstone-siltstone lithofacies (LF-6) was deposited by eolian processes in a setting similar to a modern siliciclastic-dominated sabkha.

4) Most sediments are abiotic in origin, but may have formed due to, or in conjunction with, biochemical processes such as photosynthesis.

5) During deposition of the Glenburn bed in the study area, equilibrium conditions existed between sedimentation rates and rates of subsidence/sea level-rise. The equilibrium conditions resulted in stable water depths, water energies, and water chemistries, which in turn resulted in a vertical stacking rather than a lateral progradation of facies.

6) Distribution of lithofacies deposited in a sublittoral setting (LF's 1 through 5) was controlled by the presence of a horizontal salinity gradient increasing to the northeast, or shoreward direction. The salinity gradient formed due to continued

evaporation of marine water flowing northeast to replace that lost by evaporation. The greater the distance the water traveled, the longer it was exposed to evaporation, thus increasing the salinity in a northeast direction across the study area.

7) The "digitate" (in plane-view) interfingering of carbonate and sulfate dominated lithologies in an area including the study area, may be the result of brine movements driven by evaporation. Elongate carbonate bodies, parallel to basinal dip, formed in landward-moving, more normal-marine water plumes and the sulfate bodies formed in more hypersaline, seaward-moving plumes of water.

8) The occurrence of plant megaspores (five new species) is reported for the first time in the Williston Basin.

9) The most frequent occurrence of replacement minerals, and the greatest variety of minerals, including previously unreported fluorite, are in carbonate lithofacies laterally adjacent to the contact with massive anhydrite deposits.

10) Evidence was collected supporting the near surface, sublittoral formation of dolomite by basinward-flowing, Mg-rich brines derived from shoreward areas of gypsum precipitation.

11) Porosity in the northeastern half of the Wiley Field is dominated by intercrystalline pores, while porosity in the southwestern half is dominated by vugular/enlarged fenestral pores.

12) Solution-enlarged pores may have been formed by acids created during the oxidation of sulfide ions.

13) Saddle dolomite is not present in the Wiley Field, and therefore,

may require depths greater than 4200 feet for its formation.

14) Post-Mississippian structural development plays an important role in the location of hydrocarbon-producing wells.

15) The presence of brown, replacement anhydrite (possibly containing bitumen) in updip portions of the Wiley Field adjacent to massive anhydrite bodies and updip of clear, replacement anhydrite, indicates that local sourcing of hydrocarbons may have occurred at the Wiley Field.

APPENDICES

APPENDIX A

WELL NAMES, LOCATIONS AND LEGAL DESCRIPTIONS

All wells used in this study are located in Bottineau County, North Dakota and are therefore listed in numerical order by North Dakota Geological Survey well number. The locations, legal descriptions, operators, well names, and footage cored are given in the following pages for each well studied.

NDGS#	
#771	SWSW 20 161N 81W McLaughlin Inc., Fossum-Gussty #1
#910	NWSW 18 161N 81W H. Mack Cox, O.A. Anderson #1-A cored 4060-4175
#1058	SESE 15 161N 82W Farmers Union, Stenehjem #1 cored 3973-4001 and 4147-4221
#1431	NENE 31 162N81W The Carter Oil Co., Oscar Fossum #1 cored 3722-3738, 3758-3765, 3786-3798, 3977-4022
#1776	SWSW 32 162N 81W Kaufman and Gay, Bodal #1 cored 3990-4008
#1790	SWSE 24 161N 82W Cardinal, Stratton #1
#2042	NENW 25 161N 82W Johnson Oil Co., Vernon W. Haugen #1, cored 4089-4160
#2167	NESE 25 161N 82W Johnson Oil Co. and Great Plains Royalties Inc., Nelson-Durnin #1, cored 4113-4167
#2229	NENW 30 161N 81W Johnson Oil Co. and Great Plains Royalties Inc., Nelson-Durnin #2, cored 4076-4101
#2262	SWNE 30 161N 82W Cardinal, Great Plains, and Signal, Gussty Fossum #1, cored 4093-4122
#2268	SWSE 19 161N 81W Cardinal et al, Brendsell and Federal Land Bank #1, cored 4056-4085
#2271	SWNW 30 161N 81W Johnson Oil Co. and Great Plains Royalties, Nelson-Durnin #3, cored 4104-4129
#2300	NESW 30 161N 81W Johnson Oil Co., Nelson-Durnin #4, cored 4100-4125
#2318	N2SE 30 161N 81W Cardinal, Edson Brown #1-R
#2320	SWSE 25 161N 82W Johnson Oil Co. and Great Plains Royalties, Nelson-Durnin #5, cored 4158-4183
#2343	NENE 25 161N 82W The California Co., R.H. Witherstine #1, cored 4088-4107
#2354	C SW 30 161N 81W Johnson Oil Co. and Great Plains Royalties, Nelson-Durnin #6, cored 4117-4142
#2355	SWSE 30 161N 81W Cardinal, North American, et al,. #2 Edson Brown
#2367	NESW 31 161N 81W Cardinal, Gerjets-Federal Land Bank #1
#2369	SWSW 16 161N 81W Johnson Oil Co. and Great Plains Royalties, Iverson-State #1
#2370	SWSW 19 161N 81W The California Co., T.A. Wiley #1, cored 4078-4097
#2384	SWNE 25 161N 82W The California Co., R.H. Witherstine #2, cored 4097-4110
#2401	NENE 31 161N 81W Cardinal, Brown-Fossum et al #1
#2418	SWNW 25 161N 82W Johnson Oil Co. and Great Plains Royalties, Vernon Haugen #2, cored 4124-4148

#2432 SWSW 24 161N 82W Great American Exploration Inc., George Stratton #2, cored 4115-4144

#2446 SWSW 29 161N 81W The California Co., Fossum-Federal Land Bank #1, cored 4084-4097

#2464 NESW 29 161N 81W The California Co., Fossum-Federal Land Bank #2, cored 4055-4091

#2492 NESE 24 161N 82W Great American Exploration, George Stratton #1, cored 4086-4112

#2493 NENE 26 161N 82W Johnson Oil Co. and Great Plains Royalties, Orlin C. Haugen

#2524 SWNE 24 161N 82W The California Co., H. Hofland #1, cored 4077-4094

#2540 SWSE 33 161N 81W Cardinal, Great Plains Royalties, Melvin Haakinson #1

#2542 NESW 11 161N 82W Great American Exploration and Barron Kidd, Streich et al #1

#2566 NESW 24 161N 82W Great American Exploration Co., George Stratton #3

#2669 NESE 23 161N 82W Ohio Oil Co., Peter Wilms #1, cored 4083-4099

#2692 NESW 19 161N 81W The California Co., T.A. Wiley #2, cored 4053-4078

#2718 SWNW 24 161N 82W Great American Exploration et al, #1 Stratton

#2733 NENW 24 161N 82W Great American Exploration, Barron Kidd, and Phillips Petroleum, Stratton UGLI #2

#2734 NENE 23 161N 82W Great American Exploration and Barron Kidd, Stratton #5

#2739 SWNE 23 161N 82W Great American Exploration and Barron Kidd, Stratton #6

#2778 NENW 23 161N 82W The Ohio Oil Co., Floyd Kirby #1, cored 4112-4141

#2801 NESW 23 161N 82W The Ohio Oil Co., V.V. Bull, et al #1

#2813 SWSE 23 161N 82W The Ohio Oil Co., Peter Wilms #2

#2843 NESE 32 161N 81W Cardinal, T.S.&T. Inc., #1 Paul Haakenson

#2877 NESE 9 161N 82W Kerr-McGee, Ernest Rice #1

#2890 SWNW 13 161N 82W Great American Exploration, Barron Kidd, B&K Exploration, V. Haugen #1

#3042 SWNW 23 161N 82W Calvert Exploration, #1 Floyd Kirby, cored 4134-4153

#3095 SESW 13 161N 82W Barron Kidd, Erickson #1

#3130 SWSW 23 161N 82W Simcox Oil and Calvert Exploration Co.

#3240 SWNE 22 161N 82W Jack Rouse-Dick Zajic, Arthur J. Lunde #1

#3249 NENE 24 161N 82W The California Oil Co., #2 H. Hoffland

#3286 NENE 27 161N 82W Simcox Oil Co., Tufte B#1, cored 4148-4176

#3287 NESE 22 161N 82W Simcox Oil and Calvert Exploration, cored 4146-4169

#3310 SWNE 32 161N 81W Simcox Oil Co., Haakenson #1, cored 4112-4137

#3313 SWSE 22 161N 82W Simcox Oil Co. and Calvert Exploration Co., Newhouse #2, cored 4170-4197

#3322 NENE 19 161N 81W Petroleum Inc., Searle #1, cored 4070-4100

#3343 NENW 26 161N 82W The California Oil Co., O.C. Haugen #1, cored 4132-4200

#3347	NESW 14 161N 82W The California Oil Co., Newhouse #1, cored 4102-4178
#3360	NENW 29 161N 81W Great Plains Royalty and John D. Dalton, Fossum #1
#3544	SWNE 7 161N 81W H.L. Hunt, R.C. Streich #1, cored 4048-4068
#3653	NWNE 20 161N 81W Cardinal Petroleum and South Petroleum Exploration Inc., Ondracek #1
#3702	NESE 21 161N 81W Arrowhead Exploration Co., Kelley #43-21
#3766	NESW 28 161N 81W Arrowhead Exploration Co., 23-28 Nichol et al, cored 4040-4095
#3771	NENE 15 161N 82W Clyde W. Jones and Alpine Oil Co., Eckmann #1, cored 4175-4225
#3916	NESW 27 161N 82W Monsanto, Kirby #1, cored 4172-4222
#3940	SWSE 27 161N 82W Monsanto, Newhouse #1
#3971	SWNW 27 161N 82W Monsanto, Rice #1, cored 4192-4242
#4037	NENE 33 161N 82W Tenneco, Savelkoul #1
#4918	NWSW 33 161N 82W Marathon Oil Co., George Adams #1, cored 6490-6715
#5329	S2NE 14 161N 82W Chandler and Associates, Haugen State #7-14
#5669	SESW 13 161N 82W Kerr McGee, Erickson #4
#5797	SESE 29 161N 81W Phillips, Haakenson State #A-2
#5798	SESE 30 161N 81W Phillips, Brown P #2-6
#5799	NWSE 25 161N 82W Phillips, Durnin A #5-R
#5990	SESE 13 161N 82W The Wiser Oil Co., Berentson BND #1, cored 4050-4100
#6021	SWNW 27 161N 82W Cities Service, Wiley Rice A#1
#6037	NESE 25 161N 82W Phillips, Durnin "A" #1-R, cored 4107-4164
#6238	SESW 30 161N 81W Phillips, Durnin "A" #14-30, cored 4093-4153
#6239	SESE 23 161N 82W Phillips, Wilms "A" #16-23, cored 4093-4172
#6240	NWSW 23 161N 82W Phillips, Phillips-Sunbehm #12-23 Bull "B", cored 4124-4184
#6257	SWNW 34 161N 82W Cities Service Co., Kirby A#1
#6261	NWNE 23 161N 82W Phillips, Stratton "A" #2-23, cored 4108-4168
#6262	NWNW 24 161N 82W Phillips, U.C.L.I.-Stratton #4-24, cored 4086-4146
#6332	NWNE 24 161N 82W Chevron, H. Hofland #3, cored 4078-4133
#6333	NWNE 25 161N 82W Chevron, Witherstine #2, cored 4102-4162
#6364	NESW 25 161N 82W Robillard and Todd, Halstead #1, cored 4116-4171
#6365	NESW 27 161N 82W Ram Oil Co., Adams R#1
#6389	NWSE 14 161N 82W Kerr McGee, Erickson #8, cored 4110-4170
#6390	NESW 13 161N 82W Kerr McGee, Erickson #7, cored 4060-4176
#6391	NWSW 13 161N 82W Kerr McGee, Erickson #6, cored 4063-4169
#6392	SESE 14 161N 82W Kerr McGee, Erickson #5, cored 4110-4154
#6517	SWSE 14 161N 82W Kerr McGee, Erickson #3R, cored 4115-4175
#6692	SESW 14 161N 82W Phillips, Newhouse #14-14, cored 4119-4179
#6693	SENW 25 161N 82W Phillips, Haugen #(B) 6-25
#6694	SENE 30 161N 81W Phillips, Fossum (A) #8-30, cored 4076-4136
#6717	NWSE 30 161N 81W Phillips, Brown #10-30, cored 4095-4155
#6719	NENE 31 161N 81W Phillips, Fossum "C" #1-31, cored 4109-4169
#6720	NESE 22 161N 82W Phillips, Newhouse "A" #9-22, cored 4143-4203

#6727	SENE 25 161N 82W Chevron, Witherstine #3, cored 4094-4150
#6728	SENE 24 161N 82W Chevron, Hofland #4, cored 4088-4144
#6729	SESW 19 161N 81W Chevron, Wiley #4, cored 4058-4123
#6730	SESW 29 161N 81W Chevron, Fossum #4, cored 4076-4137
#6731	NWSW 19 161N 81W Chevron, Wiley #3, cored 4080-4137
#6733	NWSW 25 161N 82W Robilard Oil, Halstad #2
#6741	SESE 24 161N 82W Phillips, #16-24 Stratton "C", cored 4083-4142
#6742	NWSW 29 161N 81W Chevron, Fossum-Federal #3, cored 4068-4129
#6743	SENW 24 161N 82W Phillips, U.C.L.I.-Stratton #6-24, cored 4090-4150
#6792	NWSE 19 161N 81W Phillips, Brendsel "A" #10-19, cored 4036-4096
#6803	NWNW 30 161N 81W Phillips, Durnin #4-30, cored 4088-4153
#6804	SENW 30 161N 81W Phillips, Durnin "A" #6-30, cored 4096-4156
#6805	SWSW 30 161N 81W Phillips, Durnin #13-30, cored 4108-4168
#6824	SESE 19 161N 81W Phillips, Brendsel "A" #16-19, cored 4038-4098
#6825	NWNW 23 161N 82W Phillips, Kirby (B) #4-23, cored 4120-4179
#6836	SESW 24 161N 82W Phillips, Stratton #14-24, cored 4121-4181
#6837	NWNE 30 161N 81W Phillips, Fossum "B" #2-30, cored 4070-4130
#6898	SWNW 25 161N 82W Phillips, Haugen "C" #5-25, cored 4118-4177
#7040	SWNW 19 161N 81W Maxbass Natural Gas, M. Grorud 1-R, cored 4038-4098
#7258	NWNW 29 161N 81W Phillips, Fossum "D" #4-29, cored 4051-4111
#7259	SENE 22 161N 82W Phillips, Rice "A" #8-22, cored 4150-4210
#7260	SENE 26 161N 82W Phillips, Haugen "D" #8-26, cored 4134-4194
#7261	NENW 31 161N 81W Phillips, Nelson "D" #3-31, cored 4108-4168
#8772	NESE 6 161N 81W Keldon Oil Co., Tyler-Piquette #1
#8773	NWSW 25 161N 82W Robilard Oil, #2 Halstad
#8917	SESW 27 161N 82W Ram Oil Co., Adams #2
#9238	NWNE 32 161N 81W Maxbass Natural Gas, Haakenson #3
#9491	SWNE 12 161N 82W Mallon Oil Co., Streich #12-7
#9658	NWSW 27 161N 82W Ram Oil Co., Adams #3
#9679	NENE 27 161N 82W Gofor Oil Co., #1R Tufte, cored 4157-4216
#10391	SWSW 27 161N 82W Ram Oil Co., Adams #4
#10804	NENW 32 161N 81W Maxbass Natural Gas, #2-R Haakenson
#10920	SWSE 33 161N 82W M and J Oil Co., George Adams #34-33
#11019	SESW 28 161N 82W Ballantyne Oil, Asheim #1
#11062	SWSE 28 161N 82W Ballantyne Oil Co., #1 Rice
#11156	SWNW 19 161N 81W Maxbass Natural Gas Co., #2 Grorud, cored 4075-4135
#11236	SESW 25 161N 82W Robillard Oil Co., Halstead #4
#11271	SENE 28 161N 82W Walt Ohmart, #1 Henry Hagelie Trust, cored 4204-4234
#11400	SENE 21 161N 81W General Atlantic Energy Corp., Mad Max #1

APPENDIX B

WELL LOG DATA

The top of the Mississippian Madison Group (Mesozoic unconformity) as well as several porosity zones and marker beds used by industry and the North Dakota Geological Survey are listed below. Tops included are: the Madison Group (Madi), Midale porosity zone (Mida), State "A" marker (StaA), Sherwood argillaceous marker (Shar), "K-1" marker (K1), "K-2" marker (K2), and the top of the Frobisher-Alida carbonate unit or the Glenburn porosity zone (Glen). In some instances the top of the Frobisher-Alida carbonate unit lies within the underlying Wayne porosity zone. Such footages will be marked with a * symbol. In addition, a thickness is given for the interval between the top of the "K2" marker and the underlying (first porosity) Frobisher-Alida carbonate (K2FA). The elevation of the Kelly bushing (KB) is given in feet above mean sea level. All tops are measured in feet below the Kelly bushing. The well log data on the following pages are listed numerically by North Dakota Geological Survey well number.

Well#	KB	Madi	Mida	StaA	Shar	K1	K2	Glen	K2FA
771	1511	3842	3854	3925	3959	3977	4019	4025	6
910	1521	3851	3867	3936	3969	3993	4044	4077*	33
1058	1540	3903	3945	4023	4060	4084	4130	4143	13
1431	1523	3726	3753	3819	3852	3868	3913	3971*	58
1776	1524	3758	3773	3842	3873	3894	3943	4002*	59
1790	1535	3895	3933	4008	4044	4064	4099	4113	14
2042	1531	3894	3935	4009	4047	4068	4109	4115	6
2167	1530	3884	3935	4007	4043	4065	4106	4113	7
2229	1531	3874	3899	3974	4005	4028	4070	4078	8
2262	1535	3871	3910	3982	4016	4037	4082	4088	6
2268	1524	3854	3869	3938	3973	3993	4037	4045	8
2271	1526	3875	3920	3995	4030	4052	4091	4099	8
2300	1523	3864	3912	3989	4028	4047	4090	4096	6
2318	1528	3860	3913	3988	4024	4042	4084	4091	7
2320	1536	3896	3966	4043	4079	4101	4140	4148	8
2343	1526	3877	3912	3989	4023	4045	4087	4095	8
2354	1533	3884	3940	4016	4051	4070	4108	4115	7
2355	1524	3861	3919	3993	4028	4047	4085	4094	9
2367	1528	3864	4010	4085	4121	4142	4185	4189	4
2369	1513	3764	3831	3901	3933	3953	4003	4062*	59
2370	1532	3880	3903	3976	4011	4031	4076	4080	4
2384	1529	3887	3924	3997	4034	4056	4097	4103	6
2401	1523							4119?	
2418	1532	3892	3943	4016	4052	4072	4120	4126	6
2432	1537	3908	3934	4007	4046	4067	4107	4114	7
2446	1519	3852	3907	3982	4014	4036	4082	4084	2

Well#	KB	Madi	Mida	StaA	Shar	K1	K2	Glen	K2FA
2464	1522	3832	3885	3956	3993	4011	4053	4060	7
2492	1537	3878	3899	3973	4008	4028	4070	4080	10
2493	1542	3903	3943	4018	4053	4076	4117	4125	8
2524	1538	3887	3902	3974	4011	4033	4078	4086	8
2540	1523	3837	3934	4002	4035	4055	4102	4107	5
2542	1533	3853	3896	3965	4001	4024	4079	4130*	51
2566	1529	3882	3923	3998	4036	4057	4098	4105	7
2669	1530	3890	3909	3981	4017	4041	4081	4088	7
2692	1528	3870	3882	3953	3987	4006	4050	4059	9
2718	1538	3897	3918	3992	4030	4052	4095	4103	8
2733	1539	3880	3897	3967	4002	4028	4072	4078	6
2734	1538	3902	3930	4001	4040	4061	4104	4114	10
2739	1540	3893	3927	4002	4041	4062	4100	4114	14
2778	1541	3909	3933	4010	4047	4073	4118	4123	5
2801	1538	3908	3930	4006	4042	4068	4114	4116	2
2813	1548	3905	3939	4017	4054	4075	4126	4134	8
2843	1516	3861		4008					
2877	1561	3911	3969	4039	4079	4102	4157	4215*	58
2890	1534	3865	3865	3936	3972	3994	4040	4054	14
3042	1543	3914	3949	4026	4061	4083	4124	4134	10
3095	1531	3865	3869	3938	3977	4002	4051	4058	7
3130	1541	3931	3959	4031	4066	4090	4133	4150	17
3240	1545	3928	3983	4052	4097	4122	4166	4170	4
3249	1537	3872	3880	3948	3986	4007	4053	4063	10
3286	1541	3934	3973	4051	4086	4109	4149	4158	9
3287	1543	3925	3965	4042	4080	4103	4141	4151	10
3310	1511	3852	3936	4010	4043	4061	4103	4111	8
3313	1546	3949	3998	4076	4115	4133	4174	4186	12
3322	1519	3842	3850	3922	3957	3976	4019	4030	11
3343	1541	3916	3958	4035	4072	4095	4142	4150	8
3347	1536	3870	3921	3991	4032	4055	4109	4116	7
3360	1530	3815	3862	3933	3966	3984	4022	4035	13
3544	1520	3805	3814	3883	3918	3936	3987	4048*	61
3653	1520	3810	3855	3925	3957	3978	4025	4075*	50
3702	1511	3773	3815	3884	3918	3932	3977	4034*	57
3766	1509	3806	3855	3928	3959	3975	4019	4083*	64
3771	1551	3894	3960	4033	4069	4092	4141	4150	9
3916	1549	3953	3994	4073	4110	4133	4176	4184	8
3940	1547	3944	3996	4075	4112	4134	4175	4186	11
3971	1549	3958	4007	4083	4120	4142	4182	4192	10
4037	1544	3989	4042	4120	4158	4182	4220	4230	10
4918	1561	4058	4149	4228	4267	4294	4334	4346	12
5329	1535	3881	3910	3979	4017	4039	4086	4091	5
5669	1533	3865	3871	3942	3981	4005	4047	4050	8

Well#	KB	Madi	Mida	StaA	Shar	K1	K2	Glen	K2FA
5797	1521	3836	3890	3962	3997	4013	4053	4058	5
5798	1521	3859	3915	3989	4026	4045	4083	4094	11
5799	1532	3885	3934	4008	4044	4063	4100	4112	12
5990	1520	3851	3859	3928	3965	3986	4031	4046	15
6021	1553	3966	4011	4088	4126	4150	4191	4198	7
6037	1527	3877	3929	4007	4040	4061	4100	4109	9
6238	1526	3869	3920	3994	4034	4052	4087	4098	11
6239	1539	3908	3931	4005	4040	4060	4100	4110	10
6240	1544	3919	3943	4018	4056	4077	4116	4124	8
6257	1547	3989	4065	4142	4183	4206	4244	4254	10
6261	1539	3905	3929	4007	4047	4067	4111	4117	6
6262	1538	3890	3906	3979	4022	4044	4085	4093	8
6332	1541	3879	3887	3960	3998	4018	4062	4075	13
6333	1530	3884	3922	3996	4034	4052	4092	4104	12
6364	1534	3892	3942	4018	4058	4077	4116	4124	8
6365	1547	3949	3991	4071	4110	4132	4173	4179	6
6389	1547	3877	3917	3989	4028	4050	4094	4110	16
6390	1535	3862	3884	3956	3994	4018	4064	4079	15
6391	1539	3870	3890	3961	4000	4021	4064	4077	13
6392	1538	3884	3908	3981	4020	4045	4090	4100	10
6517	1537	3896	3923	3995	4033	4056	4100	4112	12
6692	1537	3900	3920	4000	4038	4060	4104	4117	13
6693	1532	3896	3938	4016	4052	4073	4110	4121	11
6694	1533	3844	3895	3969	4005	4023	4063	4075	12
6717	1531	3856	3909	3984	4018	4037	4077	4088	11
6719	1522	3872	3937	4011	4047	4066	4104	4116	12
6720	1543	3909	3946	4024	4061	4083	4120	4131	11
6727	1528	3875	3927	3998	4035	4056	4094	4104	10
6728	1540	3875	3887	3960	3996	4013	4054	4068	14
6729	1540	3869	3882	3954	3987	4008	4048	4062	14
6730	1517	3848	3903	3977	4007	4025	4063	4075	12
6731	1536	3877	3888	3960	3995	4013	4054	4067	13
6733	1533	3895	3948	4024	4058	4083	4121	4129	8
6741	1523	3859	3885	3962	3997	4020	4061	4072	11
6742	1524	3845	3893	3967	4004	4022	4061	4072	11
6743	1534	3877	3897	3971	4007	4027	4071	4082	11
6792	1520	3852	3861	3930	3965	3982	4026	4039	13
6803	1530	3871	3912	3986	4024	4043	4085	4095	10
6804	1534	3874	3920	3993	4028	4048	4089	4100	11
6805	1531	3881	3940	4015	4051	4070	4108	4118	10
6824	1522	3847	3857	3928	3964	3982	4026	4036	10
6825	1536	3902	3937	4013	4049	4071	4115	4125	10
6836	1534	3897	3939	4013	4050	4071	4108	4119	11
6837	1534	3868	3891	3964	3997	4016	4055	4068	13

Well#	KB	Madi	Mida	StaA	Shar	K1	K2	Glen	K2FA
6898	1534	3896	3940	4015	4052	4072	4109	4120	11
7040	1522	3857	3866	3935	3970	3987	4032	4041	9
7258	1531	3824	3878	3950	3984	3999	4040	4051	11
7259	1546	3926	3966	4040	4076	4100	4141	4151	10
7260	1538	3908	3949	4027	4062	4084	4122	4134	12
7261	1526	3876	3937	4011	4047	4066	4104	4113	9
8772	1530	3780	3796	3864	3899	3918	3968	4035*	67
8773	1533	3902	3948	4024	4060	4082	4121	4130	9
8917	1547	3958	4005	4082	4119	4143	4181	4190	9
9238	1519	3862	3910	3982	4013	4033		4085?	
9491	1528	3828	3828	3898	3932	3952	4006	4068*	62
9658	1547	3941	3985	4064	4103	4124	4161	4168	7
9679	1541	3935	3935	4052	4090	4111	4150	4162	12
10391	1549	3958	4002	4081	4119	4141	4187	4188	1
10804	1516	3850	3910	3986	4021	4039	4078	4087	9
10920	1559	4018	4094	4175	4213	4236	4274	4277	3
11019	1549	3998	4044	4122	4162	4187	4225	4235	10
11062	1548	3990	4039	4116	4156	4182	4222	4231	9
11156	1534	3870	3876	3949	3984	4006	4048	4061	13
11236	1539?	3891	3950	4027	4067	4089	4126	4134	8
11271	1551	3971	4016	4092	4130	4153	4193	4203	10
11400	1523	3788	3830	3899	3933	3950	3996	4048*	52

APPENDIX C

CORE AND THIN-SECTION DESCRIPTIONS

The following core and thin-section descriptions are arranged by North Dakota Geological Survey well number. The core intervals are arranged stratigraphically in descending order and core descriptions are supplemented by thin-section descriptions where sampled. The interval described is assumed to be limestone unless otherwise noted. Within each description textural terms (Dunham, 1962) are listed first. This is followed by color, then major allochems, with the most abundant being first, and the least abundant allochem being last. Next orthochems, with emphasis placed on porosity reducing, replacement or displacive minerals. This is followed by sedimentary and pressure solution features. Where found, fossil types and oil staining are noted.

NDGS# 910
Depth Description

Locations (depth) of cores described from this well are only approximate as core was packed 10' per 3' box and there were no indications of footage other than the markings on the box.

4060-70
Anhydrite-dolomudstone: lt gray-lt brown, minor intercrystalline porosity, anhydrite massive to small nodules, thin bedded to distorted dolostone.

4070-80
Anhydrite: lt gray-med gray, nodular to massive.

4080-90
Anhydrite-dolomudstone-wackestone: lt gray-lt brown, anhydrite sand, peloidal, oolitic, minor intercrystalline porosity, localized thin laminations, possibly algal.

4090-100
Anhydrite-dolomudstone-wackestone: gray-white, lt gray-med brown, anhydrite sand, minor intercrystalline porosity, nodular to massive, localized thin laminations.

4100-4107
Anhydrite-grainstone-wackestone: med gray-lt gray brown, anhydrite sand overlying oolitic, intraclastic limestone grains, anhydrite nodules and replacement, calcite interparticle and vug fill, very minor porosity, distorted laminations, alternating grain rich/poor, fenestral in part, type II stylolites.

4107-4117
Grainstone-wackestone: lt gray brown-tan, pisoids peloids, ooids, fossils, calcite filling and lining interparticle and vugular porosity, replacive anhydrite, anhydrite vug and fenestral fill, very minor-good small vug and interparticle porosity, alternating grain rich/poor thin bedding, much pressure solution on grains, fossil types include calcispheres, ostracods, oncoids.

4117-4127

Packstone-mudstone: dolomitic in part, tan-med brown, peloids, small intraclasts, fossils, calcite vug lining, good small vug, interparticle, and intercrystalline porosity, localized fenestrae, type I stylolites, recrystallized fossils; calcispheres, ostracods, slight oil show.

4127-4137

Packstone-wackestone: dolomitic in part, med red brown-med brown, fossils (molds or recrystallized), possible peloids, isolated anhydrite vug fill, very good moldic and intercrystalline porosity, fairly massive, microstylolites, horizontal burrows, pressure solution on grains, fossils include; fragments, gastropods, bivalves, horn corals, forams, small carbon fragments.

4137-4147

Grainstone-packstone: dolomitic in part, lt-med yellow brown, fossils, possible peloids, minor small vug and interparticle porosity, massive, horizontal burrows, microstylolites, fossils; fragments, echinoderm, coral, bivalve, foram, gastropod.

TS 4145'

Bioclastic peloidal grainstone-packstone: Allochems; fossils 40%, peloids 20%, intraclasts 30%. Orthochems; spar 5%, dolomite 5%. Fossils; echinoderms 60%, rugose corals 15%, bryozoans 10%, endopunctae brachiopods 5%, mollusc 5%, foraminifera 5%. Fossils are compacted and many fragmental, micritic coatings and syntaxial spar cements are common. Intraclasts and peloids; micritic, very spherical, possibly micritized ooids or bioclasts. Spar; bladed-blocky filling and lining porosity, syntaxial overgrowths on echinoderm fragments. Dolomite; lining some porosity, associated with pressure solution on grain boundaries. Porosity; small vug 5%, interparticle 3%, intraparticle 2%. Sediment poorly sorted, very little fine grained material.

<u>NDGS# 2167</u>
<u>Depth Description</u>

4113-4113.5

Wackestone-packstone: Slightly dolomitic, med-lt gray brown, ooids, small intraclasts, anhydrite vug and interparticle filling, minor intercrystalline and moldic porosity, alternating course/fine grain beds, oil stained.

4113.5-4114.5

Wackestone-recrystallized: med-lt gray brown, ooids, small intraclasts, blocky calcite vug fill, moderate vug and moldic porosity, thin crusts, fenestral.

4114.5-4115

Wackestone, thin grainstone: lt gray, ooids, small intraclasts, pisoids, anhydrite filling fenestral, interparticle, and fracture porosity, some pyrite vug lining, very minor vugular porosity, fenestral, sorted pisoid laminations, type II stylolites.

4115-4115.9

Packstone-wackestone: lt-med gray, well sorted ooids, calcite vug filling, very minor porosity, many small type I stylolites.

TS 4115'

Oolitic packstone-wackestone: allochems; ooids 25-35%, peloids 15-20%, orthochems; micrite 30-40 %, spar 25-35%, dolomite tr., halite tr. Allochems are mostly irregularly shaped and micrite cored. Micrite makes up the bulk of the matrix where present. Spar consists of large blocky crystals filling vugs and interparticle porosity. Interparticle porosity may have been cemented by bladed spar originally as minor amounts remain in these areas. Type I stylolites appear to cut spar in places. Open vertical and horizontal fractures are present. Porosity less than 5%. Apparent early cementation of better sorted ooids followed by disruption and covering by micritic crusts or silt. Filled matrix selective and interparticle porosity.

4115.9-4117.1

Wackestone-packstone: lt gray brown, small intraclasts, ooids, some calcite vug fill, minor vug and moldic porosity, alternating course/fine grain laminations, many type II and small type I stylolites, much pressure solution on grains, isolated ostracod.

4117.1-4117.4

Packstone (recrystallized): lt brown, large intraclasts, pisoids, possible recrystallized small ooids, calcite vug fill, good moldic and interparticle porosity.

4117.4-4118

Wackestone-thin grainstone (well preserved): ooids, anhydrite interparticle and fenestrae fill, minor vug and moldic porosity, fenestral appearance.

4118-4118.6

Wackestone-packstone: lt gray brown, ooids, small intraclasts, blocky calcite vug lining, fair vug and interparticle porosity, alternating course/fine grain laminae, thin crusts, some pressure solution on grains.

TS 4118.6'

Ooid grainstone-packstone: allochems; ooids 70%, intraclasts 9%, orthochems; micrite 12%, spar 8%, dolomite 1-2%, Ooids; radially fibrous, spherical, concentric laminations. Intraclasts; micrite and poorly sorted ooids, some pseudo pisoids. Micrite; matrix or cement, some microstalactitic and meniscus cement. Spar; blocky, some intergrown and bladed. Dolomite; replacing some ooids, associated with pressure solution on grain boundaries. Pressure solution extensive in zones not spar cemented. Ooids well sorted. Interparticle porosity 20-25%.

4118.6-4120.3

Wackestone-packstone, some thin grainstone: lt brown, ooids, small intraclasts, pisoids > downward, isopachous and blocky calcite porosity fill and lining, good vug and moldic porosity, slight fenestral look, pressure solution on some grains, heavy oil staining.

4120.3-4121.1

Grainstone, possibly a wackestone originally, lt brown, pisoids, ooids, anhydrite primary porosity fill or replacing matrix, blocky calcite vug lining, slight to good porosity, locally anhydrite filled zones, poorly sorted, fairly massive, geopetal structures.

4121.1-4122.4

Wackestone-packstone: lt gray brown-lt brown gray, ooids, small intraclasts, isolated pisoids, isopachous and blocky calcite vug lining and fill, slight-fair vugular porosity, alternating course/fine grain laminations, many type II stylolites (some cut by type I stylolites), much pressure solution on grains (overpacking), slight fenestral look.

4122.4-4123.5

Packstone-wackestone, thin grainstone: lt gray brown, ooids, small pisoids (some recrystallized) dolomite associated with stylolites, slight-fair vug, intercrystalline, and interparticle porosity, slight fenestral look, type II stylolites, and much pressure solution on grains.

TS 4123.5'

Dolomitic intraclastic grainstone-packstone: allochems; intraclasts 65-75%, fossils 3-5%, orthochems; dolomite 20-35%, spar 3-5%, anhydrite 2-5%. Intraclasts; micrite, weak concentric laminations, spherical-irregular. Fossils; ostracod 50%, calcisphere 50%, fair preservation. Dolomite; replacement, draping and geopetal silt, along grain boundaries. Spar; bladed-blocky filling calcispheres and anhydrite lined porosity. Anhydrite; filling porosity along thin horizontal zone. Porosity; interparticle 10%, fenestral 5-10%, intercrystalline 5%.

4123.5-4124.9

Packstone-wackestone: (dolomitic in part), lt gray-med brown, ooids, fossils, small pisoids and intraclasts, localized thin anhydrite filled zones, slight > downward to good fenestral and vug porosity, open vertical fractures, fenestrae, dessication cracks, thin crusts, type II stylolites, pressure solution on grains, fossils consist of calcispheres.

4124.9-4128.2

Dolomudstone-wackestone, locallized thin packstones: limey in part, lt gray-med brown, ooids, small intraclasts, isolated pisoids, locallized anhydrite filled zones, fair-very good vugular, fenestral, and intercrystalline porosity, some vugs > up to 8mm in size, alternating thin bedded grain rich/poor layers, fenestrae, oil stained where not anhydrite plugged.

TS 4126'

Oncolitic dolopackstone: allochems; oncoids 50 to 60%, orthochems; micrite 25-35%, dolomite 10-15%, anhydrite and gypsum 10-15%. Oncoids; dolomitized, some weak concentric laminations, irregular laminations. Micrite; matrix. Dolomite; clean, euhedral, lining pores. Anhydrite and gypsum; filling some interparticle porosity, some poikilotopic. Porosity; moldic 10-15, interparticle and matrix selective vugular 5-10.

4128.2-4131

Wackestone-thin grainstones: lt gray brown, ooids, pisoids (many broken), calcite lining porosity, isolated anhydrite filled zones, good vug porosity (mostly matrix selective), pisoids located in fine grained matrix, slight vadose look (gravity cements), thin bedded-laminated alternating grain rich/poor, some type I stylolites.

4131-4133.7

Packstone-wackestone with thin grainstones: lt gray brown, ooids, pisoids, calcite porosity lining and fill, isolated anhydrite vug and fracture fill, possible chlorite, good-very good vug, interparticle, moldic, shelter, and fracture porosity, thin bedded-laminated alternating grain rich/poor, some laminations steeply dipping, type I and II stylolites, pressure solution on grains.

4133.7-4138.7

Packstone-wackestone: lt brown-dk gray, ooids, pisoids, calcite lining and filling porosity, slight-fair interparticle, vug, and moldic porosity, thin bedded-laminated alternating course/fine grain layers, many thin crusts, isolated thin fenestral zones, much pressure solution on grains, type II stylolites and some microstylolite swarms.

TS 4135.3'

Oolitic peloidal grainstone: allochems; ooids and isolated pisoids 65-95%, peloids 0-20%, orthochems; spar 2-20%, micrite 3-8%. Ooids; radially fibrous, concentric laminations, many broken and recoated, some laminations dolomitized. Peloids; lower half of slide, draping and geopetal silt. Spar; small, blocky along margins, larger toward center, not intergrown. Micrite; isolated meniscus cement, possibly some matrix. Much pressure solution on grains in non-spar filled zones. Porosity; vugular 2-15%, matrix selective in spar filled areas, nonselective in open vug areas.

4138.7-4140.5

Wackestone-grainstone: lt gray brown, pisoid, ooid, fossil, calcite filling and lining interparticle and vugular porosity, fair-good vug (mostly non-fabric selective), fenestral, and interparticle porosity, thin bedded-laminated alternating course/fine grain and grain rich/poor, type II stylolites, much pressure solution on grains, fossils; calcispheres, gastropod, locally oil stained.

TS 4139.4'

Ooid peloid pisoid wackestone-packstone: Allochems; ooids, pisoids and pseudo-pisoids 45-55%, peloids 10-15%, fossils trace. Orthochems; micrite 30-40%, spar 5-15%, dolomite 1-3%. Ooids, pisoids and pseudo-pisoids; radially fibrous, concentric laminations, irregular shape, many broken and recoated, some dolomitized. Peloids; located in thin well sorted laminations, normal grading. Fossil; ostracod 30%, calcisphere 70%. Micrite; matrix. Spar; blocky, vug filling. Dolomite; large euhedral clear crystals, lining some vugs, replacing matrix in isolated zones. Porosity; nonselective vugular 5-10%, fenestral 2-5%.

4140.5-4141.9

Wackestone-thin grainstones: lt gray brown-med brown, large pisoids, ooids, blocky calcite vug lining and fill, micrite pendant cements, slight to good vug porosity, thin crusts, pisoids alternating with fine grain vug filling crusts, locally slight fenestral look.

TS 4140.5'

Pisolitic peloidal packstone: Allochems; pisoids 0-70%, peloids 25-5%, ooids 5-10%, quartz silt trace. Orthochems; microspar 0-70%, spar 5-15%, micrite 0-15%. Pisoids; irregular shaped, most with micritic pendant cement, pendants not oriented, some with radial fibrous laminations, some with porous micritic layers which resemble tufa. Peloids; spherical, micritic, and apparently draping some pisoids and filling voids. Ooids; small radially fibrous, acting as matrix to pisoids. Microspar; matrix material in half of slide not containing pisoids, sharp contact between the microspar and micrite. Spar; blocky filling vugular and fenestral porosity, isopachous lining some vugs within porous pisoids. Micrite; matrix. Porosity; nonselective vugular 3-8%, fenestral 1- 2%.

4141.9-4145

Wackestone-packstone: lt gray brown, ooids, pisoids, calcite lining and filling vugs and interparticle porosity, fair interparticle and vugular porosity (non-matrix selective), laminated alternating course/fine grains and mud poor/rich layers, much pressure solution on grains, many type II and some type I stylolites, possible chalcopyrite associated with type I stylolites.

4145-4146.4

Packstone-wackestone: tan-yellow brown, ooids, fossils, calcite lining and filling vugs and interparticle porosity, slight-fair interparticle and vug porosity, fairly massive with isolated thin crusts, some type II stylolites, fossils; calcispheres, ostracods, oil stained.

TS 4145'

Intraclastic peloidal fossiliferous grainstone-packstone: Allochems; intraclasts 40-50%, peloids 20-30%, fossils 5-10%, ooids tr. Orthochems; micrite 10-15%, spar 15-25%, opaque 1-2%, possible chlorite tr. Intraclasts; micrite, round, contain fossils. Peloids; micrite, round. Fossils; calcispheres 95%, ostracods 4%, gastropods 1%. Micrite; matrix. Spar; 2-3 generations, isopachous, dog tooth, blocky. Opaque; pyrite?, associated with type I stylolite. Stylolites; one cutting spar. Fair sorting of sediments. Porosity; vugular 5- 10%, interparticle 1-2%, intraparticle 1%, stylolite 1%.

TS 4146.4'

Fossiliferous peloidal grainstone-packstone: Allochems; Fossils 35-45%, peloids 25-30%, intraclasts 5%. Orthochems; spar 25-35%, micrite 5-10%. Fossils; calcispheres 55%, algae, Ortonella, possible Girvanella and Hedstroemia 40%, ostracods, 5%. Peloids; micrite, round. Intraclasts; micrite, round. Spar; mostly dog tooth and blocky, some isopachous, filling interparticle, fenestral and some vugular porosity. Porosity; intraparticle and moldic < 5%.

NDGS# 2271

Depth Description

4104-4105.3

Dolomudstone-packstone: lt gray-lt brown gray, ooids (most recrystallized), isolated anhydrite porosity fill, slight-fair intercrystalline and vug porosity, thin packstone laminations within mudstone.

TS 4104'

Peloid dolograinstone-wackestone: Allochems; peloids 30-85%, intraclasts 5%, brown organic fragment (possible fossil) tr.

Orthochems; micrite 0-60%, dolomite 5-25%, anhydrite 5-10%. Peloids; dolomitized, irregular (squashed) shape in some zones. Intraclasts; micrite, round, located in a single layer. Micrite; dolomitized. Dolomite; large, clean, euhedral, lining porosity. Anhydrite; filling possible fenestral porosity. Porosity; vugular 5%, fenestral 2-3%.

4105.3-4107.9

Mudstone-wackestone: lt gray brown-lt brown, possible peloids (recrystallized), ooids, small intraclasts, some anhydrite filling of interparticle and vug porosity, fair-good intercrystalline and vugular porosity, thin grain rich layers, pressure solution on grains, oil stained.

TS 4106.5'

Dolomitic intraclastic peloidal packstone-wackestone: Allochems; intraclasts 40-50%, peloids 20-30%. Orthochems; dolomite 20-35%, micrite 10-20%, spar tr. Intraclasts; micrite, round-subround, some with fossils in core (ostracod). Peloids; micrite, irregular shape. Dolomite; lining porosity and grain margins, some replacement. Micrite; micritic crusts, some matrix. Spar; blocky pore filling, small crystals in low porosity zones. Porosity; 5-10% matrix selective vugular, <5% enlarged fenestral.

4107.9-4108.6

Wackestone-packstone: lt brown, ooids, peloids, intraclasts, good vug porosity, isolated thin crusts, much recrystallization, oil stained.

TS 4107.9'

Dolomitic intraclastic peloidal packstone-wackestone: Allochems; intraclasts 30-40%, peloids 20-30%, Orthochems; microspar 20-30%, dolomite 10-20%, micrite 5-10%, spar 5-10%. Intraclasts; highly altered, dolomitized, neomorphosed, micritic. Peloids; micritic, irregular shaped. Microspar; replacing micritic matrix and grains. Dolomite; lining most porosity and grain margins, possibly replacing micritic crusts. Micrite; matrix. Spar; some dogtooth. Porosity; both spar and non-spar lined, nonselective vugular 10-15%, matrix selective 2-5%, possible interparticle 2%.

4108.6-4110

Mudstone-wackestone: lt-med brown, ooids, some intraclasts, anhydrite crystals within limestone matrix, fair intercrystalline and moldic porosity, some type II stylolites, oil stained.

TS 4109.3'

Intraclastic peloidal packstone-wackestone: Allochems; intraclasts 5-25%, peloids 10-30%, ooids tr. Orthochems; anhydrite 0-70%, micrite 10-30%, microspar 5-15%, dolomite 5-10%, spar 2-5%. Intraclasts; small, micritic. Anhydrite; replacing calcite matrix and grains, enclosing dolomite. Micrite; matrix. Microspar; replacing matrix and some grains. Dolomite; large euhedral crystals associated with stylolites and some porosity. Spar; blocky lining some vugular porosity. Type I and II stylolites.

4110-4111.5

Wackestone-packstone: lt-med brown, ooids, pisoids (recrystallized), fair-good moldic, vug, and intercrystalline porosity, thin grain rich layers within thick mud rich layers, heavy oil stain.

TS 4111.5'

Intraclastic dolowackestone: Allochems; intraclasts 25-35%. Orthochems; micrite 55-65%, anhydrite 5-10%, dolomite 2-5%. Intraclasts; virtually all removed (molds). Micrite; dolomitized. Anhydrite; filling some fenestrae, many dolomite inclusions. Dolomite; large euhedral crystals lining most porosity. Porosity; 20-30% moldic, 5-10 fenestral, 2-3% intercrystalline. Some thin dolomitized crusts.

4111.5-4115.5

Dolopackstone-wackestone, with thin grainstones: lt-med brown, ooids and peloids (recrystallized), anhydrite locally filling porosity, good moldic and vugular porosity, some thin mud laminations, type II stylolites, fenestrae, heavy oil stain.

TS 4114'

Dolomitic intraclastic peloidal packstone-wackestone: Allochems; intraclasts 30-35%, peloids 20-25%, Orthochems; micrite 30-40%, dolomite 10-15%, pyrite tr. Intraclasts; subround, micrite, some dolomitized. Micrite; matrix, most dolomitized now. Dolomite; large euhedral crystals lining porosity, grain margins, and along insoluble laminations. Pyrite; associated with thin possibly organic insoluble laminations. Porosity; micropore 2-3%, intercrystalline 2-3%, fenestral 2-3%. Many type II stylolites. Very laminated looking but laminations are discontinuous, overlapping.

4115.5-4117

Dolomudstone: lt gray, anhydrite locally filling vugs, slight-fair intercrystalline and vugular porosity, slight patterned look, oil stain.

TS 4116.5'

Dolomudstone: Dolomite 70-80%, Orthochems; anhydrite 20-30%, Dolomite; fine grained, massive. Anhydrite; blocky, filling most vugs. Porosity; vugular 10%. Coarse dolomite flooring some vugs.

4117-4119.6

Packstone-mudstone: lt gray brown, peloids, ooids, intraclasts, fair-good moldic, enlarged fenestral, and vugular porosity, alternating grain rich/mud rich laminations, some type II stylolites, oil st.

TS 4119'

Dolomitized peloidal intraclastic wackestone: Allochems; peloids 5-25%, intraclasts 5-15%, Orthochems; dolomite 70-80%. Peloids; micrite. Intraclasts; micrite, irregular shaped. Dolomite; fine grained, some coarse grained associated with porosity. Porosity; enlarged fenestral 5-10%, intercrystalline <5%. Some lamination evident, due both to grain size as well as possible organics.

4119.6-4120.4

Mudstone-wackestone: lt brown, peloids, intraclasts, slight intercrystalline porosity, thin fine grained laminations, type II stylolites.

4120.4-4121

Dolomitic mudstone-packstone: lt brown gray-med brown, ooids, fair-good moldic, intercrystalline, and vugular porosity, alternating thin beds of grain rich/poor.

4121-4124.5

Wackestone: lt gray brown, pisoids, ooids, some small intraclasts, some anhydrite porosity filling, slight-fair intercrystalline, vugular, and moldic porosity, alternating grain rich/poor laminations, fenestrae, type I and II stylolites, oil stained.

TS 4121.5'

Peloidal intraclastic wackestone-packstone: Allochems; peloids 35-45%, intraclasts 10-15%, radially fibrous crusts (isolated fragments) 1-2%. Orthochems; micrite 35-45%, dolomite 5%. Peloids; micrite, some with one-two outer laminations (pseudo ooids). Intraclasts; subround, micrite and peloid composition. Micrite; matrix. Dolomite; associated with porosity and type II stylolites. Type I and II stylolites. Porosity; fenestral 5%, along dolomite lined/filled stylolites 5%.

TS 4124'

Oncolitic peloidal packstone-wackestone: Allochems; Oncoids 35-45%, peloids 20-30%, fossils tr. Orthochems; micrite 10-15%, microspar 10-15%, spar 2-3%, dolomite tr. Oncoids; subround, containing fossils, weakly laminated, isolated radially fibrous laminations. Fossils; Girvanella, calcispheres. Spar; large blocky vug filling. Dolomite; associated with stylolites, lining some vugs. Virtually everything micritized. Isolated type I stylolite. Much porosity lined completely by several radially fibrous layers, some then filled with peloids and micrite. Porosity; 5-10% vugular.

4124.5-4127

Wackestone-mudstone: lt gray brown, pseudo? pisoids, intraclasts, fair vugular porosity, thin caliche crusts, some of which are cut up by type II stylolites forming pseudo grains, oil stained.

TS 4126.5'

Peloidal intraclastic packstone: Allochems; peloids 50-60%, intraclasts 10-20%, fossil tr. Orthochems; micrite 20-30%, dolomite 5-10%, spar tr. Intraclasts; subround, micrite and peloid. Fossils; calcispheres. Micrite; matrix. Dolomite; associated with stylolites and lining fenestral porosity. Spar; blocky vug fill. Vugs contain very little dolomite, squashed fenestrae contain much dolomite. Porosity; vugular 5-10%, squashed fenestral 5%.

4127-4127.8

Grainstone-wackestone: dk brown, ooids, pisoids, some broken and recoated, spar lining and filling vugs, very minor-very good interparticle and vugular porosity, some open vertical fractures, massive, heavy oil stain.

TS 4127'

Dolomitic peloidal intraclastic packstone-grainstone: Allochems; peloids 55-65%, intraclasts 10-20%, pisoids 5%, Orthochems; micrite 10-20%, spar 5%, dolomite 5%. Peloids; most dolomitized, most with one radially fibrous outer lamination (pseudo ooid). Intraclasts; round, micrite. Pisoids; radially fibrous, many broken fragments. Micrite; matrix. Spar; blocky, filling some vugs. Dolomite; some entire small zones appear dolomitized. Porosity; 5% vugular, 5% interparticle. Poor sorting.

4127.8-4128
Dolomitic mudstone: lt brown, ooid, anhydrite filling vugs and fenestrae, very minor intercrystalline porosity, fenestral looking.

4128-4129.6
Packstone-wackestone: lt brown, well preserved ooid, pisoid, spar lining some porosity, good vugular and moldic porosity, thin micritic crusts within grain rich layers, some type II and I stylolites.

TS 4129'
Intraclastic peloidal packstone-grainstone: Allochems; intraclasts 40-50%, peloids 35-45%, fossils tr. Orthochems; Micrite 5-10%, dolomite 5-10%. Intraclasts; round, micrite and peloids. Micrite; matrix. Dolomite; crystals associated with porosity and grain boundaries. Some pressure solution on grain boundaries. Type II stylolites. Some reverse grading of peloids and intraclasts. Porosity; 3-5% vugular, 5% intercrystalline along stylolites as well as squashed fenestral and interparticle.

NDGS# 2384
Depth Description

Core from this well is very fractured and unmarked except for footage marked on boxes.

4097-4098.5
Quartz sandstone: med. gray, subangular, fine, moderately sorted, slightly coarser/finer grain lamination.

4098.5-4099.8
Interlaminated anhydrite and dolostone: tan-dark gray, nodular and laminated anhydrite (some argillaceous), distorted dolostone laminations, some pyrite rich laminations, very poor-no porosity.

4099.8-4101.5
Interbedded silty/sandy anhydrite and dolostone: dark olive gray-white, anhydrite sand, quartz silt and fine sand, nodular and laminated anhydrite, distorted dolostone containing gypsum crystals, alternating grain rich/poor laminations.

4101.5-4103.4
Calcitic dolowackestone-dolowackestone: medium brown, ooid, small intraclasts, oncoids, anhydrite filling fracture, interparticle, and fenestral porosity, fair intercrystalline porosity, alterna- ting fine grain rich/poor laminations, slight fenestral appearance, heavy oil stain.

TS 4103'
Stromatolitic oncoidal doloboundstone: Allochems; algal lamination fragments 30%, oncoids 5-10%, ooid ghosts 1-3%, quartz silt tr. Orthochems; dolomite 30-40%, anhydrite 20-40%. Oncoids; flattened, weakly laminated. Dolomite; fine grained replacement, coarse grained filling fenestrae and associated with stylolites. Anhydrite; nodular, filling sheet cracks, some vertical fracture fill. Probable stylolites associated with algal laminations. Porosity; 5% fracture, 5% intercrystalline.

4103.4-4104
Interlaminated dolomudstone and anhydrite: lt. gray-lt. brown,

rounded gypsum grains, much pyrite, nodular anhydrite, thinly laminated dolomudstone.

4104-4105.5

Dolomitic packstone-wackestone: lt. brown-lt. gray, peloids, small intraclasts, fossils, anhydrite filling vugular porosity (some pyrite lined), fossils consist of calcispheres, fair small vugular and intercrystalline porosity.

TS 4104'

Peloidal intraclastic dolopackstone-grainstone: Allochems; peloids 60-70%, intraclasts 5-10%. Orthochems; anhydrite 15-25%, dolomite 10-20%. Anhydrite; filling interparticle and vugular porosity. Dolomite; fine grain replacing micrite, coarser grain associated with both open and anhydrite filled porosity. Massive looking. Porosity; 5-7% vugular, <5% intercrystalline.

4105.5-4106.2

Mudstone: lt. gray brown-dk. gray, anhydrite and pyrite fenestrae or sheet crack fill, thinly laminated muds and stylolite seams (clay seams) up to 3cm thick, minor vugular porosity.

4106.2-4107.5

Packstone-wackestone: lt. brown, large intraclasts, peloids, isolated pisoids with possible gravity cements, brown anhydrite (replacive), anhydrite filling interparticle porosity and vertical fractures, alternating fine/course grain laminations, pressure solution on some grains, thin crusts, fair vugular porosity, oil stained.

TS 4106.2'

Anhydrite replacing intraclastic peloidal packstone-grainstone: Allochems; intraclasts 10-50%, peloids 5-25%, fossils tr. Orthochems; anhydrite 5-70%, dolomite 15-25%. Intraclasts; micrite, round, some contain fossils. Fossils; calcispheres 90%, ostracods 10%. Anhydrite; massive front replacing micritic grains. Dolomite; associated with grain boundaries and lining porosity. Porosity; 5-7% interparticle, <5% vugular, <5% intercrystalline.

4107.5-4109

Wackestone-mudstone: lt. brown-lt. gray brown, poorly sorted intraclasts, isolated pisoids, anhydrite filling fenestrae and vugs locally, fair nonselective vugular porosity.

NDGS# 2464

Depth Description

Core from this well is poorly marked and broken up in sections.

4055-4056

Thin bedded anhydrite: lt. gray-white, thin bedded, nodular looking in places.

4056-4058.7

Quartz sandstone: med. gray, angular-subangular fine quartz sand, small anhydrite nodules, anhydrite interparticle cement, massive, no porosity.

TS 4058.7'

Interlaminated quartz siltstone and dolowackestone: Allochems; quartz silt 30-35%, anhydrite lathes 5%. Orthochems; dolomite

30-35%, anhydrite 20-25%. Quartz silt; coarse, subangular, some K-spar. Anhydrite lathes; contained within dolomudstone, small. Dolomite; fine grain, distorted laminations. Anhydrite; forming cement in quartz silt laminations. Porosity; 1% intercrystalline.

4058.7-4064

Interlaminated anhydrite and dolomudstone: tan-lt.gray, very fine anhydrite crystals or sand, thin slightly-very distorted dolomite laminations, some nodular (chicken wire) anhydrite, no porosity.

TS 4059'

Laminated-displacive anhydrite: Allochems; very fine anhydrite crystals or silt 45%, quartz silt tr. Orthochems; anhydrite nodules 45%, dolomite stringers 5%, pyrite 5%. Anhydrite silt; very fine cubic crystals, massive. Pyrite; framboids and crystals, concentrated in thin stringers. Porosity; <1% intercrystalline.

4064-4067

Interlaminated dolomudstone and anhydrite: lt. gray, anhydrite sand, pyrite, dolomudstone slightly patterned, fair-good small vugular and micropore porosity.

TS 4064.5'

Calcitic celestite sand dolopackstone-wackestone: Allochems; celestite sand 40-70%. Orthochems; dolomite 30-60%, micrite 1-3%, and celestite rosette. Celestite sand; fine-very fine, subangular-subround. Dolomite; matrix, argillaceous. Celestite rosette has many small K-spar grains in the center. Porosity; <1% intercrystalline.

4067-4068.6

Dolowackestone-mudstone: lt. gray, peloid, fair intercrystalline and small vugular porosity, thin wavy (uniformly distorted) laminations, some oil staining.

TS 4068'

Calcitic laminated dolomudstone: weakly laminated and uniformly distorted dolomudstone, laminations consist of course/fine dolomite, numerous sheet cracks. Porosity; horizontal cracks 5-10%.

4068.6-4070

Dolomudstone-packstone: lt.gray-lt.brown, ooid, intraclast, anhydrite mold fill, fair intercrystalline and small vugular porosity, thin grain rich laminations, some oil staining.

4070-4073.5

Interlaminated dolomudstone & anhydrite: lt.gray-lt.brown gray, anhydrite sand or crystals, small anhydrite nodules locally, minor intercrystalline porosity, weakly laminated, possible algal laminations.

4073.5-4078.5

Dolomitic wackestone-grainstone: med.brown, peloid, intraclast, anhydrite filling porosity locally, anhydrite replacing carbonate locally, fair intercrystalline and small vugular porosity, type II stylolites, thin laminations, erosional surfaces, heavy oil stain.

TS 4075'

Calcitic peloidal dolopackstone-wackestone: Allochems; peloids 65-75%, intraclast <5%, Fossils tr. Orthochems; dolomite 20-30%, anhydrite 1-2%, spar tr. Peloids; dolomitized. Fossil; possible stromatolitic laminations. Dolomite; matrix, associated with possible algal laminations. Anhydrite; filling fenestrae. Type II stylolites. Porosity; small vugular 2-3%, intercrystalline 2-3%, fenestral 1-2%.

4078.5-4081

Packstone-wackestone: lt.brown, peloid, intraclast, isolated ooids, replacive anhydrite, fair small vugular porosity, numerous type II stylolites.

TS 4081'

Oolitic peloidal intraclastic packstone-wackestone: Allochems; ooids 35-45%, peloids 15-20%, intraclasts 10-15%. Orthochems; anhydrite 10-30%, microspar 10-15%, spar 2-5%. Ooids; very few radially fibrous coatings on round-irregular shaped micrite/peloid core, some partially dolomitized. Intraclasts; round-irregular peloid/micrite. Anhydrite; replacing finer grains and matrix. Microspar; replacing micrite. Spar; located in some pores and enclosed by anhydrite in places. Isolated type I stylolite. Porosity; 2-7% matrix selective vugular, 1-2% moldic.

4081-4084

Grainstone-wackestone:lt.-med.brown, ooid, peloid, intraclast (pseudo pisoid), replacive anhydrite, spar vug lining, fair small-medium vugular porosity, alternating thin course/fine grain laminations, oil st.

TS 4083'

Calcitic peloidal fossiliferous dolowackestone: Allochems; peloids 5-10%, intraclasts 5%, fossils 2-3%. Orthochems; dolomite 80-85%, microspar 5%. Intraclast; very vague boundaries. Fossils; calcispheres 90%, ostracods 10%. Dolomite; course, replacement. Microspar; matrix. Porosity; micropore 2-5%, intercrystalline 2-3%.

4084-4085.4

Packstone-wackestone: lt.-med.brown, peloids, intraclasts, oncoids, fair intercrystalline porosity, flattened oncoids and possible algal laminations, oil st.

4085.4-4086.5

Dolopackstone-wackestone: lt.-med.brown, peloid, ooid, small intraclast, anhydrite nodules, anhydrite filling cracks, fenestrae, and interparticle porosity, slight-fair intercrystalline and small vugular porosity, some areas appear to be dessication cracked, fenestral appearance, oil stained.

TS 4085.7'

Peloidal oolitic dolopackstone-wackestone: Allochems; peloids 20-60%, ooids 10-30%. Orthochems; anhydrite 10-70%. Ooids; small, radially fibrous. Anhydrite; filling vertical and horizontal cracks, displacive nodules, replacing grains and matrix. Porosity; 5% fracture, intercrystalline 1-2%.

4086.5-4087

Mudstone: lt.brown, possible very small peloids, anhydrite filling dessication cracks and porosity associated with stylolites, fair intercrystalline porosity as well as porosity associated with stylolites, many typeII stylolites.

4087-4090

Packstone-wackestone: lt.brown, small ooids, peloids, anhydrite filling horizontal cracks, slight interparticle porosity, possible sheet cracks and algal laminations, oil stained.

NDGS# 2669
Depth Description

4083-4085
Quartz sandstone: med.gray, fine grain quartz, anhydrite cemented, some anhydrite crystals, massive, no porosity.
4085-4089
Interlaminated anhydrite and dolomudstone: med. gray-tan, possible algal remnants, scattered pyrite, some dolomud laminations appear cracked, slight-no porosity.
TS 4085.8'
Sandy dolomudstone: Allochems; sand 20-25%, dolomud 75-80%. Sand; 70% medium anhydrite sand, 15-25% fine quartz sand, 5-10% dolomite sand. Slightly distorted thinly laminated sands interlaminated with dolomudstone. Sand fairly well sorted within a single lamination, usually with a dolomud matrix. Porosity; 1-3% intercrystalline.
TS 4088.3'
Silty dolomudstone: Allochems; silt 10-25%, dolomudstone 75-90%. Silt; quartz 5-10%, anhydrite 5-10%, possible coarse dolomite tr. Possible vertical oil migration or vertical oriented stylolite. Porosity; horizontal crack 2-3%, intercrystalline 1%.
4089-4090.5
Calcitic dolowackestone: med.-dk.brown, flattened oncoids, ooids, intraclasts, nodular anhydrite, anhydrite filling fenestrae and horizontal and vertical cracks, slight intercrystalline porosity, alternating mud rich/poor, fenestral looking, hvy. oil staining.
4090.5-4092.4
Dolomudstone: lt.brown gray-lt.gray, isolated ooids and small intraclasts, anhydrite filling vertical and horizontal cracks, very slight porosity, massive-patterned.
4092.4-4094
Packstone: lt.brown, small intraclast, peloid, fossil, blocky spar filling and lining vugular porosity, fair-good small vugular porosity, type I and II stylolites, ostracods.
4094-4096.5
Wackestone-packstone: lt.brown, ooid, peloid, intraclast, spar lining and filling vugular porosity, anhydrite replacing matrix and grains, good-very good small-medium vugular porosity, fenestral appearance, possible algal structure.
TS 4094'
Dolomitic peloid wackestone: Allochems; peloids 30-40%, fossils tr. Orthochems; micrite 35-45%, dolomite 10-30%, anhydrite 5-10%, spar 5%. Fossils; calcispheres. Dolomite; most is replacing replacive anhydrite, fine crystals lining some fenestrae. Anhydrite; vugular and fenestral poro sity filling. Spar; blocky, filling some fenestrae. Porosity; 10-15% fenestral.
4096.5-4097
Wackestone-grainstone: lt.brown, ooid, peloid, small pisoid,

replacive anhydrite, spar lining vugular porosity, good vugular and fenestral porosity, thin crusts and graded laminae, some fenestrae.

TS 4096.5'

Oolitic peloidal wackestone-grainstone: Allochems; ooids 20-50%, peloids 15-30%, pisoids 10-15%. Orthochems; anhydrite 5-65%, micrite 5-10%, spar 5-6%. Ooids; radially fibrous concentric laminae. Peloids; matrix and sorted laminae. Pisoids; irregular shaped, some pseudo. Anhydrite; replacement, vug filling. Spar; blocky vug fill, isopachous vug lining. One radial fibrous crust, bored, micritized. Graded laminations and several crusts. Fenestral looking in part. Porosity; 10% vugular, 2-3% fenestral.

4097-4097.5

Packstone-wackestone: lt.brown, ooids, intraclasts, spar vug lining, good vugular porosity, type I and II stylolites, much pressure solution on grains, thin fine grain laminations.

4097.5-4099

Wackestone-packstone: lt.brown-lt.gray brown, ooids, peloids, isolated pisoids, anhydrite filling fenestrae and vertical fractures, good-very good medium-large vugular porosity, some fenestral porosity, possibly some silt infill of porosity.

<u>NDGS# 3286</u>

<u>Depth Description</u>

4148-4151.5

Bedded anhydrite: white-med.gray, thin-medium bedded, no porosity.

4151.5-4152

Sandy anhydrite: med.gray, angular quartz fine sand, slightly laminated and distorted looking, no porosity.

4152-4154.5

Quartz sandstone: med.gray, fine quartz sand, anhydrite cemented, massive-weakly laminated (courser/finer grain), no porosity.

4154.5-4158

Interbedded anhydrite and dolomite: white-dk.gray, scattered quartz silt and sand, some nodular anhydrite, distorted dolomud laminations, minor porosity.

4158-4162

Packstone-wackestone: lt.gray brown, ooids, peloids, large intraclasts, possible oncoids, anhydrite filling vugs and replacing carbonates, fair vugular porosity, type II stylolites.

4162-4166

Packstone-wackestone: lt.gray brown, ooids, peloids, isolated pisoids, spar filling all porosity, very minor vugular porosity, type II stylolites, weakly laminated, thin local concentration of ostracods.

4166-4168.5

Packstone-wackestone: lt.gray brown, ooids, peloids, isolated pisoids, spar filling some porosity, fair vugular porosity, oil stained.

TS 4168'

Dolomitic oolitic grainstone-packstone: Allochems: ooids 65-75%, intraclasts 5-10%, fossils tr. Orthochems; dolomite 20-25%, spar tr. Ooids; small, radial fibrous, most with no core, possibly microspar. Intraclasts; micritic, irregular shaped. Fossils; calcispheres 100%. Dolomite; replacing micritic matrix and grain boundaries. Spar; blocky vug filling. Weakly sorted, one argillaceous rich zone. Porosity; 10-15% nonselective vugular, 5% intergranular.

4168.5-4176

Packstone-wackestone: lt.gray brown, ooids, peloids, isolated pisoids, spar filling some vugular porosity, fair vugular porosity, many thin wackestone laminations with fenestrae.

NDGS# 3287

Depth Description

Only portions of this core were found. Representative pieces from approximately six feet of core were packed in each three foot core box.

4146-4149.5

Anhydrite: lt yellow white-lt gray, massive with isolated dolomitic stringers.

4149.5-4150

Anhydrite-dolomudstone: lt gray, containing anhydrite sand or crystals, some displacive anhydrite, very minor porosity, distorted dolomudstone laminae.

4150-4152

Dolowackestone-packstone: med. brown, algal fragments, oncoids, recrystallized ooids/intraclasts, anhydrite filling vugular and interparticle porosity, fair intercrystalline and moldic porosity, slightly fenestral looking, oil stained.

4152-4152.5

Calcitic dolowackestone-mudstone: lt. gray, peloid, intraclast, fair intercrystalline porosity, very patterned looking, possibly burrowed.

4152.5-4154

Packstone-wackestone: lt. brown, peloid, isolated ooid, possible fossil, minor small vugular porosity, many type II stylolites, much pressure solution on grains, alternating fine/course grain laminations.

4154-4155

Dolomudstone-wackestone: lt. gray, peloid? (recrystallized), pyrite, fair intercrystalline and small vugular porosity, slight patterned look.

4155-4156.5

Dolomitic wackestone-packstone: lt. gray brown-lt. brown, peloid? (recrystallized), fossil, intraclast, minor intercrystalline and small vugular porosity, weakly laminated, fossils; ostracods, slight oil staining.

4156.5-4160

Wackestone-packstone: lt.gray brown, poorly sorted peloids, ooids, pisoids, anhydrite and some spar filling vugs, good fenestral and small vugular porosity, much type II stylolites, fenestrae, alternating course/fine grain laminations, oil staining in the fenestrae.

4160-4160.5

Dolomudstone: lt.gray, good vugular and intercrystalline porosity, some patterning, weak laminations.

4160.5-4167.5

Wackestone-packstone: lt.brown-lt.gray brown, alternating peloid, ooid, and pisoid rich zones, localized anhydrite vug fill, localized spar vug lining, fair-good fenestral and matrix selective vugular porosity, some pressure solution on grains, alternating fine/course grain laminations, fenestral looking, isolated thin crusts.

4167.5-4169

Packstone-wackestone: lt.brown, peloid, small ooids, pisoid rich zones, isolated coated intraclasts, anhydrite vug and interparticle fill or replacement, spar vug fill, very minor small vugular porosity, type I and II stylolites, thin alternating course/fine grain laminations.

NDGS# 3343

Depth Description

This core is poorly marked, badly broken up, and only portions of the core are left for the uppermost cored interval of the well. Approximately 13 feet contained in a 3 foot core box.

4137-4142

Anhydrite: lt.gray, massive, bedded.

4142-4143

Anhydrite: lt.gray, pyrite rich zones, massive, bedded.

4143-4143.5

Silty Anhydrite: lt.-med.gray, silt, thinly laminated, some compacted anhydrite nodules, slight chickenwire appearance.

4143.5-4146.5

Quartz sandstone: med.gray, quartz, fine, angular, moderate sorting, anhydrite cement, weakly laminated, grain rich/poor.

4146.5-4147

Silty Anhydrite: lt.-med.gray, silt, thinly laminated.

4147-4148

Dolomudstone: lt.brown gray, small round grain ghosts, anhydrite filling cracks (sheet?), minor intercrystalline porosity, thin distorted laminations.

4148-4150

Anhydrite: med.-lt.gray, some nodules, most bedded, distorted argillaceous laminations.

4150-4150.6

Anhydrite and dolomitic packstone-grainstone: med.gray-lt.gray brown, intraclasts (rip-up clasts), gypsum crystals, peloids, small ooids, anhydrite filling shelter porosity, minor small vugular porosity, rip-up layer, distorted thin laminations, slight fenestral look.

TS 4150.1'

Calcitic oolitic intraclastic dolopackstone-mudstone with celestite crystals: Allochems; ooids 20%, intraclasts 10%.

Orthochems; dolomite 30%, anhydrite 20%, celestite 20%. Ooids; small, radially fibrous, in well sorted laminations, dolomitized. Intraclasts; small, round-very irregular, flooring filled vugs. Dolomite; fine grain, possible dolomitized micrite matrix and laminations, course lining celestite crystal margins. Anhydrite; most now celestite, filling solution enlarged voids and cracks as well as possible gas escape structures, filling interparticle porosity. Celestite; crystals in a fine grain matrix. Porosity; fenestral 5%, interparticle 2-3%, intercrystalline 2-3%, vugular 2%.

4150.6-4152.5

Grainstone-wackestone: lt.brown, ooids, peloids, small intraclasts, blocky spar lining and filling fenestrae and vugs, locally anhydrite filled, minor-fair moldic and vugular porosity, many type II stylolites, fenestral looking, alternating course/fine grain laminations.

TS 4150.9'

Oolitic peloidal packstone-wackestone: Allochems; ooids 20-30%, peloids 15-20%, intraclasts 5-10%, fossils tr. Orthochems; micrite 25-35%, spar 20- 25%, anhydrite 2-5%, dolomite 1-2%. Ooids; micritized, weakly laminated. Intraclasts; micritic, round, some weakly laminated. Fossils; calcispheres 50%, unID 50%. Spar; both isopachous and bladed mosaic. Anhydrite; replacing spar and grains locally, filling fenestrae and vugs. Dolomite; coarse, lining anhydrite filled fenestrae and vugs. Porosity; 2-3% moldic. Large number of filled fenestrae.

4152.5-4152.9

Overpacked grainstone-packstone: lt.gray brown, ooids, peloids, brown anhydrite (replacing carbonate), spar filling porosity, very minor moldic porosity, much pressure solution on grains, many type II stylolites.

4152.9-4155.2

Grainstone-wackestone: lt.gray brown, ooids, peloids, isolated intraclasts, blocky spar lining vugs and fenestrae, fair vugular and moldic porosity, fenestral looking, mud rich/poor laminations, thin fine grain gray dolomite layers, alternating ooid/peloid laminations, some pressure solution.

4155.2-4155.3

Clay seam: dk.gray, massive stylolite seam.

4155.3-4157.3

Silty dolomudstone: lt.-med.gray, silt, isolated small intraclasts, pyrite, very minor intercrystalline porosity, local cross-bedding, thin pyritic laminations.

TS 4155.6'

Silty intraclastic dolowackestone: Allochems; intraclasts 20-30%, silt 10-20%. Orthochems; dolomite 60%, pyrite tr. Intraclasts; fine grain, irregular shape, some faint radial fibrous. Silt; quartz 40%, course dolomite 60%, small green grains tr. Dolomite; fine grain, matrix. Porosity; <1% intercrystalline. Many dendritic patterns occurring in round forms.

TS 4157.2'

Calcitic cross-bedded dolosiltstone: Allochems; dolomite 35-65%, quartz 10-15%. Orthochems; microspar 20-40%, pyrite 2-3%.

Dolomite; course, silt. Quartz; angular, silt. Microspar; matrix, locally concentrated. Pyrite; local concentrations, framboids. Porosity; 2-5% along horizontal cracks. Good low angle cross-bedding of silts.

4157.3-4157.8

Dolomudstone: tan, ooid or small intraclast ghosts, good intercrystalline and very large vugular porosity, slight patterned look.

4157.8-4158.2

Solution brecciated mudstone: lt.-med.gray, some spar vug fill, fair intercrystalline, small vugular and horizontal fracture porosity, massive type II stylolite swarm, possibly brecciated.

4158.2-4161.5

Calcitic dolomudstone: lt.brown gray-lt.brown, some pyrite, good micropore and intercrystalline porosity, slight patterned look, weak dark/light color laminations, some open vertical fractures.

TS 4159.8'

Dolomitized wackestone: Allochems; peloid-small ooid sized ghosts and molds 50-60%, quartz silt tr., organic fragments tr. Orthochems; dolomite 40-50%. Porosity; moldic 30-40%, intercrystalline 5%. Fairly massive, poorly sorted.

4161.5-4162.8

Calcitic Dolomudstone-packstone: lt.-med.olive gray, fossils, peloids or sand size fossil fragments, pyrite, very good moldic and intercrystalline porosity, some type II stylolites, both horizontal and vertical burrows, thin-bedded, some weak cross-bedding locally, possibly stromatolitic, fossils include: brachiopods (3cm wide), ostracods, and calcispheres. Vertically fractured.

TS 4162.5'

Calcitic peloidal fossiliferous dolowackestone-packstone: Allochems; peloids 30-40%, fossils 20-25%, quartz silt tr. Orthochems; dolomite 40-50%, pyrite 1-2%. Peloids; replaced by microspar. Fossils; ostracod 55%, gastropod 15%, brachiopod 15%, algae 5%, calcispheres 5%, organics (plant or animal) 5%. Most fossils replaced by pseudo-spar. Dolomite; fine grain, probably replacing matrix. Porosity; moldic 10-15%, intercrystalline 2-3%. Weak thick laminations, fair-poor sorting.

4162.8-4164.7

Mudstone-wackestone: lt.gray white, ostracods, intraclasts, spar filling vertical fractures and moldic porosity, blocky spar lining vugular porosity, anhydrite filling some vugs, minor small vugular porosity, massive, type I stylolites, horizontal burrows, both open and closed vertical fractures.

4164.7-4166

Packstone-wackestone: lt.brown gray, fossil, spar filling some vugs, fair small vugular and micropore porosity, weakly laminated, fossils include: calcispheres, ostracods, algae.

4166-4167

Grainstone-packstone: lt.brown, small ooids, anhydrite cement, some type of green mineral, fair interparticle and moldic porosity, low angle bedding, thin mudchip and mudball bed.

4167-4168

Packstone-wackestone: lt.brown, fossils, ooids, isolated small pisoids, blocky spar filling porosity, minor microporosity, slight grain rich/poor laminations, fossils include: calcispheres, ostracods, branching algae, gastropods.

TS 4167.8'

Fossiliferous intraclastic packstone-wackestone: Allochems; fossils 55%, intraclasts 10%, ooids 5%, peloids 5%, quartz silt tr. Orthochems; micrite 10%, spar 10%, dolomite 5%. Fossils; calcispheres 35%, algae (Garwoodia) 25%, ostracod 20%, gastropod 10%, mollusc 5%, algae (unID) 5%. Intraclasts; micritic, some containing fossils, round-subround. Ooids; weakly laminated, intraclast core. Spar; filling interparticle and intraparticle porosity, bladed mosaic fill of vugs. Dolomite; dolomitized zone under spar filled horizontal crack, some ostracods within the dolomitized zone, Type II stylolites associated with dolomite. Porosity; fracture 1-3%. Some mud filled depressions contain articulated ostracods. All vugs spar filled, most carbonate silt floored.

4168-4172

Core not recovered for this interval.

4172-4173.7

Grainstone: lt.brown-lt.gray brown, ooids, intraclasts, spar filling interparticle porosity, minor fracture and moldic porosity, alternating course/fine grain laminations, vertical fractures.

TS 4172.5'

Oolitic oncoidal peloidal grainstone-packstone: Allochems; ooids 35%, oncoids 25%, peloids 15%, fossils 5%, quartz silt tr. Orthochems; spar 20%, dolomite tr., pyrite tr. Ooids; radial fibrous and concentric laminations. Peloids; matrix, flooring some vugs. Fossils; algal mat 99%, echinoderm fragment 1%. Spar; bladed mosaic, filling vugs, interparticle porosity and fractures. Dolomite; associated with stylolites. Pyrite; flooring some vugs. Porosity; moldic 3-5%, vertical fracture 1-2%. Most vertical and horizontal fractures spar filled. Small type I stylolite. Pressure solution on some oncoids. Sharp contact between ooids and oncoids. Some reverse graded laminations. Vugs fenestral looking.

4173.7-4175.8

Wackestone-packstone: lt.gray brown, ooids, peloids, both clear and brown spar filling vugs and fenestrae, very minor porosity, fenestral looking, some type II stylolites, possible algal or microstalactitic structures.

TS 4173.7'

Peloidal fossiliferous grainstone: Allochems; peloids 50%, ooids 10-15%, oncoids 10%, fossils 5-10%. Orthochems; spar 10-15%, micrite 5%, dolomite 1-2%. Ooids; concentric laminations, some weakly laminated. Oncoids; round, weakly laminated. Fossils; Algae (lense shape structure with tubules) 50%, stromatolite? (linked, possibly layered microstalactites) 40%, ostracods (geopetal within vugs) 10%. Spar; probably 2 generations, fibrous and blocky, filling vugs, fenestrae, and spaces between microstalactites or stromatolites. Dolomite; associated with stylolites. Porosity; 2-5% horizontal fracture. Fenestral looking. Possible microstalactites associated with grain size changes. Pyrite replacing some ooid laminations.

TS 4174.7'

Peloidal oolitic grainstone-packstone: Allochems; peloids 30-40%, ooids 25-30%, pseudo pisoids 20-25%, fossils 1-2%, quartz silt tr. Orthochems; spar 10-20%, micrite 2-3%. Ooids; concentric radially fibrous, some micritized. Pseudo pisoids; intraclast with a few outer coatings, round-subround. Fossils; ostracod (geopetal in a vug) 70%, calcispheres 30%, layered microstalactites possibly algal in origin. Spar; two generations, fibrous, blocky and bladed mosaic, filling enlarged fenestrae, fractures, and possible sheet cracks. Micrite; microstalactite or algal layer. Porosity; moldic tr. Probable sheet crack, large coated blocks of previously cemented grains. Possible microstalactitic layer, spar filled vertical fracture ends at this layer, type I stylolite associated with this layer.

4175.8-4178.5

Grainstone-mudstone: lt.brown-tan, ooids, fossils, blocky spar filling fenestrae, vugs, and vertical fractures, minor small vug and intercrystalline porosity, alternating grain/mud rich, isolated type II stylolites, fenestral looking, fossils include: ostracods, branched algae, calcispheres, gastropods, rugose coral.

4178.5-4182

Dolomudstone: lt.gray-med.olive gray, possible small intraclast ghosts, argillaceous, pyrite, minor-fair small vug and intercrystalline porosity, patterned-very bioturbated, both horizontal and vertical burrows, some ostracod molds, possible algal mat.

4182-4183

Dolomudstone-wackestone: lt.-med.olive gray, fossil molds, possible grain ghosts, minor-fair moldic and intercrystalline porosity, weakly laminated, possible algal laminations, numerous well preserved plant fragments, possible organic animal fragments, ostracod molds, argillaceous.

4183-4184.5

Dolomitic mudstone-wackestone: med.olive gray, fossil fragments, possible silt, minor-fair moldic and intercrystalline porosity, weak laminations, possible algal laminations, burrowed, plant fragments, other organic fragments, ostracods.

TS 4183.6'

Calcitic fossiliferous dolopackstone-wackestone: Allochems; fossils 20-30%. Orthochems; dolomite 35-45%, microspar 30-40%. Fossils; replaced or removed except for organic types, calcispheres 50%, ostracods 30%, organics (including plant and animal) 20%. Porosity; moldic 5-20%, intercrystalline 2-3%. One thin fine-grain dolomite lamination separating two fossil rich zones.

4184.5-4185.7

Mudstone-wackestone: lt.-med.olive brown, fossil, isolated ooid, minor intercrystalline porosity, well defined thin laminations, compacted, plant fragments, ostracods.

TS 4184.5'

Thinly laminated dolomitic fossiliferous grainstone-wackestone: Allochems; fossils 20-30%, intraclasts or oncoids 5%, ooids tr.

Orthochems; dolomite 30-40%, microspar 30-40%. Fossils; replaced by spar (except for organics), compacted, ostracod 50%, calcisphere 30%, organics (plant and animal) 15-20%, brachiopod tr. Intraclasts or oncoids; compacted, confined to thin laminations, some weak laminations visible within grain. Ooids; small, radially fibrous. Dolomite; coarse, euhedral, scattered throughout. Microspar; matrix. Porosity; 1-2% intercrystalline, 1-2% micropore. Many small microstylolites or organic remnants.

TS 4185.5'

Laminated dolomitic fossiliferous wackestone: Allochems; fossils 15-25%. Orthochems; microspar 40-50%, dolomite 30-40%. Fossils; spar replacing calcispheres and ostracods, organics (plant and animal) 45%, calcispheres 30%, ostracods 20%, brachiopod 5%. Brachiopod was large, crushed, well preserved, some micritic coating. Dolomite; coarse, euhedral, scattered throughout. Porosity; intercrystalline 1-2%, intraparticle tr., shelter tr. Possibly some burrowing.

4185.7-4186.4

Dolowackestone-packstone: med.olive gray-brown, probable fossil fragments (removed), good moldic and intercrystalline porosity, possible ripple mark, fossils include: plant fragments, coral, ostracods? (molds).

TS 4185.7'

Fossiliferous dolopackstone-wackestone: Allochems; fossils 25-35%. Orthochems; dolomite 65-75%, microspar tr. Fossils; possible ostracods and calcispheres (molds) 80-85%, coral 10%, organics (possible scolecodont) 5-10%. Porosity; moldic 20-30%, intercrystalline 5%. Massive looking.

4186.4-4187

Dolomitic wackestone-packstone: med.-lt.brown, fossils, small intraclasts, fair-good intercrystalline, interparticle, and small vug porosity, fairly massive, fossils include: forams, calcispheres, gastropods. Vertically fractured.

TS 4186.4'

Calcitic fossiliferous intraclastic dolowackestone-packstone: Allochems; fossils 40%, intraclasts 15-25%, ooids tr. Orthochems; dolomite 25-35%, micrite 15%, pyrite tr. Fossils; most replaced with spar, calcispheres 35%, algae (possible dasycladacean) 25%, foraminifera 20%, mollusc 10%, organics (plant and animal) 10%. Intraclasts; small, micritic, dolomitized in half of thinsection. Ooids; radially fibrous. Dolomite; localized zone, probably replacement. Porosity; moldic 5-15%, intercrystalline 2-5%, fracture 1-2%. Pronounced gradational boundary between dolomitized and nondolomitized zones.

4187-4187.5

Wackestone-packstone: lt.brown, fossils, small intraclasts, blocky spar filling and lining vugs, pyrite associated with stylolites, minor small vug porosity, type I and II stylolites, fossils include: ostracods, calcispheres, gastropods. Vertically fractured.

4187.5-4193

Wackestone-grainstone: lt.brown, ooids, isolated fossils, intraclasts and pisoids, blocky spar lining and filling vugs, large amount of a green mineral associated with fractures and some stylolites, minor small vug porosity, alternating grain rich/mud rich thin bedding, type I and II stylolites, fenestral looking, many thin crusts, some crusts distorted, fossils include: calcispheres and ostracods. Vertically fractured.

TS 4191.5'

Peloidal oolitic intraclastic grainstone-packstone: Allochems; peloids 35%, ooids 25%, intraclasts or pseudo pisoids 10%, fossils 5%, quartz silt tr. Orthochems; spar 25%. Ooids; some slightly dolomitized. Intraclasts or pseudo pisoids; most coated on outside with several layers, possibly algal in origin. Fossils; ostracod (geopetal in vugs) 90%, foraminifera 10%. Spar; several types, fibrous, bladed mosaic. In some vugs there are several cementation events: fibrous to micritic to fibrous to bladed mosaic or blocky. Fenestrae are spar filled. Porosity; 1-2% fracture. Some type II stylolites. Possible sheet crack or hardground. Vertical fractures continue only through single sheets or laminae. Four reverse graded layers, some draping evenly over high spots. Possible microstalactitic surface.

NDGS# 3347

Depth Description

The top 17' of this core consists of representative samples placed in a 3' core box. The remainder of this core is in poor shape, and unmarked other than by box number and footages marked on the boxes.

4102-4111

Massive-bedded anhydrite: gray white-lt.gray.

4111-4113

Quartz sandstone: med.gray, fine-very fine angular-subround quartz grains, anhydrite cement and isolated nodules, massive.

4113-4114

Argillaceous-silty anhydrite: med.gray, silt, clays, some thin argillaceous laminations.

4114-4115

Dolowackestone: lt.gray brown, clastic anhydrite, minor intercrystalline porosity, laminated, distorted.

4115-4116

Quartz sandstone-anhydrite wackestone: med.olive gray, quartz sand, possible clastic anhydrite, weakly laminated.

4116-4119.3

Nodular anhydrite and dolomudstone: lt.gray, pyritic, very minor intercrystalline porosity, displacive anhydrite nodule, dolomud stringers.

TS 4119.3'

Calcitic silty dolomudstone and nodular anhydrite: Allochems; silt 10-20%. Orthochems; anhydrite 40%, dolomite 30-40%, microspar 10%. Silt; 70% coarse dolomite, 30% quartz. Anhydrite; displacive no dules. Dolomite; fine grain, massive. Microspar; matrix. Porosity; vertical and horizontal fracture 1-2%.

4119.3-4119.6

Dolomudstone-wackestone: med.gray, argillaceous, some silt, minor intercrystalline and fracture porosity, very weak laminations.

4119.6-4123

Dolopackstone: lt.brown gray, peloids, anhydrite filling vertical fractures, fair intercrystalline and small vugular porosity, weak-well laminated, small teepee structure.

4123-4126

Dolopackstone-wackestone: lt.gray brown-lt.brown, peloids, small intraclasts, possible stromatolite fragments, anhydrite filling vugs or molds, fair intercrystalline and small vugular or moldic poro sity, alternating course/fine grain laminations.

TS 4124'

Calcitic intraclastic peloidal dolopackstone-wackestone: Allochems; intraclasts 35-40%, peloids 20-25%. Orthochems; dolomite 20-30%, anhydrite 10-15%, microspar 5%, pyrite 1-2%. Intraclasts; recrystallized or molds. Peloids; recrystallized or molds. Dolomite; matrix, replacing micrite. Anhydrite; filling enlarged fenestrae, some very cloudy, some very clear, possibly two episodes. Microspar; replacing some peloids and micrite. Pyrite; lining some anhydrite filled fenestrae or vugs. Porosity; moldic 5-10%, intercrystalline 1-3%. Some anhydrite filled fenestrae floored with course dolomite silt.

4126-4127.5

Dolowackestone-mudstone: lt.gray, anhydrite or celestite (after gypsum?) crystals and possible sand, fair-good fracture and intercrystalline porosity, small anhydrite nodules.

4127.5-4129.9

Dolomudstone: lt.gray-lt.brown, fair intercrystalline porosity, very weak laminations.

4129.9-4131

Dolowackestone-mudstone: lt.brown gray, possible peloids and intraclasts (recrystallized or removed), anhydrite filling vertical fractures, fair-good moldic and intercrystalline porosity, thinly laminated to massive, slight oil stain.

4131-4133.5

Dolopackstone-wackestone: lt.gray-med.brown, peloids, intraclasts, anhydrite filling vertical fractures and possible sheet cracks and fenestrae, pyrite lining vugs or fenestrae, fair-good moldic and intercrystalline porosity, thin laminations locally, oil stained.

4133.5-4135.8

Dolomitic packstone-wackestone: lt.brown-lt.gray, intraclasts, peloids, fossils, clear anhydrite filling vertical fractures, brown anhydrite replacing carbonates adjacent to fractures and stylolites, minor fracture and small vug porosity many type II stylolites, pressure solution on grains, possible solution breccia, very fractured, thin laminations locally.

TS 4134'

Dolomitic intraclastic peloidal packstone: Allochems; intraclasts 40%, peloids 15%. Orthochems; anhydrite 20%, dolomite 15%, micrite 5%, microspar 5%, fluorite tr. Intraclasts; subround, micritic or microspar. Anhydrite; replacing micritic grains and matrix, incorporating dolomite grains, associated with type II stylolite swarms, stylolites run through some anhydrite crystals. Dolomite; associated with stylolites and grain boundaries. Micrite and microspar; matrix. Fluorite; within carbonates, and replacement anhydrite along stylolites. Porosity; small vug 2-3%, intercrystalline 1-3%.

TS 4135'

Calcitic intraclastic fossiliferous wackestone-packstone: Allochems; intraclasts 20-25%, peloids 10-15%, fossils 2-5%, ooids tr. Orthochems; dolomite 40%, spar 5-10%, anhydrite 5-10%, micrite 5%, microspar 5%. Intraclasts; micritic with peloids, various shapes. Fossils; ostracods 35%, calcispheres 35%, unID fragments 30%. Ooids; radial fibrous. Dolomite; fine grain massive zones, course associated with fenestrae or stylolites. Spar; large nodule, possibly filled bivalve mold. Anhydrite; filling vertical fractures and adjacent fenestrae and other porosity. Porosity; small vug 2-3%, intercrystalline 1-3%. Weak laminations locally. Fossils associated with finer grained sediments.

4135.8-4137

Packstone-wackestone: lt.gray brown, recrystallized peloids and intraclasts, anhydrite filling several vertical fractures including a large (1cm wide) one, brown anhydrite replacing carbonates, fair small vug and fracture porosity, weak thin bedded, very fractured.

4137-4140

Packstone-grainstone: lt.brown, ooids, peloids, isolated intraclasts, anhydrite filling vugs, sheet cracks, and fractures, brown anhydrite replacing carbonates, minor small vug and interparticle porosity, fine grain crusts, alternating course/fine grain laminations, some pressure solution on grains.

TS 4138'

Peloidal pseudo ooid packstone: Allochems; peloids 35-45%, pseudo ooids 20-25%. Orthochems; anhydrite 20-30%, microspar 10%, spar 2-5%, dolomite 1-2%. Pseudo ooids; very irregular shape, micritic, concentric layers of mud followed by fibrous layer. Anhydrite; filling vugs and fenestrae (some silt floored), replacing adjacent carbonates. Microspar; matrix. Spar; blocky-bladed, vug fill. Dolomite; lining anhydrite filled vugs and fenestrae. Porosity; small vug 2-4%. Type II stylolites.

<u>NDGS# 3544</u>

<u>Depth Description</u>

The cored interval of this well is probably from the Wayne porosity zone.

4048-4049.5

Dolomitic packstone-wackestone: yellow brown-lt.gray, ooids, peloids, some anhydrite vug, fracture and mold fill, good intercrystalline and moldic porosity, thin laminations, alternating course/fine grains, possible type II stylolites.

4049.5-4052

Dolowackestone-packstone: lt.yellow brown, peloids, fossils, ooids, anhydrite filling vugs, molds, possibly replacing carbonates, good intercrystalline, moldic, and small-medium vugular porosity, massive, fossils: gastropod, bivalve.

TS 4052'

Calcitic ooid packstone-wackestone and boundstone: Allochems; ooids 15-25%, fossils 10%. Orthochems; dolomite 40-50%, anhydrite 10-20%, micrite 1-5%. Ooids; irregular shape, compacted, micrite cored, possibly algal origin. Fossils; stromatolite laminations 98%, ostracods 2%. Dolomite; most very fine grained, nodular looking in places, sharp boundary with calcite. Anhydrite; filling moldic and fracture porosity. Micrite; matrix and possible meniscus cement. Porosity; micropore and moldic 4-5%, intercrystalline 2-3%. Anhydrite filled grain molds are oil lined. Type II stylolites associated with stromatolites.

4052-4057

Calcitic dolopackstone-wackestone: lt.yellow brown, ooids, peloids, fossils,isolated pisoids, anhydrite filling molds and possible dessication cracks, good intercrystalline and small vug porosity, alternating thin beds of poorly sorted coarse grains with well sorted fine grains, possible dessication cracks, steeply dipping, fossil: bivalve.

TS 4057'

Dolomitic fossiliferous intraclastic packstone-wackestone: Allochems; fossils 20-30%, intraclasts 20%, ooids 5%. Orthochems; dolomite 20-30%, micro spar 10-15%, spar 10%, pseudospar 5%, micrite 2-3%, anhydrite 1-2%. Fossils; many micrite coated, ostracods 80%, pseudopunctate brachiopod 10%, gastropod 5%, foraminifera (micritized) 5%, calcispheres 3%. Intraclasts; micritic, small. Ooids; many broken, radial fibrous. Dolomite; locally replacing all carbonates but spar. Spar; filling fossils and some interparticle porosity. Pseudospar; replacing many fossils (counted as fossils), replacing some spar. Anhydrite; associated with stylolites. Porosity; micropore 5-7%, moldic 1-2%, vertical fracture 1-2%, intercrystalline tr. Many type I and II stylolites, and pressure solution on grains. Fossil rich/intraclast poor laminations.

4057-4059

Grainstone-wackestone: lt.yellow brown-lt.gray, peloids, fossils, small-large intraclasts, ooids, isolated pisoids, spar filling inter and intraparticle porosity, fair moldic, and interparticle porosity, type I and II stylolites, pressure solution on grains, possible solution breccia, fossils: ostracods, forams, bivalves, gastropods.

TS 4059'

Oolitic intraclastic grainstone: Allochems; ooids 70-75%, intraclasts 10%. Orthochems; spar 15-20%. Ooids; bimodal size, poorly sorted, many broken, many mud-cored. Intraclasts; irregular-round, consist of micrite, peloids, calcispheres. Spar; fibrous (isopachous), blocky, filling interparticle porosity. Porosity; interparticle 1-3%, moldic 1-2%. Some pressure solution on grains.

4059-4061.5

Grainstone: lt.gray brown, ooids, small pisoids, grapestone, spar filling interparticle porosity, minor interparticle porosity, poorly sorted, weakly laminated, some pressure solution, isolated large brachiopod.

4061.5-4063

Dolomitic wackestone-packstone: lt.gray tan, peloids, ooids, fossils, small pisoids, anhydrite filling fractures, fair intercrystalline and small vug porosity, massive, fossils: calcispheres, ostracods, forams, algae.

4063-4068

Calcitic dolowackestone-mudstone: med.brown, fine grains (fossils?), good-very good intercrystalline and micropore porosity, vertical burrows, micro stylolites, possible bivalve.

TS 4063.5'

Dolomitized fossiliferous intraclastic wackestone-packstone: Allochems; fossils 10-15%, intraclasts 5-10%. Orthochems; dolomite 70-80%, spar 5%. Fossils; echinoderm 49%, calcisphere 49%, organic (plant or animal) 2%. Intraclasts; only remnants not dolomitized. Dolomite; coarse, probably replacement. Spar; isolated grains, possibly early cement. Porosity; micropore 2-3%, intercrystalline 2-3%. Possible oil lining some porosity.

NDGS# 3766

Depth Description

4040-4049.5

Fine grain massive-nodular anhydrite: lt.gray, anhydrite lathes, sand size grains or crystals of sulphate, dolomudstone, nodular anhydrite and distorted dolomudstone alternating with clastic looking sulphates.

TS 4040'

Nodular anhydrite and argillaceous dolomudstone: Allochems; clay, undetermined amount. Orthochems; anhydrite with some celestite 80-90%, dolomite 10-20%. Anhydrite; felted nodules and laminae, single isolated lathes, some euhedral celestite crystals and possible silt. Dolomite; argillaceous, very fine grain, matrix. Porosity; 0-1% intercrystalline.

TS 4048'

Nodular anhydrite and celestite crystals in argillaceous dolomudstone: Allochems; argillaceous, undetermined amount. Orthochems; felted anhydrite nodules 50-60%, celestite after euhedral gypsum crystals (large) 30-40%, dolomite 10-15%. Celestite crystals are within argillaceous dolomudstone. Dolomudstone; very fine grain. Porosity; 0-1% intercrystalline.

4049.5-4051.5

Dolowackestone-packstone: lt.gray brown, ooid and peloid ghosts, anhydrite, minor intercrystalline porosity, fine grain fragments (possibly algal), slight oil stain.

TS 4051'

Dolowackestone and nodular anhydrite: Allochems; intraclast sized dark areas, possible grain ghosts or oil residue 10-20%. Orthochems; Dolomite 65-75%, anhydrite 15-25%. Grain ghosts?; flattened. Dolomite; coarse, probably replacing calcite and some anhydrite. Anhydrite; felted nodules, many small blocky patches, possible cement, being replaced by dolomite. Porosity; moldic 2-3%, intercrystalline 1-2%.

4051.5-4056

Nodular-massive anhydrite: lt.gray-white, with thin distorted dolomud or argillaceous laminae.

4056-4057
Dolowackestone-packstone: lt.gray brown-lt.gray, argillaceous, local concentrations of ooids, peloids, anhydrite crystals in dolomudstone, minor intercrystalline porosity, slight patterned look.

4057-4063.5
Nodular-massive anhydrite and thin dolostone laminations: lt.gray, anhydrite sand or crystals, chickenwire looking, small anhydrite nodules and thin distorted dolostone stringers, some large (2") vertically elongate anhydrite or gypsum crystals.

4063.5-4064.5
Nodular anhydrite with thin dolowackestone laminations: lt.gray, flattened oncoids, fine grain fragments (possibly algal), minor intercrystalline porosity, oncoids within dolostone as well as some within anhydrite, dolowackestone distorted.

4064.5-4069.5
Nodular-massive anhydrite: lt.gray, some anhydrite sand or crystals locally, thin distorted dolostone stringers, nodule size < downward.

4069.5-4071
Argillaceous dolomudstone and nodular anhydrite: lt.-dk.gray, anhydrite sand or crystals within dolostone, minor intercrystalline porosity, dolostone distorted.

4071-4072
Nodular anhydrite: lt.gray, thin distorted dolomudstone stringers.

4072-4074.5
Dolomudstone-packstone: lt.brown, peloids, fossil, anhydrite filling moldic or vugular porosity, pyritic, minor-fair intercrystalline porosity, very thinly laminated-massive, oil stained anhydrite filled vugs.

TS 4072'
Dolomudstone-wackestone: Allochems; Fossils 3%, possible sand size fossil fragments (molds) 5%. Orthochems; dolomite 65-75%, anhydrite 20-30%. Fossils; ostracod, filled molds. Dolomite; med.-fine grain, probably replacement. Anhydrite; filling moldic, and possible fenestral or vugular porosity. Porosity; moldic 3-5%, intercrystalline 1-2%. Well laminated, some microstylolites associated with laminations. Oil lining possible fenestral porosity and within some anhydrite crystals (not as inclusions).

4074.5-4079.5
Dolomudstone-wackestone and nodular anhydrite: lt.gray-lt.brown, anhydrite sand or crystals, fossils, pyrite, displacive anhydrite, minor intercrystalline porosity, thinly laminated dolomudstone, distorted, isolated ostracods.

TS 4074.5'
Distorted interlaminated calcitic dolomudstone and anhydrite: Allochems; fossils tr., round gypsum grains tr. Orthochems; Anhydrite 50-60%, dolomite 40-50%. Anhydrite; occurring as nodules and as thin interlaminations with dolomudstone. Dolomite; possibly argillaceous, thinly interlaminated, distorted by nodular anhydrite. Porosity; fracture 1-2%. Very fractured, possible dessication cracks.

4079.5-4082.5

Dolowackestone-mudstone and interbedded nodular anhydrite: lt.-med.brown, fine grain angular fragments (possibly algal), fossils, anhydrite filling moldic and vugular porosity, minor intercrystalline porosity, patterned looking, thinly laminated (possibly algal), isolated ostracods, slight oil stain.

4082.5-4084.5

Packstone: lt.brown, peloids, small intraclasts, anhydrite filling vugs locally, fair vugular and intercrystalline porosity, pressure solution on grains, some type II stylolites, isolated ostracods.

4084.5-4087

Wackestone-packstone: lt.brown, intraclast, fossil, fair moldic and intercrystalline porosity, massive, fossils; algae, gastropods, ostracods, calcispheres.

TS 4084.5'

Calcitic dolowackestone: Allochems; molds (probable fossil). Orthochems; dolomite 90%, micrite 2-3%, microspar 2-3%, anhydrite 1-2%. Fossils; calcispheres? 50%, ostracods? 50%. Dolomite; medium-coarse, probable replacement. Micrite; isolated patches. Microspar; isolated patches. Anhydrite; filling isolated molds. Porosity; moldic 10-15%, intercrystalline 1-3%. Massive.

4087-4092

Grainstone-packstone: tan-lt.brown, peloids, small intraclasts, fossils, ooids, anhydrite filling vertical fractures and replacing adjacent matrix, fair-good interparticle and vugular porosity, alternating fine/coarse grain laminations, fossils; ostracod, gastropod, foraminifera.

TS 4087'

Intraclastic fossiliferous grainstone-packstone: Allochems; intraclasts 55-65%, fossils 5-10%. Orthochems; anhydrite 15-20%, micrite 10-15%, dolomite 1-5%. Intraclasts; small, round, micritic, some weakly laminated. Fossils; compacted, well preserved, ostracod 60%, calcisphere 40%. Anhydrite; filling vertical fractures and replacing adjacent carbonates. Micrite; matrix. Dolomite; associated with grain boundaries. Porosity; interparticle 10-15%, fracture 1-2%, intraparticle 1-2%. Interparticle porosity possibly enlarged, elongate vertically. Alternating mud rich/poor laminations.

NDGS# 5990

Depth Description

4050-4051

Dolomudstone-wackestone: lt.brown gray, isolated round sulphate grains, anhydrite filling dessication cracks, minor intercrystalline porosity, laminated, distorted.

4051-4052

Nodular anhydrite: med.gray, chickenwire texture, small nodules.

4052-4055.5

Nodular anhydrite and distorted dolowackestone: lt.brown-med.gray, peloids, small intraclasts, gypsum sand or crystals, anhydrite nodules, pyritic, minor intercrystalline porosity, interbedded dolowackestone and anhydrite, some anhydrite crystals in apparent upward growth positions, numerous small vertical fractures.

TS 4054'

Intraclastic peloidal dolopackstone: Allochems; intraclasts 20-25%, peloids 15-20%. Orthochems; anhydrite 10-20%, fine grain dolomite 20%, course dolomite 15%, silica 3-8%. Intraclasts; dolomitized, some molds. Peloids; dolomitized. Anhydrite; filling moldic porosity and vertical fractures. Fine grain dolomite; cloudy, replacing calcite. Course dolomite; clear, associated with and appearing to replace anhydrite. Silica; filling vertical fractures and some moldic porosity, possible replacement of carbonates and anhydrite. Porosity; moldic 1-3%. Very fractured vertically, brecciated looking. Locally laminated.

4055.5-4060.5

Nodular anhydrite with dolostone stringers: med.gray-lt.brown gray, anhydrite sand or crystals within dolostone stringers, displacive anhydrite nodules.

4060.5-4063.2

Dolomudstone-wackestone: lt.gray brown, isolated anhydrite sand or crystals, some peloids, minor intercrystalline porosity, isolated laminated zone (possibly algal).

4063.2-4064.5

Interbedded anhydrite sand and dolomudstone-wackestone: med.gray, anhydrite sand; peloids, small intraclasts, minor intercrystalline porosity.

4064.5-4064.7

Interlaminated wackestone and anhydrite: med. brown, peloids, small intraclasts, minor intercry stalline porosity, brown anhydrite (probably replacing carbonates).

4064.7-4065.5

Packstone-wackestone: lt.gray brown-med.brown, peloids, small intraclasts, isolated coated grains, anhydrite filling possible fenestrae and replacing carbonates, minor small vugular porosity, type II stylolites, pressure solution on grains.

4065.5-4066

Dolograinstone-wackestone: lt.gray brown-lt.gray, small intraclast, peloids, anhydrite filling interparticle porosity and vertical fractures, thin silicified zone, minor small vugular porosity, alternating course/fine grain bedding, fine grain areas cracked (possible dessication).

TS 4065.5'

Intraclastic peloidal dolopackstone-wackestone: Allochems; intraclast and peloid ghosts 45%. Orthochems; silica (quartz) 35-45%, anhydrite 10%, dolomite 10%. Allochems are all dolomitized. Silica; intergrown crystals. Anhydrite; dirty looking, possibly being replaced by dolomite and later by silica, filling vertical fractures. Dolomite; fine grain, possibly replacing matrix. Porosity; 1% intercrystalline, <1% moldic. Massive.

4066-4067

Wackestone-packstone: lt.brown-lt.gray, small intraclasts, peloids, isolated ooids and small pisoids, anhydrite filling vugs and fenestrae, and replacing carbonates, minor small vug and intercrystalline porosity, alternating fine/coarse grain bedding, bedding disrupted, slight oil stain.

4067-4068

Wackestone-packstone: lt.-med.brown, small intraclasts, peloids, isolated ooids and small pisoids, anhydrite filling vugs and fenestrae, and replacing carbonates, some siliceous replacement, fair small vugular porosity, thin bedded, sheet-cracked, fenestral looking, good oil stain.

TS 4067'

Calcitic intraclastic peloidal dolopackstone-dolomudstone: One half of this thin section dolostone with no grain ghosts. Percentages for the other half are as follows. Allochems; intraclasts 50-60%, peloids 20-30%. Orthochems; anhydrite 8-12%, dolomite 5-10%, silica 2-5%. Intraclasts and peloids; partly dolomitized-totally micritic. Anhydrite; filling fenestrae and vugs, possible replacement. Dolomite; fine grain, associated with grain boundaries and flooring fenestrae or vugs. Silica; apparently replacing and pseudomorphed after anhydrite. Porosity; intercrystalline 1-3%, moldic 1-2%.

4068-4070.5

Wackestone-packstone: med.yellow brown, peloids, small intraclasts, anhydrite filling vugs and vertical fractures, and replacing carbonates, isolated dolomite crystals, minor-fair intercrystalline and small vugular porosity, type II stylolites, pressure solution on grains, slight oil stain.

TS 4069'

Peloidal intraclastic packstone-wackestone and replacement anhydrite: Allochems; peloids 30-35%, intraclasts 20-25%, pisoids tr. Orthochems; anhydrite 30-35%, microspar 5-10%, dolomite 5%, spar 1-2%, fluorite tr. Peloids; elongate, micritic. Intraclasts; subround, micritic, some weak laminations. Pisoids; broken up. Anhydrite; replacing micritic grains and matrix, incorporating dolomite. Microspar; matrix, borderline micrite. Spar; bladed, isopachous locally. Dolomite; large euhedral crystals, scattered throughout, concentrated along stylolites. Fluorite; within carbonate grains and matrix, and within replacement anhydrite. Porosity; moldic 1-2%. Much pressure solution.

4070.5-4077

Anhydrite and dolowackestone: lt.-med.gray, peloids in dolostone, displacive nodular anhydrite, some massive anhydrite, sharp contact with overlying limestone, limestone vertically fractured, dolowackestone distorted by anhydrite nodules.

TS 4075.7'

Nodular anhydrite and dolomudstone: Allochems; possibly argillaceous dolomite 40-50%. Orthochems; anhydrite 50-60%, pyrite tr. Dolomite; fine grain, possibly argillaceous. Anhydrite; felted anhydrite nodules, some very small, coalesced into larger nodules. Porosity; <1% intercrystalline.

4077-4079

Nodular anhydrite and dolomudstone: lt.-med.gray, anhydrite sand or crystals with in dolomudstone, small anhydrite nodules, minor intercrystalline porosity, distorted.

4079-4083.5

Dolomudstone-wackestone: lt.brown gray-lt.gray, possible peloids, fine grain fragments (possibly algal related), isolated anhydrite sand or crystals, anhydrite filling vugs locally, pyritic, fair intercrystalline porosity, slight laminated-patterned look, isolated anhydrite sand laminations.

4083.5-4084

Dolopackstone-wackestone: med.gray brown, poorly sorted peloids, small intraclasts, small ooids, some anhydrite filling porosity, minor intercrystalline porosity, thin laminated-thin bedded, uniformly curved (upward doming), some type II stylolites, pressure solution on grains.

TS 4083.5'

Intraclastic peloidal dolowackestone-packstone: Allochems; intraclasts 40%, peloids 10%. Orthochems; course dolomite 30-35%, fine dolomite 10%, anhydrite 5-10%, opaque 1%. Intraclasts and peloids; dolomitized. Course dolomite; apparently replacing matrix. Fine grain dolomite; flooring former fenestrae or replacing micritic crusts. Anhydrite; filling molds and possible compacted fenestrae. Opaque; dark, possible organic origin. Porosity; intercrystalline 1-3%, moldic 1%. Laminated, numerous microstylolites, possible organic residues, some pressure solution on grains. Possible oil lining filled molds.

4084-4085

Dolowackestone-packstone: med.gray brown, peloids small intraclasts (many filled molds), anhydrite filling moldic porosity, minor intercrystalline porosity, massive.

4085-4087

Displacive-massive anhydrite: lt.-med.gray, some dolomudstone, dipping.

4087-4089

Packstone-wackestone, some grainstone: lt.gray-med.brown, small intraclasts, ooids, peloids, compacted anhydrite nodules, anhydrite filling moldic porosity and replacing carbonates, minor intercrystalline, alternating course/fine grain thin bedding, locally extensive type II stylolites and pressure solution on grains.

TS 4088.5'

Dolomitic intraclastic peloidal packstone-wackestone: Allochems; intraclasts (pseudo pisoids) 50-55%, peloids 25-30%, quartz silt tr. Orthochems; anhydrite 10%, dolomite 5-10%, micrite 5%. Intraclasts; round-subround, micritic, some fibrous laminations, 60% replaced by anhydrite. Peloids; 60% replaced by anhydrite. Anhydrite; replacing large blocks of calcite and incorporating most dolomite as inclusions. Dolomite; replacing micritic matrix. Micrite; matrix, mud rich zones. Porosity; 1-2% small vug or moldic, 1-2% intercrystalline. Pressure solution on some grain boundaries. Very weak vertical fractures.

4089-4093.8

Interbedded nodular anhydrite and dolomudstone: med.-lt.gray, small nodules, dolomudstone stringers, dolomudstone >50% locally.

4093.8-4095

Wackestone-packstone: tan-med.brown, fossils, peloids, anhydrite replacing carbonates along bedding planes and vertical fractures, minor intercrystalline porosity, isolated laminations, fossils; calcispheres, ostracods, algae.

TS 4093.8'

Peloidal fossiliferous grainstone-packstone: Allochems; peloids 60-70%, fossils 2-4%. Orthochems; anhydrite 15-20%, microspar 5-10%, spar 3-5%, micrite 2-3%, dolomite 1-2%. Fossils; compacted, well preserved, mud filled, possibly micritized first, most articulated, ostracods 70%, calcispheres 30%. Anhydrite; replacement, many inclusions. Microspar; replacing carbonate near anhydrite, most matrix. Spar; interparticle cement, some bladed-fibrous. Porosity; 1-2% interparticle. Section heavily compacted.

4095-4097

Wackestone-packstone: lt.brown-lt.red brown, fossils, peloids, small intraclasts, fair intercrystalline porosity, isolated laminations, burrowed, pressure solution on grains, fossils; calcispheres, ostracods, algae.

4097-4100

Interbedded nodular anhydrite and dolomudstone: lt.-med.gray, minor intercrystalline porosity, small-medium anhydrite nodules, dolomudstone >50% locally.

NDGS# 6037

Depth Description

Original fabrics, grains, etc., are much better preserved in core from this well, than in any previous wells. Core was wrapped in plastic and foil. Core footages 4107-4108 are missing, loaned to Sunbehm 2/22/77.

4108-4110.2

Dolomitic wackestone-packstone: lt.brown gray, recrystallized ooids, intraclasts, pisoids, anhydrite filling vugular and fenestral porosity, some vugs lined with a dark iridescent material, minor vugular and moldic porosity, fenestral looking.

4110.2-4110.4

Same as above except: med.brown, fair moldic and intercrystalline porosity, heavy oil staining.

4110.4-4110.7

Dolomitic wackestone-dolomudstone: lt.brown-lt.gray, small ooids, peloids, anhydrite filling vugular and fenestral porosity, minor vug and moldic porosity, fenestral-massive looking, locally laminated (poss. algal), reddish staining (possible Fe oxide).

4110.7-4111

Packstone-wackestone: lt.gray, ooids, large intraclasts, anhydrite filling vugs and fenestrae, good moldic and vugular porosity, slight fenestral look.

4111-4111.8

Mudstone-wackestone, some packstone: lt.brown, ooids, intraclasts, anhydrite filling interparticle porosity, blocky spar lining vugs locally, fair-good vugular, moldic and fracture porosity, thin bedded-laminated, possible sheet cracks, alternating course/fine grain laminations.

TS 4111'

Intraclastic peloidal packstone-mudstone: Allochems; intraclasts

40%, peloids 20%. Orthochems; Microspar 20-30%, anhydrite 5-10%, dolomite 1-3%, spar tr. Intraclasts; microspar, small. Anhydrite; filling most fenestrae and vugular porosity. Dolomite; lining fenestrae. Spar; blocky, located in fenestrae. Porosity; 2-4% vug/enlarged fenestrae, 1% horizontal fracture. Thin laminated zone (possible algal).

4111.8-4112.3

Wackestone-packstone: lt.gray brown, ooids, intraclasts, anhydrite filling primary porosity, spar porosity lining, green mineral lining fractures, good moldic and vugular porosity, thin bedded alternating mud/grain rich, ostracod (anhydrite filled).

4112.3-4113

Packstone-grainstone and clay seam (stylolitic): lt.gray-reddish metallic black, ooids, small intraclasts, blocky spar vug fill, very minor horizontal fracture porosity (associated with clay seam), type I & II stylolites.

4113-4114

Wackestone: lt.gray brown-lt.brown, ooids, small intraclasts, blocky spar lining vugs, good vugular and moldic porosity, thin bedded, thin crusts/fine grain laminations approximately every 15 cm.

4114-4115

Wackestone-packstone: lt.brown, ooids, pisoids, large intraclasts, anhydrite filling fenestrae, spar filling vugs, fair-good vugular and fenestral porosity, pisoids in separate thin layer.

4115-4116.5

Wackestone-grainstone: lt.brown-lt.gray brown, ooids, intraclasts, anhydrite interparticle cement, blocky spar lining vugs, fair-good vugular and interparticle porosity, many crusts/fine grain laminations, type II stylolites and pressure solution on some grains.

4116.5-4117.1

Dolowackestone: lt.gray, ooid ghosts, anhydrite filling some vugs and fractures, minor-fair small vug and moldic porosity.

TS 4116.5'

Oolitic dolowackestone: Orthochems; dolomite 90-95%, microspar/pseudospar 5-10%, organics tr. Ooid ghosts; dolomitized, radially fibrous concentric laminations. Microspar/pseudospar; scattered patches and crystals throughout. Dolomite; matrix and grains. Organics; locally concentrated, possibly oil. Porosity; moldic 1-2%, intercrystalline 1-2%.

4117.1-4121.5

Dolomitic wackestone: lt.brown, intraclasts, ooids, pisoids, anhydrite filling porosity, blocky spar lining vugs, fair-good moldic and vugular porosity, type II stylolites, alternating course/fine grain laminations.

TS 4121.3'

Dolomitic intraclastic pisolitic wackestone-packstone: Allochems; intraclasts 45-55%, pisoids 20-25%, peloids 5%. Orthochems; Dolomite 10-15%, microspar 10-15%, spar tr. Intraclasts; small, subround, micritic-microspar. Pisoids; concentric laminations, peloid cored, thick even micritic-microspar outer lamination. Dolomite; scattered throughout, concentrated along grain margins. Spar; blocky. Porosity; vugular or enlarged fenestrae 8-10%. Slightly fenestral looking.

4121.5-4122.5

Dolowackestone: med.brown, ooids, small intraclasts, anhydrite filling fenestrae, good moldic and fenestral porosity, very fenestral looking, very heavy oil stain.

4122.5-4123.2

Dolomudstone-wackestone: lt.gray, grain ghosts, anhydrite filling some vugs, some vugs lined with a dark iridescent material (possibly chlorite), fair large vugular porosity, slightly patterned.

4123.2-4125.1

Wackestone-packstone: lt.gray brown, ooids, pisoids, large intraclasts, thin peloidal zone, blocky spar lining and filling porosity, good vugular porosity, some vertically elongate vugs associated with peloidal zone, dark green mineral (possibly chlorite) associated with type I and II stylolites, and lining some pores, laminated, alternating fine/coarse grains, oil stained.

TS 4124.7'

Peloidal intraclastic packstone-grainstone: Allochems; peloids 55-65%, intraclasts 15-20%. Orthochems; Microspar 10-15%, spar 5-7%. Peloids; very small, round. Intraclasts; small, some weak laminations. Microspar; matrix. Spar; small blocky crystals lining some vugs, large blocks filling some vugs. Porosity; 10-15% vertically elongate vugs. Some small vertical and horizontal fractures, oil lined. Some green mineral along fractures (possibly chlorite). Massive, oil stained porosity.

TS 4125'

Dolomitic oolitic pisoidal grainstone-packstone: Allochems; ooids 35-45%, pisoids 20-25%. Orthochems; dolomite 20-25%, pseudospar 5-10%, microspar 5%. Ooids; small, many dolomitized. Pisoids; large-small, many broken, radial fibrous laminations. Dolomite; some zones entirely dolomite, some zones grains only dolomitized. Porosity; interparticle 2-3%, small vug 1-2%, intercrystalline 1-2%. Alternating beds (more or less cemented) of poorly sorted pisoids and moderately sorted ooids. 2-3 erosional surfaces/possible crusts and stylolites. Green mineral (chlorite?) associated with fractures.

4125.1-4126

Dolowackestone-mudstone: med.brown-lt.gray, ooids, small intraclasts, minor-good vugular and moldic porosity, fenestral-patterned looking, heavy oil stain.

4126-4127.5

Wackestone-packstone: lt.gray brown, ooids, pisoids, large intraclasts, blocky spar lining and filling vugular and interparticle porosity, minor-good vugular porosity, massive, type I and II stylolites.

TS 4126'

Dolomitic oolitic intraclastic peloidal packstone: Allochems; ooids 40-50%, intraclasts 20-25%, peloids 15-20%. Orthochems; microspar 5-10%, spar 5%. Ooids; concentric radial fibrous laminations, some odd shaped. Intraclasts; very large >10mm, cemented ooid grainstone clasts, some with thin coatings. Spar;

blocky, vug fill. Porosity; medium-large vug 10-12%. Some pressure solution on grains. Oil in pores.

4127.5-4128.2

Wackestone-packstone: lt.gray brown, poorly sorted ooids, pisoids, intraclasts, anhydrite filling primary porosity, spar lining porosity, good vugular porosity, type I and II stylolites.

4128.2-4130.4

Packstone-wackestone: lt.gray brown, ooids, pisoids, intraclasts, spar lining and filling porosity, fair-good moldic and vugular porosity, type I and II stylolites, 2mm size gastropod.

TS 4128.2'

Ooid/pisoid peloidal packstone-grainstone: Allochems; large ooids-small pisoids (gradational) 55-65%, peloids 15-20%. Orthochems; Microspar (some micrite) 10-15%, spar 5%, dolomite 1-2%. Ooids/pisoids; radial fibrous concentric laminations, mostly non-broken. Spar; blocky, single crystals filling vugs. Dolomite; associated with pressure solution. Porosity; matrix selective vugular 8-10%. Small vertical fractures. Type I stylolites and pressure solution on grains.

4130.4-4132.7

Grainstone-wackestone: lt.gray brown, ooids, some pisoids, intraclasts, anhydrite filling fractures and interparticle porosity, blocky spar filling and lining vugular porosity, fair-good vugular porosity, locally ooid laminations fractured and disrupted, pressure solution on grains.

4132.7-4133.5

Oxidized? dolomudstone: lt.gray bounded by red tinted areas top and bottom, minor intercrystalline porosity, very patterned.

TS 4132.7'

Oncolitic packstone-dolowackestone: Allochems; oncoids 30-35%, fossils tr. Orthochems; dolomite 55%, microspar 10-15%, spar 1-2%. Oncoids; compacted, micritic, weakly laminated. Fossils; calcispheres. Dolomite; thin light/dark and fine/course grain laminations. Microspar; matrix in nondolo mitized zone. Spar; remnants in dolomitized zone and vug fill in nondolomitized zone. Porosity; 1% small vug in nondolomitized zone, and 1-2% moldic and 1-2% intercrystalline in dolomitized zone. A fine grain microspar lamination separates dolomitized from nondolomitized zones.

4133.5-4134

Wackestone-packstone: lt.gray brown, ooids, intraclasts, spar lining porosity, fair moldic and vugular porosity, alternating grain rich/poor laminations, pressure solution on some grains.

TS 4133.5'

Ooid/oncoid peloidal packstone-dolowackestone: Allochems; ooids or oncoids 35-45%, peloids 15-20%, fossils tr. Orthochems; dolomite 20-25%, microspar and some micrite 15-20%, spar 2-3%. Ooids/oncoids; microspar, weakly laminated, round-subround. Fossils; calcispheres. Dolomite; massive-weakly laminated. Spar; blocky, filling vugs. Porosity; 1-2% intercrystalline in dolomitized zone, and 1-3% small vugular in nondolomitized zone. A sharp contact between dolomitized and nondolomitized zones marked by a type II stylolite. Several type II stylolites, some oil stained.

4134-4134.5

Packstone-grainstone: lt.gray brown, ooids, pisoid rich laminations, blocky spar lining porosity, fair moldic/vugular and interparticle porosity, alternating grain rich/poor laminations.

TS 4134'

Oolitic peloidal packstone-grainstone: Allochems; ooids 40%, peloids 40-45%, small pisoids tr. Orthochems; microspar and some micrite 10-15%, spar 5%. Ooids; small, radial fibrous concentric laminations, including a coated gastropod. Peloids; small, matrix, one clear example of an ooid partially replaced by peloids, peloids may not be primary grains. Spar; blocky, filling vugs. Porosity; 2-5% enlarged fenestrae/small vug, oil lined. Massive-light fenestral look.

4134.5-4138

Wackestone-packstone: lt.gray brown, ooids, pisoids, some intraclasts, spar lining porosity, thin zone anhydrite cemented, fair-good vugular and moldic porosity, type I and II stylolites, pressure solution on grains, some thin fine grain laminations.

4138-4139

Wackestone-grainstone: lt.gray brown, ooids, pisoids, some large coated intraclasts, spar lining and filling porosity, fair-good fenestral and vugular porosity, some vugs vertically elongate in muddier zone, thin alternating course/fine grain bedding.

NDGS# 6240

Depth Description

4124-4126

Calcitic dolowackestone-packstone: med.brown, peloids, ooids, isolated pisoids, anhydrite filling fenestrae and possible dessication cracks, fair-good intercrystalline and small vugular porosity, alternating finer/courser grains, heavy oil stain.

4126-4128

Argillaceous dolomudstone-wackestone: med. green gray, isolated intraclasts, pyritic, fair-good intercrystalline and small vugular porosity, patterned, thin distorted laminae, isolated microstylolite seams.

4128-4132

Packstone-wackestone: lt.brown-lt.gray brown, peloids, small-medium intraclasts, isolated ooids and fossils (ostracod), blocky spar filling and lining vugs, anhydrite replacing carbonates locally, fair-good small-medium nonselective vugular porosity, type I and II stylolites, pressure solution on grains, possible thin crusts.

TS 4128'

Interbedded calcitic dolomudstone and intraclastic fossiliferous packstone: Allochems; intraclasts 35-40%, fossils 5-8%. Orthochems; dolomite (zone) 40%, micrite 10%, microspar 5%, dolomite (scattered in nondolomitized zone) 5%, pyrite 1-2%. Intraclasts; micritic, small compacted, hard to distinguish individual grains. Fossils; calcispheres 50%, ostracods 30%, algae 15%, gastropods (within dolomitized zone) 5%. Micrite; matrix. Microspar; associated with porosity. Pyrite; scattered throughout. Porosity; 3-5% small vugular, 1-2% fracture in dolomitized zone. Sharp contact between fine grain dolostone zone and nondolostone zone.

4132-4137.5

Interbedded packstones and wackestones: lt.gray brown, poorly sorted ooids and pisoids, blocky spar filling and lining vugs, brown anhydrite replacing carbonates along fractures and stylolites, good medium-large nonselective vugular porosity, teepee structure, fenestral looking in part, type II stylolites, alternating course/fine grains.

TS 4134.4'

Ooid/oncoid intraclastic wackestone-packstone: Allochems; Ooids 35-45%, intraclasts 20%. Orthochems; microspar and some micrite 30-35%, spar 5%, dolomite 1-3%. Ooids/oncoids; large, micritic, weakly laminated, round, most with a thick micritic outer lamination. Intraclasts; small, irregular shape, micritic?. Microspar; matrix, slight peloidal look. Spar; blocky, partially filling some vugs. Dolomite; scattered throughout. Porosity; 15-20% medium-large nonselective vugular. Poorly sorted. Dendritic looking pattern within some grains.

4137.5-4139.5

Wackestone-packstone: lt.gray brown, peloids, small intraclasts, ooids, spar filling vugs, minor-fair vugular porosity, fenestral looking.

TS 4139.3'

Peloidal intraclastic packstone-wackestone: Allochems; peloids 55-65%, intraclasts 10%, ooid/oncoid 10%, quartz silt tr. Orthochems; micrite and some microspar 10-15%, spar 8-12%, dolomite tr. Peloids and intraclasts; small, micritic. Ooid/oncoid; micritic, weakly laminated. Quartz silt; fine grain, angular, concentrated in a graded peloid lamination, but scattered throughout. Spar; blocky, filling enlarged fenestrae and vugs. Dolomite; many zoned crystals, scattered throughout and associated with stylolites. Porosity; 2-5% compacted fenestrae. Type I stylolite associated with lithology change. Reverse graded peloidal zone, large coated grains with preferentially oriented micrite coatings, and associated micrite lined fenestrae. Brecciated looking.

4139.5-4141.5

Grainstone-wackestone: lt.gray brown, ooids (possible tangential), pisoids, (many broken and delaminated), spar filling and lining vugs, some anhydrite vug fill, fair medium-large vugular porosity, some type II stylolites, thin crusts, fenestrae rich laminations between pisoid layers. A green mineral (possibly chlorite) associated with a type II stylolite.

4141.5-4144

Poorly sorted grainstone-wackestone: lt.brown, peloids, intraclasts, isolated pisoids and ooids, spar lining and filling porosity, fair-very good small-medium vugular porosity, alternating course/fine grain bedding.

4144-4144.2

Laminated mudstone: lt.olive gray, anhydrite associated with type I stylolite, type I stylolite forming sharp contact between mudstone and overlying grainstone, minor intercrystalline porosity.

4144.2-4148

Packstone with isolated wackestone and grainstone: lt.gray brown, ooids, small pisoids, isolated intraclasts, blocky spar lining and filling vugs, anhydrite filling interparticle porosity in thin beds associated with thin micritic crusts, fair small vugular porosity, type I and II stylolites, much pressure solution on grains.

4148-4152

Packstone-wackestone, isolated grainstone: lt.brown, ooids, small-medium pisoids, some intraclasts, anhydrite filling a large vertical fracture (1-2cm wide) and vugs locally, blocky spar lining and filling vugs, especially in fenestral zones associated with wackestone, pyrite replacing some pisoids, good fenestral, vugular and some interparticle porosity, type I and II stylolites, much pressure solution on grains.

4152-4153

Grainstone: lt.-med.brown, well sorted peloids, isolated pisoids, anhydrite filling a large vertical fracture and adjacent vugs, some replacive anhydrite, spar lining vugs, fair-good medium- large vugular porosity, slight fenestral look.

4153-4157.5

Packstone-wackestone: lt.gray brown, ooids, small-large pisoids, peloid rich zones, isolated intraclasts, anhydrite filling a large vertical fracture and adjacent vugs, some replacive anhydrite, spar lining vugs, fair-good small-large vugular porosity, type I and II stylolites, much pressure solution on grains, thin crusts, fenestral looking locally.

TS 4154'

Pisolitic oolitic packstone: Allochems; pisoids 20-30%, ooids 10-15%, peloids 10%. Orthochems; anhydrite 35-45%, micrite and some microspar 10-15%, spar 4-6%, pyrite 1-2%. Pisoids; large, radial fibrous laminae, sub-round, thick micritic outer layer. Ooids; large, radial fibrous, thick micritic outer layer. Anhydrite; filling large vertical fracture and large vugs, Spar; blocky, partially to totally filling vugular porosity. Pyrite; within coated grains, replacive. Porosity; 1-3% small vugular porosity. Some pressure solution on grains.

4157.5-4161.5

Packstone-wackestone: lt.brown-tan, ooids, small-large pisoids, peloids, spar lining and filling vugs, minor-fair vugular porosity, type I and II stylolites, pressure solution on grains, locally fenestral, some thin crusts.

4161.5-4166

Packstone-wackestone: lt.gray brown-tan, ooids, small-large pisoids, peloids, anhydrite filling vertical fractures and adjacent vugs, spar lining and filling vugs, minor-fair vugular porosity, type I and II stylolites, pressure solution on grains, locally fenestral, some thin crusts.

NDGS# 6332

Depth Description

4078-4079.2

Anhydritic dolomudstone: lt.brown gray, small anhydrite nodules locally, pyrite, minor intercrystalline porosity, thinly laminated (possibly algal), anhydrite filled vertical fractures.

TS 4078.7'

Laminated dolopackstone-mudstone: Allochems; local concentrations of ooid ghosts, quartz silt tr. Orthochems; dolomite 95%, opaques 4%, anhydrite 1%. Dolomite; both course and medium crystal size, slightly limey. Opaques; pyrite and possible dead oil, forming uniform thin laminae. Anhydrite; filling vertical fractures. Porosity; 1% micropore, 1% intercrystalline.

4079.2-4081

Dolomudstone: lt.-med.brown, pyritic, isolated large bivalve mold, fair intercrystalline and small vugular or moldic porosity, weakly laminated, isolated type II stylolites, anhydrite filling vertical fractures, oil stained.

4081-4082

Dolomudstone: lt.gray brown, fair intercrystalline, small vugular or moldic, and horizontal fracture porosity, distorted-patterned looking.

TS 4081.4'

Laminated dolomudstone-wackestone: Allochems; small grain ghosts, quartz silt tr. Orthochems; dolomite 99%. Dolomite; fine grain, distorted laminations, possible dessication feature, course dolomite lining horizontal cracks. Porosity; micropore 1-2%, intercrystalline 1%.

4082-4083.8

Dolowackestone-mudstone: lt.gray brown, possible small intraclasts or peloids (ghosts), fair vugular and intercrystalline porosity, oil stained.

TS 4082.2'

Intraclastic dolopackstone-wackestone: Allochems; possible intraclasts 50-75%. Orthochems; dolostone matrix 20-40%, anhydrite 5%. Intraclasts; ghosts, small, angular, possibly brecciated, dolomitized. Dolostone matrix; fine-course replacement grains. Anhydrite; filling a small vertical fracture. Porosity; small vugular and moldic 5-8%, intercrystalline 1-3%.

4083.8-4085

Dolopackstone-mudstone: med.brown, ooids, small intraclasts, calcispheres, minor intercrystalline porosity, oil stained.

4085-4086.5

Dolomudstone-wackestone: lt.gray-med.brown, grain ghosts, ostracods, possible gastropods, pyritic, fair moldic and intercrystalline porosity, type II stylolites, seam, fossils concentrated.

TS 4085.2'

Laminated dolomudstone-wackestone: Allochems; possible intraclasts 5-10%. Orthochems; dolomitized matrix and possible grains 90-95%. Intraclasts; locally concentrated, small chips or angular grains, possibly some organic rich grains, dolomitized. Dolomitized matrix; thick to thin laminations, fine-course crystals. Porosity; small vugular or moldic 5%, intercrystalline 3-5%. Dark possible organic, distorted thin laminations or stringers. Fine grained dolomite laminations cracked, cracks filled with course dolomite crystals.

4086.5-4088.3

Anhydritic dolomudstone: lt.gray, fine sand-silt size sulphate grains and possible quartz, fine grain dolomudstone matrix, very minor intercrystalline porosity, isolated thin laminations.

TS 4087.4'

Silty dolomudstone: Allochems; possible sulphate and quartz silt sized grains 2%. Orthochems; fine grained dolomite matrix 98%. Porosity; very minor intercrystalline. Massive, some dendritic patterns.

4088.3-4091

Dolomudstone-wackestone: med.brown-lt.gray, small grain ghosts, possible peloids, ooid sized round sulphate grains, fair moldic or small vugular and intercrystalline porosity, oil stained.

4091-4092

Mudstone-packstone?: lt.brown, possible grains within heavily stylolitized zone, minor vugular porosity and possible porosity associated with pressure solution, massive type II stylolites, some type I stylolites, slight oil stain.

TS 4091'

Dolomitic pseudo? peloidal intraclastic packstone: Allochems; peloids 25-30%, intraclasts 10-15%, quartz silt tr. Orthochems; dolomite 35-45%, microspar-micrite 15-25%. Peloids and intraclasts; fine grain, stylolitic margins, possibly pseudo grains formed by pressure solution. Dolomite; associated with stylolites and adjacent matrix. Porosity; intercrystalline 2-3%, small vugs 1-2%. Many type II stylolites, slight fenestral look.

4092-4092.4

Packstone-wackestone: lt.brown, intraclasts, ooids, minor moldic and intercrystalline porosity, thin fine grain lamination.

TS 4092'

Dolomitic interbedded intraclastic/oolitic packstone: Allochems; intraclasts 35-40%, ooids 25-30%, peloids 10%, fossils 1-2%. Orthochems; dolomite 10%, micrite and some microspar 10%, pseudo-spar 1-2%. Intraclasts; round-semiround, micritic and peloidal, some possibly algal, small. Ooids; many irregular shapes, radially fibrous, many micritic cores, large. Fossils; tubiform algae 50%, calcispheres 50%. Dolomite; course, slightly laminated. Micrite; matrix, thin laminations. Porosity; interparticle 3-4%, small vug 1-2%, intercrystalline 1%. Some type II stylolites.

4092.4-4093

Silicified packstone-wackestone: lt.-gray brown, intraclasts, ooids, minor vugular porosity, sharp upper and lower siliceous boundaries, ostracod tr.

TS 4092.4'

Silicified intraclastic packstone: Allochems; intraclasts 70-75%, peloids 5-10%. Orthochems; dolomite 10-15%, micrite 5-10%, quartz 3-5%, spar tr. Intraclasts; subround, silicified within siliceous zone, small, individual grains partly silicified near siliceous boundary. Dolomite; matrix and grain boundaries in nonsilicified zone. Micrite; matrix, partially silicified. Quartz; euhedral crystals lining and filling vugs or interparticle porosity. Spar; blocky, vug filling. Porosity; 2-5% small vugular, no real difference between silicified and nonsilicified zones. Massive-weakly laminated, no evidence of pressure solution. Sharp siliceous boundaries.

4093-4103.7

Packstone-wackestone: lt.brown, intraclasts, peloids, ooids, some anhydrite filling vugs, fair-good vugular, moldic and intercrystalline porosity, several thin fine grain isolated laminations, isolated type II stylolites, oil stained.

TS 4095.2'

Peloidal intraclastic oolitic packstone-grainstone: Allochems; peloids 30-40%, intraclasts 25-35%, ooids 20%, fossils tr. Orthochems; microspar 10-20%. Peloids; small, micritic, forming matrix locally. Intraclasts; round-subangular, micritic and peloidal, some with thin radially fibrous coatings. Ooids; micrite cores, several radially fibrous coatings. Fossils; calcisheres. Microspar; matrix, some grains microspar. Porosity; small matrix selective vugular 3-5%. Slightly brecciated looking.

TS 4095.4'

Peloidal intraclastic packstone-grainstone: Allochems; peloids 25-35%, intraclasts 20-30%, ooids 5%, fossils tr-5%. Orthochems; microspar and micrite 15-25%, dolomite 15%, spar 5%. Peloids; well sorted, round. Intraclasts; many bored or containing tubular algal fragments, round-subround micritic-peloidal, some with 1-2 radially fibrous layers. Ooids; radially fibrous, micrite cored. Fossils; calcispheres and some tubular algae. Microspar; matrix. Dolomite; fine grained, possibly silt, coarse grained associated with type I stylolites and pressure solution on grains, also filling bottoms of some vugs. Spar; isopachous, lining some grains and pores, some blocky. Porosity; medium vugular 5-10%, intercrystalline 1-3%, interparticle 1-2%. Some Type I and II stylolites.

TS 4099'

Dolomitic oolitic peloidal packstone: Allochems; ooids 35-40%, peloids 15-20%, intraclasts 10-15%. Orthochems; Microspar and micrite 10-15%, dolomite 5-10%, anhydrite 5%, spar 4%. Ooids; radially fibrous, round-angular. Peloids; matrix. Intraclasts; peloids-micrite, subangular, some with a few radially fibrous coatings. Microspar; matrix. Dolomite; associated with type II stylolites, selective replacement of grains. Anhydrite; filling vugs, locally replacing micrite matrix. Spar; blocky, filling some vugs. Porosity; medium vugular 5-10%, intercrystalline 1-3%. Pressure solution on many grains, numerous type II stylolites, poorly sorted.

4103.7-4104.7

Anhydritic dolomudstone: lt.brown-lt.gray, grain ghosts, silt sized sulphate grains, anhydrite filling some porosity, minor moldic and intercrystalline porosity, patterned.

4104.7-4106.5

Dolomudstone-wackestone: med.-lt.brown, ooids, calcispheres, fair-good vugular porosity.

4106.5-4107.8

Mudstone-wackestone: lt.brown, ooids, pisoids, anhydrite filling vugs and possible fenestrae, fair-good vugular and fenestral porosity, many type II stylolites, thin fine grained isolated laminations, vertical fractures anhydrite filled.

4107.8-4108.2

Dolowackestone-mudstone: lt.brown-lt.gray, ooid grain ghosts, anhydrite filling some vugs, fair vugular and moldic porosity, patterned.

TS 4108'

Peloidal intraclastic oolitic dolowackestone-grainstone: Allochems; peloids 20-30%, intraclasts 15-25%, ooids 10%. Orthochems; dolomite 45-55%, celestite 5%. Peloids and intraclasts; dolomitized. Ooids; ghosts, separate from other grains, dolomitized. Dolomite; fine grain matrix, course grains along possible stylolite and flooring vugs. Celestite; filling isolated vugs. Porosity; medium-large vugs 5-8%, oomoldic 2-4%, intercrystalline 1-2%. Sheet-cracked looking, some type II stylolites. Possible algal influence.

4108.2-4109.5

Dolomudstone: lt.gray, isolated silt sized sulphate grains, anhydrite filling vugs, minor vugular porosity, possibly high intercrystalline porosities, patterned.

TS 4109.1'

Interlaminated peloidal/oolitic dolopackstone and mudstone: Allochems; peloids 35-45%, ooids 10-15%. Orthochems; dolomite 35-45%, anhydrite 5-10%. Peloids; small, dolomitized. Ooids; radially fibrous, concentric, some molds, dolomitized. Dolomite; fine grain laminations, course grains lining porosity and some grains. Anhydrite; filling enlarged fenestrae. Porosity; moldic 3-5%, fenestrae and small vugs 1-3%, intercrystalline 1-2%. Well sorted thin laminations. Algal mat.

<u>NDGS# 6333</u>
<u>Depth Description</u>

4102-4103

Quartz sandstone: med.gray, fine sand-silt sized angular quartz grains, anhydrite filling interparticle porosity, weak-wispy fine grain laminations, massive-thin moderately well sorted laminations, tight.

TS 4102'

Quartz sandstone: Allochems; Medium sand-coarse silt sized subangular grains, predominantly quartz 50-55%, but also including potassium feldspar 5%, trace amounts microcline and sulphate grains. Orthochems; anhydrite 40-45%, dolomite tr. Quartz; fine sand-silt size, angular-subround, grounds slightly corroded on margins, some polycrystalline, strained grains, and grains with linear inclusions. Potassium feldspar; most detrital, some with perfect crystal boundaries (authegenic?). Anhydrite; some large crystals, most blocky cement. Porosity; no visible. Several thin, wavy, fine grained isolated laminations, consisting of argillaceous and fine grained sulphates. Quartz and feldspar grains moderately well sorted, but loosely packed.

4103-4104

Silty dolomitic anhydrite: lt.brown-gray with a thin gray-black clay seam, some quartz silt, anhydrite, some dolomite > downward, little-no porosity, bedded.

TS 4103.3'

Interlaminated dolowackestone and anhydrite: Allochems; quartz silt-fine sand 1-5%, authegenic potassium feldspar tr., possible peloids-small intraclasts (included within dolomite). Orthochems; anhydrite 65-75%, dolomite 25-30%, opaques 2-3%. Anhydrite; equigranular, some cement around grains. Dolomite; very fine grained, possibly argillaceous. Thinly laminated, some distortion, possible nodules, argillaceous rich laminations.

4104-4106

Anhydrite and dolomudstone: lt.brown-med.gray, some fine sand-silt size quartz grains, possible isolated peloids, dolomudstone, anhydrite laminations and nodules, bedded-laminated, pyritic, isolated clay seams.

TS 4104'

Thin bedded silty dolomudstone: Allochems; quartz 5-10%, anhydrite grains-crystals 5-10%, peloids tr. Orthochems; argillaceous dolomudstone 75-85%. Alternating quartz rich/poor laminations. Argillaceous rich dolomudstone, slightly stylolitic looking, small vertical fractures. Porosity; very minor intercrystalline and fracture.

TS 4104.1'

Silty dolomudstone: Allochems; quartz 10-15%, anhydrite 5-10%, possible peloids 1-3%. Orthochems; dolomudstone 75-85%. Quartz; silt-fine sand, angular grains. Anhydrite; elongate crystals or sand grains, (possibly celestite). Dolomudstone; argillaceous, massive. Porosity; minor intercrystalline.

TS 4104.9'

Silty argillaceous dolomudstone and anhydrite: Allochems; quartz and feldspar 15-25%. Orthochems; anhydrite 40-50%, dolomudstone 30-40%. Quartz and feldspar; mostly quartz, fine sand-silt. Anhydrite; needles/lathes, some forming distorted laminations and loose nodules. Dolomudstone; fine grained, argillaceous. Some pyrite. Porosity; very minor intercrystalline. Weak distorted laminations. Sharp contact between quartz rich zone (top of sample) and poor zone (bottom of sample).

4106-4107

Dolomudstone: lt.brown gray, dolomitized ooid-pisoid sized grains, anhydrite filling vugular porosity, minor intercrystalline and vugular porosity, thin bedded, type II stylolites, poorly sorted, slight oil stain.

4107-4109.7

Dolomudstone-wackestone: lt.-med.gray, possible small intraclasts and sulphate grains, minor small vugular and intercrystalline porosity, massive, pyritic.

TS 4109.6'

Intraclastic peloidal? dolopackstone: Allochems; intraclasts 60%, peloids 30%, quartz silt tr. Orthochems; dolomite 10%. Intraclasts; angular to subangular dolomudstone clumps, possibly pseudo grains. Peloids; small, filling between intraclasts, slightly micritic, dolomudstone. Dolomite; lining vugs and replacing matrix. Porosity; small vugular 3-5%. Brecciated looking, grains may be pseudo-grains.

4109.7-4112

Dolomitic packstone-wackestone: lt.brown, ooid-pisoid sized grains (recrystallized), isolated distorted anhydrite nodules, fair moldic, vugular and intercrystalline porosity, type II stylolite swarm.

TS 4111.4'

Dolomitic intraclastic peloidal packstone: Allochems; intraclasts 40-50%, peloids 20-30%. Orthochems; microspar 20-30%, dolomite 5-10%. Intraclasts; poorly sorted, micritic, some with thin coatings, look like mud balls. Peloids; various shapes, poorly sorted, micritic. Dolomite; vug lining, many crystals have fallen to the bottom of vugs, isolated crystals within micritic grains. Porosity; med.-large vugs 5-10%, mostly matrix selective, possible shelter porosity. Possible pendant micritic cement on some grains.

4112-4113.7'

Dolomitic wackestone-mudstone: lt.brown, small grains (recrystallized), dolomitic matrix, fair moldic, intercrystalline and vugular porosity, thin-med. bedded, poorly sorted, some microstylolites and a clay seam.

4113.7-4114.6

Dolomitic wackestone-packstone: lt.brown, small grains (recrystallized), minor intercrystalline, moldic and vugular porosity, thin bedded.

4114.6-4118.8

Dolomitic wackestone-packstone: gray-lt.yellow brown, small grains (recrystallized), anhydrite filling fenestrae, fair vugular and moldic porosity, type II stylolites, thin bedded, disrupted locally, oil stained.

TS 4114.8'

Dolomitic intraclastic peloidal packstone-wackestone: Allochems; intraclasts 20-30%, peloids 10-20%. Orthochems; dolomite 30-40%, micrite and microspar 10-20%, celestite 10-15%. Intraclasts; poorly sorted, round, micritic, some with thin coatings, possible ooids or oncoids. Peloids; micritic, various shapes. Dolomite; several generations, replacing micrite, very clean vug lining. Celestite; single crystal, filling many vugs. Porosity; 5-15% vugular and enlarged fenestrae. Similar adjacent pores celestite filled.

TS 4117.9'

Intraclastic peloidal dolowackestone: Allochems; small intraclast and peloid sized grains (molds). Orthochems; dolomite 70-80%, anhydrite 20-25%, celestite 5%. Dolomite; several generations, large clear euhedral crystals lining vugs that are anhydrite filled, smaller crystals lining unfilled pores, fine grain matrix. Anhydrite; filling fenestral or interconnected rather than moldic porosity, both blocky and radiating fibrous types. Celestite; single crystals filling several pores. Porosity; moldic 15-20%.

4118.8-4120.8

Interbedded dolomitic wackestone and dolowackestone-mudstone: lt.brown, small grains (recrystallized), minor intercrystalline and small vugular porosity, thin-medium distorted bedding, possible caliche zones, type I and II stylolites, no visible stylolites in dolostones.

TS 4119.9'

Thinly laminated dolowackestone-mudstone: Allochems; intraclasts and peloids (molds), quartz silt tr. Orthochems; dolomite (course) 80%, dolomite (fine) 20%. Dolomite (course); associated with dark residue. Dolomite (fine); fractured. Porosity; moldic and small vugs 5-10%, intercrystalline 2-3%. Thin, discontinuous, distorted, dark laminations.

TS 4120.6'

Calcitic pseudo? oolitic pisolitic wackestone-packstone: Allochems; intraclasts (pseudo coated grains) 35-45%. Orthochems; dolomite 45-55%, microspar and some micrite 5-10%. Intraclasts; 0.1-5.0mm size, average 1.0mm, angular-round, micritic grains and radially fibrous crusts and fragments, many grains with up to 3 layers of radial coating. Dolomite; matrix, crystalline, fine grain. Microspar; possible cement remnant or micrite being replaced. Porosity; fenestral 3-6%, intercrystalline 1-2%. Poorly sorted, thinly laminated in places. Pressure solution on grain margins. Dendritic patterns on micritic grains.

4120.8-4123.9

Dolomitic wackestone-mudstone: lt.brown, small grains, possibly recrystallized, fair vugular and moldic porosity, medium-thin bedded, possible micritic crusts.

TS 4123.1'

Dolomitic peloidal intraclastic packstone-grainstone: Allochems; peloids 35-45%, intraclasts 20-30%, ooids tr. Orthochems; dolomite 25-30%, micrite and some microspar 5-10%. Peloids; micritic, round-subangular. Intraclasts; small, micritic, round-subangular. Ooids; radially fibrous. Dolomite; crystalline matrix, coarser where lining vugs, replacing micrite and grain margins. Micrite; matrix. Porosity; interparticle-intercrystalline 5-8%, nonselective vugular 1-2%, fenestral 1-2%. Poorly sorted.

4123.9-4125.2

Wackestone-mudstone: lt.gray-brown, compacted ooids and pisoids (not radially fibrous) some broken, anhydrite filling some fenestrae, minor small vugular porosity, type II stylolites, thin-medium parallel bedding.

TS 4124'

Coated grain wackestone: Allochems; coated grains 45%, fossils tr. Orthochems; micrite 40-50%, dolomite 5-10%, anhydrite tr. Coated grains; 1.0-4.0mm, micrite cored, most with 1-10 radially fibrous coatings, some alternating with micrite coatings, subround, some cracked and recoated, some coatings undulatory. Fossils; calcispheres, well preserved. Micrite; dark, massive, fine grained, slight peloidal look. Dolomite; associated with stylolites and lining porosity, some replacement of matrix. Anhydrite; filling small vertical fractures. Porosity; stylolite concentrated intercrystalline 3-5%, fenestrae 1-2%. Extensive type II and I stylolites. Dendritic patterns on micritic grains.

4125.2-4126

Argillaceous dolomudstone: lt.gray, isolated type II stylolites and one stylolitic seam, possible dessication crack, pyritic.

TS 4125.5'

Dolomudstone-wackestone: Allochems; possible small peloid sized grain ghosts. Orthochems; dolomite 99%, pyrite 1%. Dolomite; fine crystalline dolomite, possibly argillaceous. Porosity; possible moldic 1-2%, intercrystalline 1-3%. Weak light and dark laminations.

4126-4130

Dolomitic wackestone-mudstone, isolated packstones: lt.brown, recrystallized looking, small round grains, some ooids, fair small vugular and moldic porosity, thin-medium bedded, type II stylolites and seams, some type I stylolites.

TS 4129.5'

Oolitic peloidal packstone-grainstone: Allochems; ooids 75-85%, peloids 5-10%, fossils tr. Orthochems; micrite and some microspar 10-15%, dolomite 3-5%. Ooids; radially fibrous, peloidal cores, some dolomitized cores, pressure solution and compaction evident on most grains, some cracks filled with blocky spar, some grapestone. Peloids; matrix. Fossils; calcispheres 50%, unidentified (possibly neomorphosed echinoderm or bivalve fragments) 50%. Micrite; matrix. Dolomite; isolated crystals within grains, lining some vugs. Porosity; 5-10% small vugular. Much pressure solution on grain margins, several type I stylolites.

4130-4131.2

Wackestone-packstone: lt.brown, pisoids, peloids, ooids, some grains recrystallized, blocky spar, some anhydrite, good matrix selective vugular porosity, thin-medium bedded, some crusts, type I stylolites (anhydrite filled).

TS 4130.2'

Oolitic peloidal packstone-grainstone: Allochems; small ooids 30-40%, large ooids 15-25%, peloids 15-20%, intraclasts 10-20%, fossils tr. Orthochems; micrite 5-10%, microspar 3-5%, spar 5%. Small ooids; radially fibrous, small core. Large ooids; micrite-peloid cored, subround, several radially fibrous coatings. Peloids; round, micritic. Intraclasts; micritic-peloidal cored, one or more radially fibrous layers, pseudo pisoids. Fossils; ostracods 100%. Micrite; matrix. Microspar; matrix, some grains. Spar; blocky, large crystals, lining some vugs. Porosity; vugular 5-10%, interparticle 5%, and stylolitic 1-2%. Overpacked, much pressure solution on grain margins, type I stylolites.

TS 4131.2'

Intraclastic peloidal packstone: Allochems; intraclasts 40-50%, peloids 15-25%. Orthochems; micrite and microspar 25-30%, dolomite tr. Intraclasts; large, micritic, traces of radially fibrous crusts in places, possible oncoids. Peloids; possible recrystallized ooids, occur throughout matrix as well a thin horizontal sorted zone. Micrite and microspar; matrix. Dolomite; associated with pressure solution. Porosity; small-large vugular 8-12%. Compaction and pressure solution on grain margins evident. Black dendritic patterns on some grains.

NDGS# 6390

Depth Description

4060-4063.2

Silty-sandy anhydrite: med.-dk.gray, silt-very fine quartz sand, some sulphate grains, pyritic, thin sand rich laminations, argillaceous anhydrite, some showing early lithification and fracturing, some patterned looking.

4063.2-4067.5

Nodular anhydrite and dolomudstone: lt.-med.gray, argillaceous, some sulphate grains within dolomudstone, pyritic, minor intercrystalline porosity, anhydrite nodules with thin dolomudstone stringers, some thin dolomudstone and sulphate grain laminations, some vertically elongate nodules (gypsum crystal growth position?).

4067.5-4068.5

Dolomudstone-wackestone: lt.gray-lt.brown gray, possible peloids (ghosts), anhydrite filling small vugs and fractures, fair intercrystalline and small vugular porosity, possible algal laminations.

4068.5-4069

Argillaceous dolomudstone: lt.gray, fair intercrystalline porosity, thinly laminated, uniform distortion, bounded by stylolite seams.

4069-4071.2

Dolomudstone-packstone: lt.brown gray, local peloid concentrations, some intraclasts and sulphate grains, some anhydrite nodules, anhydrite replacing some grains, fair intercrystalline porosity, local weak laminations.

4071.2-4072

Nodular anhydrite: gray white, large nodules, anhydrite filled vertical fractures.

4072-4073.5

Core missing or badly rubbled for this interval.

4073.5-4074

Nodular anhydrite and dolopackstone-wackestone: lt.gray, sulphate grains and lathes, white anhydrite nodules, minor intercrystalline porosity.

4074-4076.5

Core missing or badly rubbled for this interval.

4076.5-4077

Dolomudstone: lt.gray, minor intercrystalline porosity, slight patterned look.

4077-4078

Dolopackstone-wackestone: lt.gray-lt.brown, peloids, small intraclasts, anhydrite filling some interparticle porosity, good-very good intercrystalline and small vugular porosity, weakly laminated, possible algal laminations, heavy oil staining.

4078-4078.2

Dolopackstone: brown, peloids, small intraclasts, anhydrite filling some vugs, good intercrystalline and small vugular porosity, many type II stylolites, oil stained.

4078.2-4078.6

Silicified packstone-wackestone: yellow green brown, peloids, small intraclasts, silicified, minor small vugular porosity, locally thin laminations, possible algal.

4078.6-4081.5

Packstone-wackestone: lt.gray brown, peloids, intraclasts, pseudo intraclasts? (bounded by stylolites), anhydrite vug fill locally, brown replacement anhydrite, spar vug lining, fair small vug and stylolitic porosity, much type II stylolitization, pressure solution on grains.

4081.5-4082

Dolopackstone-mudstone: lt.brown, sulphate grains and crystals, peloids, isolated anhydrite filling vugs and fractures, minor intercrystalline porosity, massive.

4082-4087

Packstone-wackestone: lt.brown-lt.gray brown, intraclasts, peloids, anhydrite filling vugs and replacing carbonates, blocky spar lining vugs, good large-small nonselective vugular porosity, many type II and some type I stylolites, isolated thin fine grain laminations or crusts, oil stained.

TS 4082'

Dolomitic peloidal intraclastic packstone: Allochems; peloids 30-35%, intraclasts 20-25%, ooids 2-4%, fossils tr.-1%. Orthochems; dolomite 15-20%, celestite 10-15%, microspar and some micrite 10-15%, spar 1-2%. Intraclasts; small, round, micritic and peloidal. Ooids; radial fibrous. Fossils; ostracod 30%, calcispheres 30%, forams 30%, tubular algae 10%, most micritized. Dolomite; locally pervasive. Celestite; gypsum type crystals in dolomudstone matrix, and blocky porosity filling. Microspar and micrite; matrix. Spar; blocky, filling vugs. Porosity; small vugular 1-2%, moldic 1-2%, intercrystalline 1-2%. Celestite and dolomudstone filling a vertical-diagonal crack or hole.

4087-4087.9

Wackestone-packstone: lt.brown, peloids, fair intercrystalline porosity, weak laminations locally, type II stylolites, recrystallized looking, oil stained.

4087.9-4088

Dolomudstone: lt.gray, fair intercrystalline porosity, patterned.

4088-4090

Nodular anhydrite and dolopackstone: white-dk.gray, peloids within dolostone, small-large anhydrite nodules, dolopackstone stringers.

4090-4097.9

Dolopackstone-mudstone: lt.brown-lt.gray, peloids, small intraclasts, anhydrite filling vugs and interparticle porosity, fair intercrystalline and small vugular porosity, localized thinly laminated zones, patterned zones, and massive-weakly laminated zones, alternating medium bedded grain rich/poor, oil stained.

TS 4095.9'

Dolopackstone-wackestone: Allochems; intraclasts (ghosts), possible quartz silt tr. Orthochems; dolomite 85-90%, anhydrite 10-15%. Intraclasts; pseudo or ghosts. Dolomite; grain ghosts and matrix. Anhydrite; filling interparticle and possible compacted fenestrae, alot of silt sized grains. Porosity; moldic 2-3%, intercrystalline 1-2%.

4097.9-4099

Mudstone-packstone: lt.brown-lt.gray brown, peloids, intraclasts, brown replacement anhydrite, minor porosity associated with stylolites, thinly laminated, much pressure solution and type II stylolites.

NDGS# 6694
Depth Description

4076-4077.1
Dolomudstone: lt.gray, sulphate grains, ooid ghosts, good intercrystalline and micropore porosity, weakly laminated, algal looking.

TS 4077'
Interlaminated stromatolitic dolomudstone and dolowackestone-packstone: Allochems; ooids 20-25%, intraclasts 10-15%, peloids 5-10%, argillaceous 1-2%. Orthochems; dolomite 40-50%, anhydrite 2-4%, opaques 2-4%. Ooids; radially fibrous, ghosts, dolomitized. Intraclasts; various shapes and sizes, ghosts, dolomitized. Peloids; ghosts, dolomitized. Dolomite; fine grain, laminated. Anhydrite; filling moldic porosity. Opaque; some pyrite, scattered-concentrated. Porosity; moldic 1-3%, intercrystalline 1-2%. Laminations are dark, fine grained, wispy. Possible stylolitization.

4077.1-4078.4
Dolopackstone: lt.gray brown, recrystallized, peloids, fossils, intraclasts, anhydrite filling molds, minor intercrystalline porosity, massive-algal looking, slight oil stain.

TS 4077.5'
Dolowackestone-packstone: Allochems; possible fossil 2-5%, grain ghosts (dolomitized), fragments 5%. Orthochems; dolomite 70-80%, anhydrite 10-15%. Fossils; gastropod?, anhydrite filled mold. Fragments; small, fine grain angular grains or remnants of laminations, possible algal. Dolomite; replacing matrix and grains. Anhydrite; filling large and small moldic porosity, most lined with a dark fine grain material. Porosity; moldic 2-3%, intercrystalline 1-2%. Fairly massive.

4078.4-4083
Dolomitic packstone-wackestone: med.brown, ooids, small intraclasts, compacted oncoids, anhydrite filling some porosity, fair-very good intercrystalline and vugular porosity, thin bedded, alternating grain rich/poor, some dessication cracks, type II stylolites, oil stained.

4083-4085
Dolomitic packstone-wackestone: lt.-med.brown-lt.gray, intraclasts, ooids, oncoids, sulphate grains, anhydrite filling fenestral and interparticle porosity, possible anhydrite nodules, good intercrystalline and micropore porosity, alternating grain rich/poor laminations, type II stylolites, oil stained.

4085-4086.5
Dolomudstone-wackestone: lt.gray, sulphate grains or crystals, fair intercrystalline porosity, possible algal laminations.

4086.5-4090.5
Packstone-wackestone: lt.brown-lt.gray brown, peloids, ooids, small intraclasts, sulphate crystals and porosity fill, good intercrystalline and small vugular porosity, thin bedded, alternating grain rich/poor, type II stylolite rich zones,

isolated thin fine grain laminations (crusts), oil stained.

TS 4087.2'

Dolomitic intraclastic peloidal packstone-wackestone: Allochems; intraclasts 25-35%, peloids 15-25%, quartz silt tr. Orthochems; dolomite 25-35%, micrite and some microspar 10-15%, anhydrite 5%, fluorite tr. Intraclasts; micritic, round-subround. Peloids; 50% dolomitized. Quartz silt; concentrated along stylolites. Dolomite; replacing matrix and grain margins locally, associated with type II stylolites. Micrite; matrix locally. Anhydrite; filling vertical fractures and possible fenestrae, associated with stylolites. Fluorite; small, cubic shape crystals, associated with stylolites. Porosity; small vugular 1-3%, intercrystalline 1-2%, stylolitic 1-2%. Type II stylolite swarm.

TS 4088.2'

Dolomitic peloidal intraclastic packstone-grainstone: Allochems; peloids 35-45%, intraclasts 35-45%. Orthochems; micrite 10-20%, dolomite 5%, anhydrite 2-4%, fluorite tr. Intraclasts; possible pseudo intraclasts formed by stylolites (solution breccia). Micrite; matrix. Dolomite; associated with stylolites, grain margins, and lining possible compacted fenestrae. Anhydrite; filling enlarged fenestrae or vugs. Fluorite; scattered within carbonate grains. Porosity; small vugular 1-3%, fenestrae 1-3%. Type I and II stylolites throughout.

4090.5-4092

Alternating Packstone-grainstone and wackestone: lt.brown-lt.gray brown, peloids, small intraclasts, ooids, anhydrite completely filling porosity locally, good interparticle and small vugular porosity, alternating fine/course grain, type I and II stylolites, isolated pressure solution on grains.

4092-4093

Dolowackestone: lt.gray, small intraclasts, anhydrite filling some porosity, fair intercrystalline porosity, patterned, burrowed looking, most burrows vertical.

4093-4096.8

Packstone: lt.brown-lt.gray brown, peloids, small intraclasts, pseudo intraclasts?, anhydrite partially filling vertical fractures and porosity, blocky spar filling some vugs, fair small vugular porosity, open vertical fracture, thin-medium bedded, type II stylolites, pressure solution on grains.

4096.8-4097.5

Grainstone-packstone: lt.brown-lt.gray brown, ooids, peloids, anhydrite filling interparticle and matrix selective vugular porosity, spar lining vugs, fair nonselective vugular porosity, much pressure solution on grains, type II stylolites.

4097.5-4103

Packstone-wackestone: lt.brown-lt.gray brown, small intraclasts, peloids, ooids locally, anhydrite filling vugs, spar lining vugs, fair small vugular porosity, massive to brecciated looking, much pressure solution and type II stylolites, calcispheres.

TS 4098.1'

Peloidal intraclastic packstone-boundstone: Allochems; peloids 30-35%, intraclasts 20-25%. Orthochems; anhydrite 25-35%, micrite and some microspar 5-10%, spar 1-3%. Intraclasts; micritic-peloidal, some large rip ups, many bored or of algal origin.

Peloids; micritic, some well sorted laminations or crusts. Anhydrite; filling large interconnected vertical and horizontal vugs and cracks, replacing adjacent micritic carbonates and incorporating spar. Spar; blocky, filling interparticle porosity or vugs. Porosity; small vugular 2-4%. Weak stylolites, weakly laminated.

TS 4101.2'

Intraclastic oolitic wackestone: Allochems; intraclasts 15%, ooids 15%. Orthochems; micrite and microspar 60-70%, spar 2-4%, dolomite tr. Intraclasts; round, microspar. Ooids; radially fibrous, large, microspar. Spar; filling porosity. Porosity; small vugular or moldic 10-12%, intraparticle 1-2%.

4103-4104

Wackestone-packstone: lt.-med.brown, peloids, intraclasts, small ooids, anhydrite filling vugs and possibly forming nodules, good intercrystalline and small vugular porosity, thinly laminated, algal looking, much pressure solution and type II stylolites, oil stained.

4104-4105.8

Packstone-wackestone: lt.gray brown, intraclasts, small ooids, pseudo pisoids, anhydrite filling interparticle and vugular porosity, good small vugular and stylolitic porosity, brecciated looking, anhydrite filled vertical fracture, oil stained.

4105.8-4110.7

Packstone-wackestone: lt.gray brown, peloids, small intraclasts, ooids locally, anhydrite filling vugs locally, fair-good small vugular and stylolitic porosity, slight fenestral look, type II stylolites.

4110.7-4111.6

Calcitic dolomudstone: lt.gray, peloids, anhydrite filling vugs locally, good medium vugular and intercrystalline porosity, massive.

4111.6-4112

Grainstone-boundstone: med.brown, peloids, small ooids, fair intercrystalline porosity, thinly laminated, alternating algal/grains, oil stained.

4112-4114.6

Calcitic dolowackestone-mudstone: lt.brown-lt.gray, peloids, anhydrite filling vugs locally, good medium-large vugular porosity, slight fenestral-patterned look.

TS 4112.4'

Dolomudstone: Allochems; silt tr. Orthochems; dolomite 80-85%, anhydrite 15-20%. Silt; course dolomite, sulphate grains. Dolomite; fine grained, argillaceous, dark. Anhydrite; filling vugs and/or fenestrae. Porosity; medium vugular 5-8%, fenestrae 1-3%. Slight fenestral look. Oil stained.

4114.6-4116.5

Packstone-wackestone: lt.gray brown, ooids, peloids, isolated anhydrite vug fill, fair small vugular and stylolitic porosity, much pressure solution and type II stylolites, possible algal laminations.

NDGS# 6720
Depth Description

4143-4144
Dolomudstone-wackestone: med.gray-lt.brown, peloids, oncoids, ooids locally, anhydrite filling vertical fractures and some vugs, good intercrystalline and small vugular porosity, possible dessication and sheet cracks, oil stained.

TS 4143.5'
Oncolitic dolowackestone-boundstone: Allochems; oncoids 10-20%. Orthochems; dolomite 75-85%, anhydrite 5-10%. Oncoids; dolomitized, compacted. Dolomite; course-fine, dark-light, possibly replacing stromatolite boundstone and carbonate mud. Anhydrite; filling enlarged fenestrae. Porosity; fenestrae 2-4%, intercrystalline 1-3%. Very fenestral looking, distorted, discontinuous dark laminations.

4144-4145.2
Dolopackstone-wackestone: lt.brown gray, ooids, small pisoids, peloids, anhydrite filling interparticle or matrix selective vugular porosity, fair moldic and small vugular porosity, slight fenestral look.

4145.2-4146
Dolowackestone: lt.gray brown, oncoids, ooids, anhydrite filling some porosity, good intercrystalline and small vugular porosity, fine grain with thin grain rich laminations.

4146-4147
Dolopackstone-wackestone: lt.gray, peloids, isolated small intraclasts and ooids, anhydrite filling vugs and fenestrae, minor intercrystalline and micropore porosity, slight fenestral look.

4147-4148.2
Dolomudstone: lt.-med.gray, minor intercrystalline porosity, patterned, possible algal laminations.

4148.2-4151.3
Packstone-grainstone: med.brown, peloids, small intraclasts, some ooids, good-very good moldic and small-medium vugular porosity, alternating course/fine grained, some type II stylolites, possible algal laminations, oil stained.

4151.3-4152
Wackestone: lt.brown-lt.gray brown, isolated ooids, peloid rich zones, isolated anhydrite vug fill, good medium vugular and intercrystalline porosity, alternating fine/course grain.

4152-4154.7
Packstone: lt.gray brown, poorly sorted peloids, small-large ooids, small-large intraclasts, blocky spar lining and filling vugs, some anhydrite filling vugs, good nonselective vugular porosity, thin crusts, type I and II stylolites.

4154.7-4155
Dolomitic mudstone-wackestone: lt.brown gray-med. brown, peloids, isolated intraclasts, isolated anhydrite vug fill, good-very good intercrystalline and small-medium vugular porosity, weak laminations, possible dessication cracks.

TS 4154.7'
Interbedded dolomitic-calcitic mudstone and intraclastic

packstone: Allochems; intraclasts 15-20%, peloids 10-15%, fossils tr. Orthochems; dolomite 30-35%, micrite 30-35%, opaque 1-2%. Intraclasts; micritic, small, subround, partially dolomitized. Peloids; dolomitized. Fossils; calcispheres 100%. Dolomite; scattered crystals throughout micrite, lining porosity and grains. Micrite; matrix, possibly some microspar. Opaque; dark, fibrous clusters. Porosity; medium-large vugular 10-15%, compacted fenestrae 1-2%.

4155-4155.4

Packstone: lt.gray brown, peloids, small ooids, spar vug lining, fair small vugular porosity, type I and II stylolites, alternating course/fine grained, calcispheres.

4155.4-4158

Calcitic dolowackestone: lt.gray-lt.-med.yellow brown, pisoids, ooids, some intraclasts, anhydrite locally filling vugs, good vugular and intercrystalline porosity, crusts, algal looking, fenestral looking.

TS 4156'

Calcitic ooid/oncoid dolopackstone-wackestone: Allochems; ooids/oncoids 50-60%. Orthochems; dolomite 40-50%. Ooids/oncoids; weakly laminated, micritic (mostly dolomitized). Dolomite; matrix. Porosity; large vugular 5-10%, moldic 5-10%, fenestral 2-4%. Several thin fine grained crusts draping over grains and with grains resting on them.

4158-4158.5

Dolomitic wackestone: med.gray brown, peloids, intraclasts, rip-up clasts, anhydrite filling vugs, good vugular and intercrystalline porosity, possible algal lamination or crust.

4158.5-4160.5

Packstone-grainstone: lt.gray brown, ooids, isolated pisoids, isopachous spar lining vugs, blocky spar filling vugs, possible chlorite lining vertical fractures, good small vugular porosity, open vertical fractures, isolated crusts, reverse grading, oil stained.

4160.5-4163

Grainstone-wackestone: lt.gray brown, ooids, small intraclasts, pisoids, anhydrite filling vugs, minor small vugular porosity, alternating course/fine grain, type II stylolites.

4163-4163.4

Dolomitic grainstone-packstone: lt.gray brown, ooids, pisoids, blocky spar lining vugs, fair small vugular porosity, alternating course/fine grain, type II stylolites, poorly sorted.

4163.4-4169.3

Packstone-wackestone: lt.brown, small ooids, peloids, pisoids and large coated intraclasts locally, blocky spar lining vugs, isolated anhydrite vug fill, fair-good vugular porosity, massive, isolated fine grain laminations (crusts), type II stylolites, massive stylolite seam.

4169.3-4170

Grainstone-packstone: lt.-med.gray, broken pisoids, ooids, small intraclasts, anhydrite filling porosity, minor vugular porosity, massive.

4170-4171.3

Grainstone-packstone: med.brown, ooids, isolated pisoids, blocky spar lining vugs, good nonselective vugular porosity, alternating more/less matrix.

TS 4170.4'

Oolitic pisolitic packstone-grainstone: Allochems; ooids and pisoids 65-70%, peloids 5-10%, fossils tr. Orthochems; micrite 10-15%, spar 5-10%, dolomite tr. Coated grains; radially fibrous, concentric laminations, many broken. Fossils; calcispheres 100%. Micrite; matrix, slight meniscus look. Spar; blocky-bladed, partially filling porosity. Dolomite; associated with stylolite. Porosity; matrix selective vugular 5-10%, enlarged fenestrae 3-4%, interparticle 1-3%. Draping fine grain lamination or crust. Type I stylolites and pressure solution on grains. Oil stained.

4171.3-4172.5

Grainstone-packstone: lt.gray brown, ooids, isolated pisoids, blocky spar lining vugs, good vugular porosity, type I and II stylolites, thin crusts and pisoid rich layers.

<u>NDGS# 6727</u>
<u>Depth Description</u>

4094-4095.3

Massive anhydrite: lt.gray, pyritic, weak wavy laminations.

TS 4094.7'

Massive-weakly nodular argillaceous anhydrite: Allochems; silt 5-15%. Orthochems; anhydrite 85-95%. Silt; mostly euhedral dolomite, some quartz, some K-feldspar (probably authegenic). Anhydrite; fine grain, 1-4 micron, some locally blocky grains. No porosity, weakly laminated.

4095.3-4095.6

Shaly anhydrite: lt.brown gray-black, pyritic, thin shaly bed with much pyrite, massive anhydrite.

4095.6-4098.6

Anhydritic quartz sandstone: lt.-med.gray, fine sand sized angular quartz, anhydrite interparticle cement, some thin anhydrite laminations (wavy), fairly massive looking, minor-no porosity.

TS 4097'

Argillaceous quartz sandstone: Allochems; sand 60-70%, clays 2-5%. Orthochems; anhydrite 25-35%. Sand; nearly all subround-subangular quartz grains, some K-feldspar (some authegenic), grains are medium sand-silt sized. Clays; scattered throughout. Anhydrite; cement, blocky, large-very fine cubes, possible clastic occurrences, locally forming nodules or lenses. Porosity; none visible. Fairly massive. Sand grains loosely packed.

4098.6-4099

Anhydritic argillaceous quartz sandstone: lt.-med.gray, angular quartz fine sand grains, some sand size carbonate grains, anhydrite cement, small anhydrite nodules, pyritic, weak wavy laminations, minor-no porosity.

TS 4098.6'

Argillaceous quartz sandstone: Allochems; sand 55-65%, clays 3-6%. Orthochems; Anhydrite 30-40%, pyrite 1%. Sand; nearly all subround-subangular quartz medium sand-silt sized grains, some K-feldspar, some plagioclase, slight course/fine grain bedding contacts. Clays; scattered throughout, concentrated in weak irregular nonparallel laminations. Anhydrite; cement, blocky, large-fine cubes, possible clastic contribution. Porosity; no visible. Weak, wavy, isolated, nonparallel, thin fine grain laminations.

4099-4099.4

Massive pyritic anhydrite: lt.brown gray, pyritic, weakly laminated, sharp contact with sand.

TS 4099'

Silty dolomitic anhydrite: Allochems; dolomite 15-25%, silt-fine sand 2-5%. Orthochems; anhydrite 70-80%. Dolomite; large pitted grains, small euhedral grains. Silt; quartz, some K-feldspar, dolomite. Anhydrite; equigranular, cubic. Porosity; none visible. Sharp break between silty-argillaceous rich and poor zones.

4099.4-4099.6

Nodular anhydrite and dolomudstone: lt.-med.gray-tan, anhydrite nodules, distorted dolomudstone laminations, pyritic.

4099.6-4099.8

Dolomudstone and anhydrite: tan, anhydrite filling dessication or sheet cracks, cryptalgal looking, thinly laminated dolomudstone.

TS 4099.6'

Sandy-silty dolowackestone: Allochems; silt 4-6%. Orthochems; dolomite 75-80%, anhydrite 5-10%, micro and pseudospar 5%, opaques 1-2%. Silt; quartz, located in thin laminated zone. Dolomite; fine and course, fine matrix, course acting as sand grains. Anhydrite; sand grains or possible round mold fill, most blocky nodules with opaque inclusions, some vug or fenestrae fill. Neomorphic spar; in laminated zone. Opaque; pyrite and other, scattered throughout with local concentrations. Porosity; none visible, possible intercrystalline. Locally thin, parallel laminations, alternating mud rich/poor laminations.

TS 4099.7'

Crystalline anhydrite and thinly laminated siltstone: Allochems; silt and sand 4-6%, intraclasts 4-5%, peloids 2-3%, clays tr. Orthochems; anhydrite 70-80%, dolomite 5-10%, opaques tr. Silt; quartz, mostly concentrated in laminations, some scattered. Intraclasts; small, dolomitic. Peloids; small, dolomitic. Clays; associated with silt laminations, reddish color. Anhydrite; small-medium cubic crystals, possible compacted nodule associated with silt, some anhydrite appears to be replacing dolomite. Dolomite; forming some mud chips at base of silt laminations, some round grains. Opaques; most pyrite, scattered throughout. Porosity; none visible. Sharp break between thinly laminated zone and massive zone.

4099.8-4101

Massive anhydrite and clay seam: lt.-med.gray to dk.green brown, some isolated carbonate grains, compacted anhydrite nodule within clay seam, thin clay seam, massive anhydrite.

4101-4102

Nodular anhydrite and dolomudstone: lt.-med.gray-tan, chickenwire looking, distorted dolostone laminations within anhydrite, little or no porosity.

4102-4102.4

Dolowackestone: lt.-med.gray brown, ooids (recrystallized), anhydrite filling vertical fractures, vugs and fenestrae, fair moldic and vugular porosity, slight fenestral look.

TS 4102.1'

Peloidal intraclastic dolopackstone: Allochems; peloids 35-45%, intraclasts 25-35%. Orthochems; anhydrite 15-20%, dolomite 10-20%, opaques tr.-1%. Peloids; round, dolomitized. Intraclasts; round, dolomitized, some weakly laminated. Anhydrite; blocky-bladed, filling vugs, vertical fractures, and large horizontal cracks. Dolomite; matrix. Opaques; not pyritic, lining some porosity and within some anhydrite. Porosity; moldic 1-3%, fenestrae 1%, intercrystalline 1%. Massive looking.

4102.4-4105

Dolowackestone-grainstone: med.brown, oncoids, ooids, peloids, anhydrite filling interparticle porosity, good moldic and intercrystalline porosity, alternating grain rich/poor zones, some vertical fractures, oil stained.

4105-4105.6

Dolomudstone-packstone: lt.gray, thin ooid laminations, intraclasts, anhydrite filling porosity, fair-good vugular porosity, thin grain rich laminations within massive mudstone, opaque vug lining.

4105.6-4106

Sulphate grains and dolowackestone: med.gray-med.brown, sulphate grains, some peloids, anhydrite filling porosity, sugary looking.

TS 4105.8'

Sulphates and argillaceous intraclastic peloidal dolopackstone: Allochems; intraclasts 25-35%, peloids 15-25%. Orthochems; sulphates 40-50%, opaques tr. Intraclasts and peloids; dark, indistinct. Sulphates; single blocky crystals replacing or growing into matrix and grains, most is celestite with some anhydrite. Opaques; dark. Porosity; moldic 2-3%, fenestrae 1-2%, vertical fracture 1-2%. Sharp contact between area with sulphate grains and area with none, no porosity in area with sulphate grains.

4106-4106.3

Dolomitic packstone: lt.brown, ooids, small peloids, some anhydrite vug fill, good vugular and interparticle porosity, type II stylolites.

TS 4106'

Calcitic interbedded oolitic dolopackstone and intraclastic peloidal dolopackstone: Allochems; intraclasts 30-35%, peloids 25-30%, ooids 20-25%. Orthochems; dolomite 15-25%, anhydrite 4-6%. Intraclasts and peloids; dolomitized. Ooids; radially fibrous, concentric laminations, mostly dolomitized. Dolomite; matrix, lining porosity and compacted fenestrae. Anhydrite; filling some vugs. Porosity; small-medium vugular 5-7%, moldic 3-4%, enlarged fenestrae 2-4%, intercrystalline 1-2%. Algal looking zone separating ooid zone from intra/pel zone.

4106.3-4108.9

Wackestone-packstone: lt.brown, ooids, peloids, some intraclasts, some anhydrite vug fill, spar lining some porosity, good vugular and interparticle porosity, alternating grain rich/poor, possible crusts, oil stained.

4108.9-4110.7

Mudstone-packstone: lt.brown, ooids, peloids, some intraclasts and pisoids, anhydrite filling some vugs, spar lining porosity, good vugular, moldic and fenestral porosity, some distorted laminations, ostracods.

4110.7-4111.3

Wackestone: lt.brown, ooids, peloids, some intraclasts, good vugular and fenestral porosity, alternating grain rich/poor, type II stylolites.

4111.3-4112.3

Interbedded dolomitic wackestone and dolomudstone: lt.brown-lt.gray, ooids, peloids, fair vugular and moldic porosity, type II stylolites.

4112.3-4113.6

Packstone-mudstone: lt.gray brown, ooids, small intraclasts, fair vugular and moldic porosity, alternating grain rich/poor, type II stylolites, possible algal laminations.

4113.6-4114

Packstone-mudstone: lt.gray brown-med.brown, ooids, small-large intraclasts, anhydrite filling some fenestral and shelter porosity, good vugular and fenestral porosity, type II stylolites, heavy oil stain.

TS 4113.6'

Calcitic peloidal intraclastic dolopackstone-wackestone: Allochems; peloids 20-30%, intraclasts 15-25%. Orthochems; dolomite 45-55%, anhydrite 4-6%. Peloids; mostly dolostone, indistinct. Intraclasts; mostly dolostone, partially micritic-microspar. Dolomite; matrix and possible crusts, coarse crystals lining anhydrite filled vugs. Anhydrite; filling vugs and fenestral porosity. Porosity; moldic 4-6%, fenestral 3-4%, intercrystalline 1-2%. Much oil staining. Several horizontal dolomitized crusts.

4114-4115.3

Dolomitic wackestone-packstone: lt.gray-lt.gray brown, ooids, small-large intraclasts, anhydrite (2 colors) filling fenestrae and vugs, good-very good moldic and vugular porosity, fenestral looking, alternating grain rich/poor, oil stained.

4115.3-4116.7

Dolomudstone-wackestone: lt.gray, anhydrite filling some vugs, good vugular porosity, some oil stain.

4116.7-4117.2

Wackestone-packstone: lt.brown gray, ooids, intraclasts, some pisoids, good vugular and moldic porosity, alternating course/fine grain, type II stylolites, vertical fracture anhydrite filled.

TS 4116.7'

Dolomitic oolitic pisolitic packstone: Allochems; ooids 40-50%, pisoids 10-15%. Orthochems; micrite and some microspar 35-45%. Ooids; partially dolomitized, concentric laminations, possibly radially fibrous. Pisoids; micritic core, radially fibrous outer laminations. Micrite; matrix. Porosity; interparticle 2-4%. Well sorted ooids, isolated pisoids. Pressure solution on pisoids.

4117.2-4121.9

Wackestone-packstone: lt.gray brown, ooids, small intraclasts, pisoids locally, anhydrite filling fractures, anhydrite pseudomorphs of gypsum crystals locally, blocky spar lining pores, good vugular porosity, alternating course/fine grain, type II stylolites and pressure solution on grain margins.

TS 4120.9'

Dolomitic pisolitic peloidal packstone: Allochems; pisoids 50-60%, peloids 10-15%, intraclasts 5-10%. Orthochems; micrite and some microspar 10-15%, dolomite 5-10%. Pisoids; large, both micritic and radially fibrous laminations within a grain, several coated to form large grapestones. Peloids; matrix, small, indistinct. Intraclasts; round, made of micrite and peloids. Micrite; matrix and crusts or thin laminations. Dolomite; associated with pressure solution, scattered throughout. Porosity; pressure solution 2-4%, small vug 1-3%, vertical fracture 1%. Several graded micritic crusts or laminations draping over pisoids. Pressure solution on grains, possible type I and II stylolites.

4121.9-4122.6

Wackestone: lt.gray brown, ooids, pisoids, good-very good vugular porosity, alternating course/ fine grain, slight fenestral look.

TS 4121.9'

Dolomitic oolitic wackestone-packstone: Allochems; ooids 25-35%, intraclasts 5-10%. Orthochems; dolomite 30-35%, micrite and some microspar 30-35%. Ooids; large, peloid/micrite cored, radially fibrous concentric laminations. Intraclasts; small, indistinct. Dolomite; replacing matrix, associated with fenestrae and pressure solution. Porosity; medium-large nonselective vugular 10-15%, intercrystalline 1-tr. Sharp contact between small well sorted ooids and large poorly sorted ooids. Dolomitization apparently after vug development.

4122.6-4123

Wackestone: lt.gray brown, ooids, pisoids, spar lining some porosity, good vugular porosity, alternating course/fine grain.

4123-4123.2

Wackestone and stylolite seam: lt.gray brown, ooids, pisoids, spar lining some porosity, good vugular porosity, pervasive type II stylolite seam.

4123.2-4123.6

Dolomudstone: lt.gray, minor intercrystalline porosity, patterned.

4123.6-4123.8

Dolomitic wackestone-mudstone: lt.gray brown, intraclasts (mudchips), fair vugular porosity, intraclasts between underlying mudstone laminations or crusts, and overlying dolomudstone.

TS 4123.6'

Dolomitic intraclastic oolitic packstone-wackestone: Allochems; intraclasts 45-50%, ooids 5-10%, peloids 5-10. Orthochems; dolomite 25-35%, micrite 10-15%. Intraclasts; small-large, micritic-peloidal, round-irregular. Ooids; small, subround, radially fibrous, micrite cored. Peloids; small, micritic. Dolomite; replacing matrix and isolated grains, associated with pressure solution. Micrite; matrix and fine grain laminations.

Porosity; small vugs 1-3%, intercrystalline tr. Weakly laminated in fine grain areas, type II stylolites, pressure solution on grain margins.

4123.8-4125

Wackestone-packstone: lt.brown, ooids, intraclasts, anhydrite filling fractures and primary porosity, good vugular and interparticle porosity, alternating grain rich/poor, possible reverse grading.

4125-4126.3

Interbedded wackstone-packstone and mudstone: lt.gray brown, ooids, intraclasts, pisoids, good vugular and interparticle porosity, type II stylolites.

4126.3-4127.5

Wackestone-packstone: lt.gray brown, intraclasts, ooids, poorly sorted, blocky spar lining pores, good vugular and moldic porosity, alternating grain rich/poor.

4127.5-4128.2

Wackestone-packstone: lt.gray brown, ooids, pisoids, blocky spar lining porosity, good-very good vugular and moldic porosity, layered fine grain laminations alternating with grain rich layers, type II stylolites.

TS 4127.6'

Pisolitic peloidal packstone: Allochems; pisoids 35-45%, peloids 30-35%, fossils tr.-1%. Orthochems; micrite 20-25%, spar 5-8%, dolomite 2-4%. Pisoids; large, many cemented/coated together, grapestone, possibly formed in place. Fossils; pseudopunctae brachiopod 30%, gastropod 30%, calcispheres 40%. Spar; fibrous isopachous lining former vugs, blocky filling most recent vugs. Dolomite; associated with pressure solution and isolated grain replacement. Porosity; small-large vugs 8-12%, intraparticle 2-3%. Type I stylolites, pressure solution on some grains.

4128.2-4131

Wackestone-packstone: lt.gray brown, pisoids, ooids, peloids, anhydrite filling fractures and some porosity, blocky spar lining porosity, good vugular and intercrystalline porosity, type I stylolite, alternating course/fine grain.

TS 4128.2'

Peloidal pisolitic grainstone-packstone: Allochems; peloids 30-40%, pisoids 25-35%, fossils tr.-1%. Orthochems; micrite 10-15%, anhydrite 5-10%, spar 2-4%, dolomite 1-2%. Pisoids; large ooid-small pisoid size, both radially fibrous and micritic laminae. Fossils; calcispheres 80%, unID replaced by single spar crystal 20%. Micrite; matrix. Anhydrite; filling vertical fractures and vugs, after stylolites. Spar; blocky, filling small vertical fractures and vugs. Dolomite; associated with stylolites. Porosity; medium vugular 5-8%, interparticle 2-3%, stylolitic 1-2%. Type I and II stylolites. Vertical fractures end at stylolites.

TS 4129'

Coated grain peloidal packstone: Allochems; coated grains 40-50%, peloids 25-30%, intraclasts 5-10%, fossils tr. Orthochems; micrite and some microspar 5-15%, spar 5-10%. Coated grains; ooid-pisoid size, micritic laminations, possible oncoids. Peloids; small, matrix. Intraclasts; large-small, micritic.

Fossils; calcispheres 100%. Micrite; matrix. Spar; blocky, filling-lining vugs and fenestrae. Porosity; small-medium vugs and fenestrae 8-12%. Fenestral looking locally.

NDGS# 6743
Depth Description

4090-4092
Dolomitic wackestone-packstone: lt.gray-brown, peloids, anhydrite filling vugs and vertical fractures, good small-medium vugs and intercrystalline porosity, Alternating grain rich/poor, thin crusts or laminations, possible algal remnants, heavy oil stain.

4092-4093.2
Wackestone-packstone: med.brown, small ooids, peloids, intraclasts, anhydrite filling some porosity, good vugular and intercrystalline porosity, type II stylolites, possible erosion surface, algal looking, oil stained.

TS 4092'
Calcitic dolopackstone-wackestone: Allochems; ooids or peloids 15-25%, fossils tr. Orthochems; dolomite 55-65%, microspar, micrite and some pseudospar 5-10%, anhydrite 5-8%. Grains; small ooid-peloid size, dolomitized, some radially fibrous. Fossils; calcispheres 100%. Dolomite; matrix, associated fenestrae and laminations. Microspar and micrite; lumps or lenses associated with laminations. Anhydrite; blocky, filling vugs and fenestrae. Porosity; fenestral and vugular 2-4%, intercrystalline 2-3%. Sharp contact between grain rich and laminated zones. Type II stylolites.

4093.2-4094.7
Wackestone-packstone: med.-lt.brown, intraclasts, peloids, some ooids, anhydrite filling some fenestrae, very good fenestral porosity, oil stained.

4094.7-4095.3
Dolowackestone-packstone: med.brown, intraclasts, peloids, anhydrite filling fenestrae or vugs, good small vugular and intercrystalline porosity, slight brecciated look, type II stylolites, oil stained.

4095.3-4095.9
Grainstone-wackestone: lt.brown, small intraclasts, peloids, fair small vugular and intercrystalline porosity, type II stylolites, pressure solution on grains.

4095.9-4096.5
Dolomitic wackestone-packstone: lt.brown-lt.gray, small intraclasts, peloids, (grains recrystallized), anhydrite filling some vugs, pyritic, good medium-large vugular porosity, slight fenestral look, alternating grain rich/poor.

4096.5-4097.8
Dolomudstone-packstone: lt.brown-lt.gray, intraclasts (rip-up clasts), peloids, anhydrite filling some vugs, fair-good vugular, intercrystalline and interparticle porosity, thin bedded, brecciated or ripped up looking, possible algal fragments.

TS 4096.5'
Interbedded silty dolomudstone and dolopackstone-grainstone:

Allochems; intraclasts 30-35%, silt tr. Orthochems; dolomite 60-65%, anhydrite 1-2%. Intraclasts; dolomudstone, rip-up clasts, some rounded, dumped. Silt; quartz. Dolomite; fine grain, thin beds, some course grains lining porosity. Anhydrite; filling some porosity. Porosity; interparticle 5-7%, fenestrae and vugs 2-3%. Fine grain layers interbedded with rip-up clasts.

4097.8-4098.5

Packstone-wackestone: med.brown-lt.gray brown, small ooids, intraclasts, poorly sorted, anhydrite filling some vugs, good-very good vugular and interparticle porosity, type I and II stylolites, alternating grain rich/poor.

4098.5-4099.2

Wackestone-packstone: lt.brown, peloids, small intraclasts, fair small-medium vugular porosity, thin nonparallel laminations, possibly algal.

4099.2-4100

Dolomudstone: lt.gray, fair small vugular porosity, mottled looking.

4100-4100.3

Dolomudstone-packstone: lt.gray-lt.brown, small intraclasts, fair vugular porosity, thinly laminated, alternating fine grain/course angular grains, laminations dipping 10 degrees, algal looking.

4100.3-4102.2

Packstone-wackestone: lt.brown gray, small intraclasts, peloids, anhydrite filling vugs locally, good fenestral and vugular porosity, type I and II stylolites, laminated, alternating grain rich/poor, fenestral looking.

TS 4100.5'

Dolomitic intraclastic packstone-wackestone: Allochems; intraclasts 45-50%, peloids 20-30%, ooids 2-5%, fossils 2-5. Orthochems; micrite and some microspar 10-20%, dolomite 5-8%, anhydrite 2-3%. Intraclasts; micritic-peloidal, small-medium, round. Peloids; matrix, micritic. Ooids; micritic cored, radially fibrous. Fossils; calcispheres, bored or algal clast, unID. Dolomite; scattered throughout and associated with stylolites. Anhydrite; associated only with type I stylolites. Porosity; fenestral or stylolitic 2-4%, vertical fracture 1-2%, vugular 1-2%. Type I and II stylolites.

4102.2-4103

Dolomitic packstone-mudstone: lt.-med.gray, peloids, pyritic, fair intercrystalline porosity, alternating grain rich/poor, patterned locally, type II stylolites.

TS 4102.2'

Calcitic intraclastic dolowackestone-packstone: Allochems; intraclasts 20-30%, peloids 10-15%, ooids 2-4%, fossils tr.-1%. Orthochems; dolomite 50-60%, microspar 2-4%. Intraclasts; small, round, micritic-dolomite. Peloids; small, micritic-dolomite. Ooids; radially fibrous, ghosts, dolomite. Fossils; bivalve fragment, possible algal fragments. Microspar and dolomite; matrix. Porosity; moldic 2-3%, intercrystalline 1%. Massive looking.

4103-4104.5

Packstone: lt.brown, peloids, some ooids, poorly sorted, isolated anhydrite replacing grains and matrix, fair interparticle and small vugular porosity, fairly massive, some thin laminations or crusts.

TS 4103'

Interlaminated peloidal/intraclastic packstone-grainstone, possible boundstone: Allochems; peloids 60-65%, intraclasts 8-12%, fossils 2-4%. Orthochems; micrite 15-20%, dolomite 2-4%, spar 1-2%. Intraclasts; round-subround, peloidal-micritic. Fossils; calcispheres 80%, ostracods 10%, stromatolite 5-10%, unID 5%. Micrite; matrix. Dolomite; scattered and associated with pressure solution. Spar; filling intraparticle porosity. Porosity; enlarged interparticle 2-3%. Thinly laminated, some graded, probable algal laminations.

4104.5-4106.5

Packstone-wackestone: lt.-med.brown, peloids, intraclasts, some ooids, isolated anhydrite filled vugs, good small vugular, stylolitic and interparticle porosity, fairly massive, type II stylolites.

4106.5-4107.5

Grainstone-packstone: lt.gray brown, ooids, small pisoids, anhydrite replacing matrix or filling interparticle porosity, fair small vugular porosity, pressure solution on grains.

TS 4107.3'

Oolitic/pisolitic packstone: Allochems; coated grains 45-55%, peloids 25-30%. Orthochems; anhydrite 20-25%, dolomite 2-4%. Coated grains; large ooid-small pisoid size, radially fibrous concentric laminations, many broken and recoated. Peloids; matrix, some possibly replacing coated grains. Anhydrite; filling porosity and replacing adjacent limestone, incorporating dolomite crystals, some vugs filled with single large crystals, others filled with small blocky crystals. Dolomite; associated with pressure solution, lining nearly all anhydrite filled vugs. Porosity; small vugs 2-3%. Some pressure solution.

4107.5-4110.8

Grainstone-packstone: lt.-med.brown, peloids, small intraclasts, some ooid rich zones, anhydrite replacing grains and matrix and filling some porosity, good interparticle and vugular porosity, fairly massive, some thin laminations or crusts, calcispheres.

4110.8-4111.8

Packstone-grainstone: lt.gray brown, peloids, intraclasts, calcispheres, fair-good small vug and moldic porosity, type II and some type I stylolites, fairly massive, pressure solution on grains.

4111.8-4112.3

Packstone: lt.brown, peloids, calcispheres, algae, intraclasts, spar lining vugs, fair vugular porosity, type II stylolites, pressure solution.

TS 4112.1'

Peloidal fossiliferous packstone-boundstone: Allochems; peloids 35-45%, fossils 30-35%, intraclasts tr. Orthochems; micrite 10-15%, spar 5-10%, dolomite 4-6%. Peloids; small, micritic. Fossils; tubular algae Girvanella, 80%, calcispheres 15%, bivalve or ostracod 5%. Spar; blocky, partially filling vugs and intraparticle porosity. Dolomite; course, associated with porosity and stylolites. Porosity; small-medium vugular 3-6%, intraparticle 1-3%. Pseudo intraclasts formed by pressure solution and type II stylolites.

4112.3-4113

Packstone-wackestone: lt.brown, peloids, calcispheres, algal mats/balls, pseudo intraclasts, blocky spar vug lining, fair vugular and fenestral porosity, dessication cracks, type II stylolites, pressure solution on grains.

4113-4114.5

Wackestone-packstone: lt.brown, ooids, peloids, calcispheres, possible oncoids, blocky spar lining and filling vugs, fair vugular porosity, alternating course/fine grain, fenestral looking, some thin laminations or crusts.

4114.5-4116

Grainstone-packstone: lt.brown, ooids, peloids, large intraclasts, blocky spar lining and filling vugs and fenestrae, fair small vugular porosity, slight fenestral look, calcispheres.

4116-4116.8

Wackestone-packstone: lt.gray brown, ooids, peloids, blocky spar lining and filling vugs, some anhydrite replacing matrix and grains, good vugular and intercrystalline porosity, type I and II stylolites, pressure solution on grains.

4116.8-4118

Grainstone-packstone: lt.gray brown-lt.gray, ooids, small peloids, blocky spar lining and filling vugs, some anhydrite replacing grains and matrix, good interparticle and vugular porosity, type II stylolites, thin fine grain laminations or crusts.

TS 4117.5'

Dolomitic oolitic grainstone-packstone: Allochems; ooids 70-80%, intraclasts 5-10%, peloids 5-10%. Orthochems; dolomite 5-10%, microspar and micrite 2-5%, spar 1-2%. Ooids; small, well sorted, concentric laminations, some dolomitized. Dolomite; associated with porosity and grain boundaries. Microspar; matrix. Spar; blocky, in vugs. Porosity; nonselective medium vugs 5-6%, interparticle 3-5%.

4118-4119.5

Packstone-wackestone: lt.gray brown, ooids, peloids, intraclasts, blocky spar lining and filling vugs, pyritic, fair vugular and stylolitic porosity, type II stylolites, pressure solution on grains.

4119.5-4120.5

Dolomitic packstone-wackestone: lt.brown-lt.gray brown, peloids, small intraclasts, anhydrite filling some fenestrae, good fenestral and vugular porosity, fenestral looking, some thin laminations.

4120.5-4122

Dolomitic wackestone-packstone: lt.gray brown, peloids, small intraclasts, isolated ooids, blocky spar lining some vugs, anhydrite filling vugs in more dolomitic areas, fair-very good vugular and stylolitic or fenestral porosity, alternating grain rich/poor, compacted fenestrae or type II stylolites.

4122-4123.5

Dolomitic wackestone-packstone: lt.gray brown, peloids, small intraclasts, isolated ooids, very good intercrystalline and vugular porosity, fenestral looking, microstylolite swarms.

TS 4123'

Dolomitic intraclastic peloidal packstone-wackestone: Allochems; intraclasts 25-35%, peloids 25- 35%, silt 1-3%. Orthochems; dolomite 15-20%, micrite and some microspar 15-20%, spar tr. Intraclasts; small, subround, micritic-slightly dolomitized. Silt; quartz, scattered throughout. Dolomite; matrix, associated with porosity and grain margins. Micrite; matrix. Porosity; enlarged fenestrae and vugs 5-8%.

4123.5-4124

Wackestone-mudstone: lt.brown, peloids, small intraclasts, isolated anhydrite filling vugs, very good medium vugular porosity, type II stylolites, pressure solution, slight fenestral look.

4124-4125.3

Dolomudstone: lt.gray, isolated small intraclasts, good intercrystalline and small vugular porosity, patterned, some laminations, possible algal.

TS 4124.7'

Calcitic dolopackstone-wackestone: Allochems; intraclasts? 30-35%, peloids?25-30%. Orthochems; dolomite 30-40%, micrite matrix. Intraclasts and peloids; dolomitized ghosts and molds. Dolomite; fine grain matrix, some course grain (replacement). Micrite; matrix. Porosity; moldic 5%, intercrystalline 1-3%. Weakly laminated, dark fine grain laminations (possibly algal).

4125.3-4126

Dolomitic packstone-grainstone: brown-lt.brown, peloids, intraclasts, isolated ooids, very good moldic and small vugular porosity, many thin dolomitic laminations, type II stylolites in less dolomitic areas.

TS 4125.3'

Interbedded laminated dolowackestone and dolomitic intraclastic packstone: Allochems; intraclasts 10-15%, peloids 10-15%, ooids 5%. Orthochems; dolomite 65-75%, opaques 1-2%, spar tr. Intraclasts; small, micritic, dolomitized margins. Peloids; small, micritic, partially dolomitized. Ooids; small, radially fibrous concentric laminations. Dolomite; 1/2 of sample totally dolostone, matrix in the other 1/2. Opaques; scattered-concentrated, dark. Porosity; moldic 2-5%, intercrystalline, small vugular and interparticle all 1-2%. Sharp contact between totally dolostone and partially dolostone.

4126-4129

Wackestone-packstone: tan, peloids, small-medium intraclasts, ooids, spar filling some vugs, good small nonselective vugular, stylolitic and intercrystalline porosity, type II stylolites.

NDGS# 6792

Depth Description

4036-4036.3

Dolomudstone and nodular anhydrite: lt.gray, small anhydrite nodules, some flattened, minor intercrystalline porosity, wispy laminations.

4036.3-4037.3

Anhydrite sandstone: med.-dk.gray, anhydrite grains, medium-fine sand size, well sorted, some anhydrite nodules, minor porosity, dolomudstone matrix.

4037.3-4040

Dolomudstone: lt.gray, some anhydrite grains, fair intercrystalline porosity, massive-thinly laminated, some weak cross-bedding, slight patterned look in places, steeply dipping thin peloid lamination with microstylolite at base.

4040-4040.5

Argillaceous dolomudstone: lt.gray-lt.green gray, fair intercrystalline and fracture porosity, thinly laminated, distorted, similar to core from well #2464.

4040.5-4043

Dolomudstone-wackestone: lt.gray-lt.brown gray, peloids, isolated small intraclasts, isolated anhydrite filling fractures and interparticle porosity, fair intercrystalline porosity, massive-weakly laminated.

4043-4045

Dolomudstone-wackestone: lt.gray-lt.brown gray, sulphate grains, brecciated dolomudstone intraclasts, anhydrite nodules, some with upward growth, anhydrite filling fractures, minor intercrystalline porosity, some argillaceous laminations or wispy microstylolites.

TS 4044'

Argillaceous dolomudstone and celestite: Allochems; clays ?%. Orthochems; dolomite 55-65%, celestite 35-45%. Dolomite; argillaceous, fine-medium crystals. Celestite; occurring in patches as well as slightly enterolithic or fenestrae fill. Porosity; horizontal fractures 1-2%. Weakly laminated.

4045-4047

Dolomudstone: lt.gray, fair intercrystalline porosity, some weak laminations.

4047-4049.5

Calcitic dolopackstone-wackestone: lt.brown-lt.gray brown, recrystallized peloids, intraclasts, and possible ooids, anhydrite filling vugs, pyrite lining some vugs, fair intercrystalline, moldic, and small vugular porosity, weakly laminated, stylolite seam, oil stained.

4049.5-4052

Dolowackestone-packstone: med.brown-lt.gray, peloids, intraclasts (most recrystallized or molds), anhydrite filling molds and vugs, good moldic and intercrystalline porosity, locally thin laminations, possible erosional surfaces, type II stylolites, oil stained.

TS 4049.5'

Interbedded dolomudstone and dolowackestone: Allochems; peloids 20-30%, intraclasts 2-5%. Orthochems; dolomite 60-65%, anhydrite and some celestite 5-10%. Peloids; dolomitized, most ghosts or molds. Intraclasts; pseudo?, formed by dissolution of fine grain laminations or brecciation of the same. Dolomite; matrix, laminations. Anhydrite and celestite; filling vugs and some molds. Porosity; small vugs or molds 3-5%, intercrystalline 1-2%. Some thin, dark residue laminations, possible stylolites or algal laminations. Some celestite filled vugs lined with dark residue.

4052-4052.3

Silicified packstone: med.yellow brown, intraclasts, silicified, some thin laminations.

TS 4052'

Interbedded silicified intraclastic packstone and thinly laminated calcitic dolomudstone: Allochems; intraclasts 45-55%. Orthochems; dolomite 30-35%, microspar 10-15%, anhydrite 5-10%, fluorite 5%, quartz 2-5%. Intraclasts; small-medium, round-subround, tight packed, silicified. Dolomite; associated with type II stylolites. Microspar; matrix. Anhydrite; blocky, with inclusions, in stylolitic zone. Fluorite; cube shaped, scattered, occurring within carbonates and silicified zone. Quartz; lining vugs. Porosity; small vugular 1-3%, horizontal cracks and intercrystalline 2-4%. Sharp break between siliceous and nonsiliceous zone, some grains half silicified.

4052.3-4053.2

Wackestone-packstone: med.brown, intraclasts, peloids, fair intercrystalline porosity, weakly laminated, oil stained.

4053.2-4053.5

Anhydrite sandstone: med.gray, fine-medium sand size grains or crystals, dolomudstone matrix.

4053.5-4056

Packstone-wackestone: lt.gray brown, peloids, intraclasts, anhydrite filling vugs and interparticle porosity, brown anhydrite replacing carbonates, fair intercrystalline and small vugular porosity, weakly laminated, alternating course/fine grain, type II and isolated type I stylolites, oil stained.

4056-4056.8

Grainstone-packstone: lt.brown, ooids, small pisoids, poorly sorted, blocky spar lining and filling vugs, minor small vugular porosity, thinly laminated alternating fine/course grains.

4056.8-4059

Wackestone-packstone: lt.brown, intraclasts, possible oncoids, ostracods, blocky spar lining and filling vugs, brown anhydrite replacing carbonates, minor intercrystalline and small vugular porosity, type II stylolites, pressure solution on grains.

TS 4056.8'

Interbedded oolitic grainstone and peloidal intraclastic fossiliferous packstone: Allochems; ooids 30-35%, peloids 20-30%, intraclasts or possible oncoids 10-15%, fossils 3-5%. Orthochems; micrite 15-20%, dolomite 5%, spar 5%. Ooids; small, radially fibrous concentric laminations, compacted, some dolomitized. Peloids; vague, matrix. Fossils; calcispheres and possible mollusc. Micrite; matrix. Dolomite; associated with stylolites. Spar; isopachous, fibrous-bladed mosaic. Porosity; interparticle 2-3%, intraparticle 1%. Type II stylolites, thin radially fibrous horizontal crusts.

4059-4060.5

Nodular-massive anhydrite and dolowackestone: med. gray-med.brown, peloids, small intraclasts, anhydrite nodules, very minor intercrystalline porosity.

4060.5-4061

Calcitic dolomudstone-wackestone: lt.gray-lt.brown gray, peloids, small intraclasts, locally, pyritic, anhydrite filling vugs, fair small vugular and intercrystalline porosity, slight patterned look.

4061-4062
Mudstone-wackestone: lt.brown, possible peloids, minor intercrystalline porosity, type II stylolites, weak laminations.

4062-4063.5
Wackestone-packstone: lt.brown, peloids, small intraclasts, anhydrite filling vugs and interparticle porosity, fair vugular and intercrystalline porosity, type II stylolites, weakly laminated, some thin laminations or crusts.

4063.5-4069
Dolomudstone-wackestone: lt.-med.gray, peloids, small intraclasts locally, good intercrystalline and small vugular porosity, weak laminations, slight patterned look.

4069-4070.5
Wackestone-packstone: lt.brown-lt.gray brown, intraclasts, peloids, anhydrite filling vugs and replacing carbonates locally, fair small vugular, stylolitic and intercrystalline porosity, alternating course/fine grain, type I and II stylolites.

NDGS# 6803
Depth Description

4088.5-4088.7
Silty dolomudstone: lt.-med.gray, very fine sand-silt size grains, some grains or crystals are sulphate, anhydrite nodule with pyrite on lower margin, minor-no intercrystalline porosity, mottled with distorted thin sand rich laminations.

TS 4088.5'
Nodular anhydrite and selenitic dolomudstone: Allochems; quartz silt tr. Orthochems; dolomite 35-45%, anhydrite 25-35%, selenitic gypsum? (replaced with celestite) 20-25%, pyrite 1-2%. Quartz silt; scattered. Dolomite; argillaceous, fine grain. Anhydrite; nodules, subfelted. Selenitic gypsum; celestite, euhedral crystals, within dolomudstone, some anhydrite. Pyrite; located at lower edge of anhydrite nodules with inclusions of both anhydrite and gypsum. Porosity; no visible.

4088.7-4089.5
Dolowackestone-packstone: lt.-med.brown, ooid size grains, recrystallized, possible oncoids, anhydrite filling porosity, minor intercrystalline and moldic porosity, alternating grain rich/oncoid rich laminations 1-5 cm thick.

4089.5-4091.8
Dolomudstone: lt.brown-lt.gray, minor vugular porosity, mottled, some thin laminations containing oncoids/mudchips, thin clay seam, oil stained.

TS 4089.5'
Thinly interbedded dolopackstone-grainstone and dolomudstone: Allochems; peloids 40-45%, intraclasts 30-35%. Orthochems; fine dolomite 10-15%, course dolomite 5-10%, anhydrite 5%, pyrite 2-3%. Peloids; small, dolomitized. Intraclasts; small-medium, dolomitized, some compacted. Fine dolomite; possibly argillaceous, laminated, horizontal and vertical fractures.

Course dolomite; matrix, course. Anhydrite; filling some molds, possible fenestrae and cracks. Pyrite; replacing grains. Porosity; moldic and small vugular porosity 1-3%. Possible algal laminated zone within packstone.

4091.8-4092.3

Dolomudstone and sulphate crystals: lt.-med.gray, sand size sulphate crystals, minor vugular porosity.

TS 4091.8'

Dolomudstone and gypsum crystals: Allochems; quartz silt tr. Orthochems; dolomite 55-65%, celestite 35-45%. Dolomite; fine grain, dark, some course zoned crystals. Celestite; after selenite?, euhedral crystals, locally concentrated, within dolomudstone. Porosity; <1% visible intercrystalline.

4092.3-4093

Calcitic dolopackstone-wackestone: lt.gray brown-black, oncoids, recrystallized ooid sized grains, fair moldic and intercrystalline porosity, clay seams, type II stylolite seam, grain rich laminations, possible algal laminations.

TS 4092.3'

Algal doloboundstone: Orthochems; dolomite 80-85%, microspar and some micrite 10-12%, algae 5-10%, opaques tr. Dolomite; fine/dark, course/light. Microspar; remnants of laminations or compacted grains. Algae; dark residue of stromatolites. Opaques; dark, associated with algal laminations. Porosity; fenestrae 2-4%, intercrystalline 2-4%. Wavy dark laminations, many associated with type II stylolites.

4093-4094.5

Mudstone-packstone: lt.gray brown, peloids, intraclasts, anhydrite filling some vugs, fair-good vugular porosity, type II stylolites, pressure solution on grains, oil stained.

4094.5-4095.2

Wackestone-packstone locally dolostone: intraclasts, anhydrite filling vugs, blocky spar lining vugs, good vugular and intercrystalline porosity, type II stylolites and pressure solution on grains.

TS 4094.5'

Intraclastic grainstone-packstone: Allochems; intraclasts 60-70%. Orthochems; microspar and some micrite 10-20%, sulphates 10-15%, dolomite 5%. Intraclasts; very large-small, subround, poorly sorted, all similar composition, fine grain microspar, some spherulites. Microspar; weak spherulitic look, matrix. Sulphates, celestite and possibly some gypsum, after anhydrite, filling vugs and interparticle porosity, replacing adjacent carbonates. Dolomite; course, associated with grain margins. Porosity; 2-3% small vugular, 1-2% interparticle. Looks brecciated except for rounded nature of grains.

4095.2-4096.2

Packstone-wackestone: lt.-med.gray brown, ooids, scattered intraclasts, anhydrite filling vugs, blocky spar lining vugs, fair-good vugular porosity, some type II stylolites, fine grain fenestral looking laminations between ooid rich layers.

4096.2-4097

Wackestone-mudstone: lt.gray brown, intraclasts, peloids, anhydrite filling vugs and fenestrae, fair vugular and fenestral porosity, type II stylolites, oil stained.

4097-4098

Dolomitic wackestone-mudstone: med.green yellow brown, intraclasts, peloids, anhydrite filling vugs, fair vugular and intercrystalline porosity, sugary (crystalline) looking.

4098-4098.4

Dolomitic packstone-wackestone: lt.green yellow brown, intraclasts, ooids, anhydrite filling vugs, good-very good vugular, intercrystalline and fenestral porosity, oil stained.

TS 4098'

Calcitic intraclastic dolopackstone: Allochems; intraclasts 55-65%. Orthochems; dolomite 25-35%, anhydrite 5-15%. Intraclasts; medium, some weakly laminated, nearly all dolomite. Dolomite; matrix, course, lining porosity and anhydrite filled vugs. Anhydrite; filling enlarged fenestrae and some molds, some single crystal, some multiple. Porosity; small vugular 2-4%, moldic 2-4%, small fenestrae 1-2%. Possible weak crusts. Heavy oil stain.

4098.4-4099.5

Wackestone-mudstone: lt.gray brown, intraclasts, minor small vugular and intercrystalline porosity, type II stylolites.

4099.5-4101.4

Dolowackestone-mudstone: lt.gray-lt.gray brown, intraclasts, anhydrite filling vugs and shelter porosity, fair vugular porosity, shelter formed by mud chip or algal crust, locally algal looking, vertical fracture anhydrite filled, oil stained.

TS 4099.5'

Intraclastic dolomudstone-wackestone: Allochems; intraclasts, 5-10%. Orthochems; dolomite 65-75%, sulphates 15-25%. Intraclasts; small, ghosts, dolomitized. Dolomite; most dark and fine grain, course, light crystals lining anhydrite filled porosity. Sulphates; mostly celestite with some anhydrite, filling large vugs, enlarged fenestrae, vertical fractures. Porosity; small-large vugular 4-6%, moldic 2-4%. Present porosity formed after sulphates filled vugs. Some weak dark/light laminations. Heavy oil stain.

4101.4-4101.6

Dolomitic mudstone: lt.gray brown, fair vugular porosity, type II stylolites.

4101.6-4103

Dolomudstone: lt.-med.gray, anhydrite locally filling vugs and vertical fractures, fair-good vugular and fracture porosity, locally patterned.

4103-4103.6

Mudstone: lt.brown, some grain ghosts, minor vugular and intercrystalline porosity, wispy type II stylolites, vertical fracture anhydrite filled.

4103.6-4105.3

Wackestone-packstone: lt.gray brown, peloids, intraclasts, broken pisoids, anhydrite filling vugs and fenestrae, fair-good vugular and intercrystalline porosity, alternating grain rich/fine grain laminations (storm deposit?), type II stylolites, slight fenestral look.

4105.3-4105.4

Wackestone-mudstone: lt.-med.brown, isolated intraclasts, peloids, anhydrite filling vugular and fenestral porosity, fair vugular and intercrystalline porosity.

4105.4-4106.3

Dolowackestone-mudstone: lt.gray brown, isolated peloids, anhydrite filling vugs and fenestrae, fair vugular porosity.

4106.3-4106.5

Wackestone-mudstone: lt.brown, ooids, pisoids, intraclasts, fair small vugular porosity, thin fine grain lamination or crust.

4106.5-4106.6

Dolomudstone: lt.gray, fair small vugular porosity, patterned looking.

4106.6-4107

Packstone-wackestone: lt.gray brown, ooids, intraclasts, pisoids, some anhydrite filling porosity, fair-good vugular and moldic porosity, alternating grain rich/dense fine grain layers (storm deposits?).

4107-4108.3

Dolomudstone-wackestone: lt.gray, isolated recrystallized grains, pyritic, patterned, type II stylolitic seam, wide vertical fracture, anhydrite filled.

4108.3-4110.3

Wackestone-packstone: lt.brown, ooids, pisoids, intraclasts, anhydrite filling fractures, minor-fair vugular and intercrystalline porosity, fine grain laminations or crusts alternating with grain rich layers.

TS 4108.3'

Dolowackestone-packstone grading into intraclastic wackestone: Allochems; intraclasts 35-45%, ooids 2-5%, fossils tr. Orthochems; dolomite 30-35%, micrite and some microspar 20-25%, anhydrite tr., opaques tr. Intraclasts; large-small, micritic, dolomitized in half of slide, some weakly laminated with 1-3 radially fibrous laminations. Ooids; weakly laminated, partially dolomitized. Fossils; ostracod 100%, crushed. Dolomite; matrix, associated with stylolites and pressure solution. Micrite; matrix. Anhydrite; filling vertical fractures. Opaques; dark, locally concentrated. Porosity; vertical and horizontal fractures 2-3%, moldic/vugular 2-3%, intercrystalline 1-3%. Pressure solution and type II stylolites. Gradational boundary between dolomitized and nondolomitized zones. Oil stained.

TS 4109.2'

Intraclastic peloidal packstone-grainstone: Allochems; intraclasts 40-45%, peloids 20-25%, fossils tr.-1%. Orthochems; anhydrite 15-20%, microspar and some micrite 5-10%, dolomite 5%, spar 2-4%. Intraclasts; micritic, small, some weak laminations (oncoids?). Fossils; calcispheres(some spiney) 40%, unID 40%, pseudopunctate brachiopod 20%. Anhydrite; filling vertical fractures and replacing adjacent carbonates. Microspar; matrix. Dolomite; course, scattered throughout. Spar; blocky, lining vugs, filling interparticle porosity. Porosity; small nonselective vugular 8-10%, vertical fracture 1-2%. Weakly laminated, oil stained.

4110.3-4110.9

Mudstone: lt.gray brown, minor vugular porosity, wispy type II stylolites or organic stringers, some thin grain rich laminations.

4110.9-4112

Mudstone-packstone: lt.gray brown, ooids, pisoids, intraclasts, anhydrite filling fractures, fair vugular and moldic porosity, alternating grain rich/poor thin beds, type II stylolites.

4112-4112.9

Grainstone: ooids, small intraclasts, anhydrite filling porosity and fractures, minor-very good interparticle and vugular porosity, reverse grading, fractured thin laminations or crusts.

TS 4112'

Oolitic peloidal grainstone: Allochems; ooids 50-60%, peloids 25-35%. Orthochems; anhydrite 15-20%, spar 3-5%, micrite 2-3%. Ooids; radially fibrous concentric laminations, large-small. Peloids; all shapes, micrite, matrix. Anhydrite; locally replacing peloid matrix and ooid margins, including or replacing spar. Spar; blocky, some bladed mosaic, filling vugs. Micrite; matrix. Porosity; small-medium vugular 2-4%, interparticle 1-3%. Thin bedded alternating good/poor sorting. Oil stained.

4112.9-4115.9

Wackestone-grainstone: lt.gray brown, ooids, small intraclasts, anhydrite filling vugs, interparticle porosity and fractures, blocky spar filling vugs, good vugular and interparticle porosity, alternating course/fine grain laminations, some reverse grading.

TS 4112.9'

Peloidal oolitic intraclastic packstone: Allochems; peloids 30-35%, ooids 20-25%, intraclasts 10-15%. Orthochems; anhydrite 15-25%, microspar and some micrite 10-15%, spar 1-3%, dolomite 1-2%. Peloids; small, micritic, matrix. Ooids; micrite/peloid cored, concentric radially fibrous laminations, many broken, irregular shape. Intraclasts; small-medium, micrite/peloid, subround. Anhydrite; filling large vertical fracture and replacing adjacent carbonates, filling vugs similar and adjacent to spar filled vugs. Microspar; matrix and thin laminations. Spar; blocky, filling and lining small vugs. Dolomite; course, associated with pressure solution and lining anhydrite filled vugs. Porosity; small vugular 2-4%. Some isolated fine grain laminations.

4115.9-4116.2

Wackestone-mudstone: lt.-med.gray brown, ooids, intraclasts, anhydrite filling stylolitic porosity and possible vugs, fair vugular porosity, type II stylolite seam broken up by type I stylolite or fracturing,.

4116.2-4117.4

Wackestone-grainstone: lt.gray brown, ooids, small intraclasts, anhydrite filling vugs, interparticle porosity and fractures, blocky spar filling vugs, good vugular and interparticle porosity, alternating course/fine grain laminations, some reverse grading.

4117.4-4118.3

Mudstone-wackestone: lt.brown, intraclasts, peloids, anhydrite filling porosity, very minor intercrystalline porosity, fine grain rich weak thin beds 2-5cm thick, isolated thin fine grain laminations or crusts, possible dessication cracks, ostracods with both valves, anhydrite filled, weak oil stain.

TS 4118'

Fossiliferous peloidal wackestone-boundstone: Allochems; fossils 10-20%, peloids 20-25%. Orthochems; micrite and some microspar 40-45%, spar 5-10%, dolomite 4-6%, anhydrite 2-4%. Fossils; calcispheres 40%, tubular algae 35%. ostracods 20%, possible dasycladacean algae 5%. Spar; blocky, filling small vugs, fenestrae, stylolitic, and intraparticle porosity. Dolomite; course, lining stylolites and some spar filled vugs. Anhydrite; filling some vugs along with spar. Porosity; small vugular 1-2%. Some type II stylolites, small dendritic patterns.

4118.3-4119.7

Wackestone-packstone: lt.brown, peloids, intraclasts, ooids, anhydrite filling fractures and pores, good interparticle, intercrystalline and vugular porosity, massive.

4119.7-4120

Grainstone-wackestone: lt.gray brown, ooids, peloids, intraclasts, anhydrite filling some interparticle porosity, fair-good interparticle and intercrystalline porosity, reverse graded bedding, type II and I stylolites, oil stained.

4120-4121.8

Wackestone-mudstone: intraclasts, ooids/oncoids?, anhydrite filling vugular and shelter porosity, good-very good vugular porosity, fine grain laminations or crusts, slight fenestral look.

TS 4120'

Dolomitic interbedded oolitic intraclastic grainstone and intraclastic peloidal packstone: Allochems; ooids 30-40%, intraclasts 25-35%, peloids 5-10%. Orthochems; dolomite 10-15%, micrite and some microspar 10-15%, anhydrite 5%, spar 2-4%. Ooids; small, weakly laminated, partially dolomite. Intraclasts; small-medium, partially dolomitized, microspar. Peloids; matrix. Dolomite; course, associated with stylolites and grain boundaries. Micrite; matrix. Anhydrite; filling some vugs, dolomite inclusions. Spar; blocky, filling some interparticle and vugular porosity, dolomite inclusions. Porosity; interparticle 5-7%, fracture and stylolitic 1-2%. Type II stylolite seam with superimposed type I stylolite. Poorly sorted, oil stained.

4121.8-4124.6

Grainstone-packstone: lt.gray brown, very small (0.25 mm) ooids, intraclasts, anhydrite filling some interparticle and vugular porosity, fair vugular porosity, well sorted ooids with isolated thin fine grain or course grain laminations, both normal and reverse grading.

TS 4121.8'

Dolomitic oolitic peloidal grainstone-packstone: Allochems; ooids 40-45%, peloids 25-35%, intraclasts 10-15%. Orthochems; dolomite 10-15%, anhydrite 2-4%, micrite 2-4%. Ooids; small, round, weak laminations, some dolomitized. Peloids; small, well preserved. Intraclasts; small-medium, micrite/peloids, locally concentrated. Dolomite; course, lining grains and filling interparticle porosity. Anhydrite; filling some vugs. Micrite; matrix. Porosity; interparticle 4-6%, small vugular 1-2%, moldic

1-2%. Weakly laminated, alternating good/poor sorting. Oil stained.

NDGS# 6804
Depth Description

4096-4098
Dolowackestone-mudstone: lt.gray brown, peloids, ooids, anhydrite filling interparticle and vugular porosity, pyritic, minor vugular and intercrystalline porosity, alternating grain rich/poor.
4098-4099
Dolomudstone: lt.gray, pyritic, anhydrite grains, minor fracture porosity, thin pyritic laminations.
4099-4099.4
Dolowackestone-packstone: lt.brown-black, ooids (recrystallized), fair intercrystalline, interparticle and moldic porosity, sharp contact with overlying mudstone, thin clay seam, type II stylolites, oil stained.
TS 4099'
Oolitic dolopackstone-wackestone: Allochems; ooids 30-35%, intraclasts 5-10%, quartz silt tr. Orthochems; dolomite 55-65%, opaques 1-2%. Ooids; radially fibrous concentric laminations, dolomitized. Intraclasts; medium, subround, dolomitized. Dolomite; fine grain dark (matrix), light, course lining vugs and filling fenestrae. Opaques; probably pyrite, scattered and concentrated. Porosity; moldic 3-5%, intercrystalline 1-3%, small vugular 1-2%. Very fenestral looking, compacted. Sharp break between packstone and wackestone. Possible crusts.
4099.4-4101.1
Wackestone-mudstone: med.-lt.gray brown, peloids, spar filling stylolitic porosity, fair vugular and intercrystalline porosity, much type II stylolites, oil stained.
TS 4100.3'
Fossiliferous peloidal boundstone-wackestone: Allochems; fossils 35-40%, peloids 25-30%, quartz silt tr. Orthochems; micrite and some microspar 25-30%, dolomite 5-10%, anhydrite 2-4%. Fossils; curled laminar stromatolites 90%, calcispheres 9%, ostracods 1%. Peloids; locally concentrated, matrix. Micrite; matrix. Dolomite; course, associated with stylolites, lining porosity, possible crusts. Anhydrite; blocky, isolated replacement. Porosity; fenestrae 4-6%, vugular 2-3%, stylolitic 1-3%. Type I and II stylolites. Open vugs after stylolites. Oil stained.
4101.1-4102.3
Wackestone: lt.gray brown, peloids, ooids, pisoids, spar filling and lining vugs and stylolites, good vugular, moldic and intercrystalline porosity, type II stylolites.
4102.3-4103
Mudstone-wackestone: lt.gray brown, peloids, intraclasts, spar lining porosity and stylolites, some anhydrite filling larger pores, fair vugular and intercrystalline porosity, alternating grain rich/poor, type II stylolites.
4103-4103.6
Grainstone-wackestone: lt.brown, ooids, intraclasts, anhydrite

filling vugular and interparticle porosity, spar lining porosity, good-very good vugular and interparticle porosity, alternating well sorted ooid grainstone with fine grain laminations or crusts.

TS 4103'

Oolitic grainstone-packstone: Allochems; ooids 55-65%. Orthochems; micrite 10-15%, microspar and some micrite 5-10%, spar 5-10%, dolomite 2-5%, anhydrite 2-5%. Ooids; small-medium, locally well sorted, radially fibrous concentric laminations, most microspar, some dolomitized. Micrite; laminations or crusts. Microspar; matrix. Spar; blocky lining vugs, bladed filling interparticle porosity. Dolomite; matrix. Anhydrite; replacing carbonates locally. Porosity; nonselective small-medium vugular 12-15%, interparticle 2-4%. Micritization along small vertical fractures. Possible pendant cements, vugular porosity above fine grain micritic laminations. Oil stained.

TS 4103.1'

Dolomitic oolitic intraclastic grainstone-packstone: Allochems; ooids 15-25%, intraclasts 25-35%. Orthochems; micrite 30-35%, spar 5-10%, anhydrite 5-10%, dolomite 2-4%. Ooids; round-rod shaped, micritic-radially fibrous laminations, partially dolomitized. Intraclasts; large sheets-round clasts, made of ooids, coated or micritized on margins, poorly sorted. Micrite; massive thin laminations, coatings, pendants, lining fractures. Spar; bladed, intergrown, filling interparticle porosity. Anhydrite; filling fractures and cracks, replacing adjacent carbonates, dolomite inclusions. Dolomite; course, associated with pressure solution. Porosity; small-large nonselective vugular 5-10%. Possible rip-up clasts or teepee structure. Diagonal fracture with 1 mm movement. Some pressure solution. Oil stained.

TS 4103.2'

Dolomitic oolitic grainstone: Allochems; ooids 50-55%. Orthochems; spar 20-25%, anhydrite 8-12%, micrite 5-8%, dolomite 5%. Ooids; rod shaped locally, rest small-medium radially fibrous concentric laminated, moderate sorting, partially dolomitized. Spar; blocky and bladed lining and filling porosity. Micrite; thin laminations, some draping over ooids and separating ooids of different sizes. Anhydrite; localized, replacing grains and filling or replacing spar in adjacent interparticle pores. Dolomite; associated with anhydrite, replacing grain margins. Porosity; medium-large nonselective vugular porosity 5-10%, interparticle 2-4%. Thin bedded, micritic laminations separating different grain sizes. One thin bed heavily dolomitized and replaced by anhydrite, adjacent beds unaffected. Oil stained.

4103.6-4104.3

Wackestone: lt.gray brown, peloids, intraclasts, fair vugular porosity, much pressure solution and type II stylolites.

4104.3-4105

Wackestone-mudstone: lt.gray brown, intraclasts, peloids, ooids, anhydrite filling vugs and fenestrae locally, good-very good vugular and fenestral porosity, alternating grain rich/poor, fenestrae in grain poor.

4105-4105.8

Calcitic dolopackstone-wackestone: med.brown, ooids or peloids (recrystallized), anhydrite filling interparticle and fenestral porosity, fair vugular and intercrystalline porosity, alternating grain rich/poor, thin fine grain laminations or crusts, oil stained.

TS 4105.6'

Intraclastic dolowackestone-packstone: Allochems; intraclasts 25-35%. Orthochems; dolomite 45-55%, anhydrite 15-20%. Intraclasts; dolomitized, many molds, poorly defined, small-medium, round. Dolomite; matrix and possible grains. Anhydrite; filling fenestrae, vugs, and possible shelter porosity. Porosity; moldic 10-15%, intercrystalline 1-3%. Slight fenestral look, possible crusts.

4105.8-4107

Mudstone-wackestone: lt.gray brown, peloids or ooids, fair vugular and intercrystalline porosity, patterned-algal laminated looking, type II stylolites.

4107-4108.2

Dolomitic mudstone-wackestone: med.brown, possible ooids (recrystallized), compacted oncoids, anhydrite filling vugs and fenestrae locally, good intercrystalline porosity, alternating grain rich/poor laminations, oil stained.

4108.2-4108.5

Dolomudstone-packstone: med.-lt.gray brown, ooid size grains (molds), good-very good moldic and vugular porosity, thin fine grain laminations or crusts alternating with packstone, oil stained.

TS 4108.2'

Interlaminated dolomudstone and wackestone: Allochems; intraclasts 20-30%. Orthochems; dolomite 70-80%. Intraclasts; small irregular shaped, most molds, some dolomitized. Dolomite; couse/light, fine/dark. Porosity; moldic 10-15%, intercrystalline 2-3%. Dark discontinuous thin laminations (possibly algal), oil stained.

4108.5-4109.5

Dolomudstone: lt.gray, minor vugular and intercrystalline porosity, vertically fractured (open), weak pattern, type II stylolite.

4109.5-4111.5

Dolomitic wackestone: lt.brown, ooids, intraclasts (recrystallized), fair moldic and intercrystalline porosity, alternating grain rich/poor thin beds.

TS 4109.5'

Oolitic dolopackstone-grainstone: Allochems; ooids 65-75%. Orthochems; dolomite 25-35%. Ooids; concentric laminations, possibly radially fibrous, small, some grapestone, all dolomitized. Dolomite; matrix and filling fenestrae (slight enterolithic look). Porosity; moldic 2-3%, small vugular and interparticle 2-3%. Fenestral looking (possibly after stylolitization) in fine grain zones. Oil stained.

4111.5-4112.3

Dolomitic wackestone: lt.gray brown, peloids, ooids, intraclasts, good fenestral and vugular porosity, fenestral looking, thin fine grain laminations or crusts.

TS 4111.5'

Dolomitic/calcitic intraclastic peloidal packstone-wackestone: Allochems; intraclasts and peloids 40-50%. Orthochems; dolomite 35-40%, micrite and some microspar 10-15%. Intraclasts and peloids; small-medium, microspar and micrite, most margins dolomitized, possibly pseudo grains. Dolomite; matrix, course-fine. Micrite; matrix. Porosity; medium-large nonselective vugular 8-12%, intercrystalline 2-4%. Weak distorted laminated look. Oil stained.

4112.3-4113.1

Mudstone: lt.gray brown, isolated peloids, ooids, and intraclasts, siliceous zone, fair vugular porosity, weakly laminated, possible calcispheres.

4113.1-4113.4

Wackestone-packstone: lt.gray brown, very small ooids, anhydrite filling some vugs, fair vugular porosity.

4113.4-4114

Wackestone-packstone: lt.gray brown, pisoids (some broken), fair vugular porosity, type I and II stylolites.

4114-4115.6

Wackestone-packstone: lt.gray brown, peloids, ooids, intraclasts, anhydrite filling some shelter and vugular porosity, fair vugular porosity, alternating grain rich/poor, rip-up clasts and fenestrae locally.

4115.6-4116

Dolomitic packstone-mudstone: lt.gray brown-lt.gray, ooids and intraclasts locally, anhydrite filling vertical fractures, minor-very good interparticle, moldic, and intercrystalline porosity, patterned locally, type II stylolite seam.

TS 4115.8'

Interbedded dolomitic intraclastic oolitic packstone and peloidal fossiliferous mudstone-wackestone: Allochems; intraclasts 20-25%, ooids 10-15%, peloids 5-10%, fossils 2-4%. Orthochems; dolomite 35-45%, micrite 10-15%, anhydrite 4-6%, spar tr. Intraclasts; irregular shape and size, small-large, micritic-dolomitic. Ooids; odd shape, poorly sorted, micritic and radially fibrous laminations. Peloids; vague. Fossils; tubular or oncolitic algae 50%, calcispheres 45%, ostracod 5%. Dolomite; matrix. Micrite; matrix. Anhydrite; filling vertical fracture and replacing adjacent carbonates. Spar; filling intraparticle porosity. Porosity; fracture 5-8%, matrix selective vugular 2-4%, intercrystalline 1-2%. Open vertical and horizontal fractures (oil stained). Sharp break between wackestone and packstone.

4116-4118

Packstone-wackestone: lt.brown, ooids, intraclasts, pisoids, fair vugular and interparticle porosity, alternating grain rich/fine grain thin beds.

4118-4119.8

Mudstone-wackestone: lt.-med.brown, some peloids, fair intercrystalline porosity, pervasive thin dark laminations (possibly algal or type II stylolites).

4119.8-4120.2

Grainstone-wackestone: lt.brown, ooids, pisoids, anhydrite filling interparticle and fenestral porosity, minor vugular porosity, grain rich laminations, fenestrae in fine grain laminations.

TS 4119.8'

Thinly interbedded oolitic peloidal packstone-grainstone: Allochems; peloids 35-45%, ooids 25-35%, fossils tr.-1%. Orthochems; spar 8-12%, anhydrite 5-10%, micrite and some spar 5-10%, dolomite 1-2%. Peloids; small, round-rod shaped, matrix. Ooids; small-large, moderate sorting, radially fibrous concentric laminations, locally dolomitized. Fossils; calcispheres 100%. Spar; blocky, lining and filling vugs. Anhydrite; filling large and small vugs (spar inclusions). Micrite; matrix. Dolomite; course, lining some vugs. Porosity; small nonselective vugular 4-6%. All grains with micritic margins.

4120.2-4120.8

Grainstone-packstone: lt.gray brown, ooids, pisoids, intraclasts, anhydrite filling interparticle porosity, minor vugular porosity.

4120.8-4122

Packstone-wackestone: lt.gray brown, ooids, pisoids, intraclasts, anhydrite filling a large cavity with ooids floating within, fair interparticle and vugular porosity, alternating course/fine grain laminations, possible crusts.

4122-4123.6

Wackestone-packstone: lt.-med.brown, peloids, intraclasts, ooids, anhydrite filling some vugs, spar lining vugs, fair vugular and intercrystalline porosity, alternating course/fine grain laminations.

4123.6-4125.5

Mudstone: lt.gray brown, peloids, minor small vugular porosity, type II stylolites and/or algal laminations.

4125.5-4126

Mudstone-boundstone: lt.gray brown, anhydrite filling vugs or fenestrae, minor intercrystalline and vugular porosity, algal laminations.

TS 4125.5'

Boundstone-fossiliferous wackestone: Allochems; fossils 65-75%, intraclasts 5-10%. Orthochems; spar 10-15%, anhydrite 8-12%, micrite 5-10%, dolomite 5-8%. Fossils; laterally linked stromatolites 90%, calcispheres 9%, ostracods 1%. Intraclasts; micritic, medium, round. Spar; blocky, bladed intergrown, filling small fenestrae and vugs. Anhydrite; filling interconnected vugs or fenestrae. Micrite; matrix. Dolomite; course, associated with stylolites and lining anhydrite filled porosity, margins of blocky spar. Porosity; small vugular 5-8%.

4126-4127

Wackestone-mudstone: lt.gray brown, ooids, intraclasts, anhydrite filling porosity, minor intercrystalline porosity, algal looking, alternating grain rich/poor, ostracods.

<u>NDGS# 6825</u>

<u>Depth Description</u>

4120-4121.5

Quartz sandstone: med.gray, fine-very fine angular quartz sand, anhydrite cement and isolated nodules, fairly massive.

4121.5-4123

Interbedded massive anhydrite and dolomudstone: lt.-med. gray-lt.brown, sulphate grains, peloids, distorted anhydrite and dolomudstone, anhydrite filling fractures, minor intercrystalline porosity, laminated dolomudstone, sharp contact with overlying sandstone.

TS 4122.6'

Laminated silty dolomudstone and nodular anhydrite: Allochems; peloids 5%, silt 2-5%. Orthochems; dolomite 60-70%, anhydrite 20-30%. Peloids; vague, molds. Silt; gypsum or celestite, dolomite (course). Dolomite; fine/course grain laminations. Anhydrite; subfelted nodules, grains or moldic porosity fill. Porosity; 1% visible intercrystalline porosity. Thin parallel laminations, locally distorted.

4123-4124

Argillaceous silty anhydrite: med.-dk.gray, quartz silt, clay, weakly laminated, possible erosional surface.

4124-4124.8

Displacive anhydrite and dolomudstone: med.gray-lt.brown gray, sulphate grains or crystals within dolomudstone, compacted anhydrite nodules or displacive layers, pyritic, very minor intercrystalline porosity.

4124.8-4128.5

Argillaceous dolopackstone-wackestone: lt.brown gray-lt.gray brown, peloids, intraclasts, thin sulphate sandstone, anhydrite filling interparticle porosity, pyritic, minor small vugular porosity, alternating course/fine grain thin beds.

4128.5-4129

Packstone-wackestone: lt.brown-lt.gray brown, intraclasts, peloids, anhydrite filling some vugs, brown replacement anhydrite, minor small vugular and stylolitic porosity, many type II stylolites, possible solution breccia.

4129-4130

Packstone-wackestone: lt.yellow brown, peloids, calcispheres, ostracods, anhydrite filling some vugs, brown replacement anhydrite, fair small vugular porosity, type II stylolites, oil stained.

4130-4133

Packstone-wackestone: lt.brown-lt.gray brown, intraclasts, peloids, anhydrite filling some vugs, blocky spar lining vugs, fair-very good small-medium vugular porosity, type II stylolites, some thin fine grain laminations.

4133-4134.4

Calcitic dolopackstone-wackestone: lt.gray-med.brown, peloids, small intraclasts, anhydrite filling vugs locally and vertical fractures, fair vugular porosity, slight fenestral look, locally laminated zones, oil stained.

4134.4-4135

Dolomitic packstone-wackestone: tan, peloids and small intraclasts (recrystallized), minor intercrystalline and small vugular porosity, type II stylolites, alternating course/fine grain.

4135-4138

Dolopackstone-wackestone: lt.gray-med.brown, peloids, small intraclasts, possible rip-up clasts, anhydrite filling vugs and fenestrae locally, and some vertical fractures, fair-good moldic, small-medium vugular, and intercrystalline porosity, fenestral looking locally, oil stained.

TS 4137.9'

Intraclastic peloidal dolopackstone-wackestone: Allochems; intraclasts 40-50%, peloids 15-20%, ooids 5-10%. Orthochems; anhydrite 15-20%, dolomite 10-20%. Intraclasts; small, dolomitic. Ooids; small, concentric laminations, dolomitized. Anhydrite; filling vugs and vertical cracks. Dolomite; fine grain, matrix. Porosity; nonselective small-large vugular 10-15%, fenestral 2-4%. Massive-slight fenestral looking. possibly argillaceous.

4138-4139.7

Packstone-wackestone: lt.brown-lt.gray brown, ooids, peloids, small pisoids, fair small vugular and interparticle porosity, type II stylolite zones, alternating grain rich/poor thin beds.

TS 4138'

Dolomitic oolitic peloidal packstone: Allochems; ooids 40-50%, peloids 35-45%. Orthochems; dolomite 5-10%, micrite and some microspar 5-10%. Ooids; both radially fibrous concentric laminations and possible tangential, most partially dolomitized, small-medium. Peloids; medium-large, round, lense shaped locally. Dolomite; matrix, course, light. Micrite; matrix. Porosity; nonselective small-medium vugular 4-6%, intercrystalline 1-3%. Locally compacted, locally dolomitized, microstylolites.

4139.7-4140.3

Dolowackestone-packstone: lt.gray-lt.brown, peloids, possible rip-up clasts (recrystallized), anhydrite filling vugs and sheet cracks, fair small vugular and intercrystalline porosity, fairly massive, slight oil stain.

TS 4140.1'

Intraclastic dolowackestone-packstone: Allochems; intraclasts 50-60%, fossils tr. Orthochems; anhydrite 20-30%, dolomite 15-25%. Intraclasts; medium-large, vague margins, some molds, dolomitized. Fossils; stromatolite 100%. Anhydrite; filling enlarged fenestrae and vugs. Dolomite; matrix, fine grain, dark. Porosity; small-medium vugular 3-5%. Slight brecciated look.

4140.3-4141

Packstone-mudstone: lt.gray brown, lt.gray brown, peloids, isolated ooids, minor intercrystalline and small vugular porosity, thinly laminated, alternating grain rich/poor.

4141-4142

Wackestone: lt.brown, peloids, small intraclasts, ooids, anhydrite filling vugs and fenestrae locally, good vugular and fenestral porosity, very fenestral looking, isolated dark laminations.

TS 4141.9'

Dolomitic intraclastic oolitic wackestone-packstone: Allochems; intraclasts 15-20%, ooids 5-10%. Orthochems; micrite and microspar 50-60%, dolomite 5-10%, anhydrite 5-8%, spar tr. Intraclasts; small-medium, peloidal/micritic. Ooids; broken, radially fibrous. Micrite and microspar; matrix. Dolomite; scattered throughout, concentrated along fenestrae. Anhydrite;

filling isolated vugs and fenestrae. Spar; blocky. Porosity; fenestrae and enlarged 10-12%. Vague grain boundaries, fenestral looking.

4142-4142.4

Packstone: lt.gray brown, ooids, pisoids (many broken), anhydrite filling matrix selective vugs or interparticle porosity, minor small vugular porosity, massive.

TS 4142.2'

Dolomitic oolitic peloidal packstone-wackestone: Allochems; ooids 30-35%, peloids 25-30%. Orthochems; dolomite 20-25%, anhydrite 15-20%. Ooids; medium-large, radially fibrous concentric laminations, some broken and recoated, some grapestone. Peloids; poorly sorted, micritic-dolomitic, locally concentrated. Dolomite; matrix. Anhydrite; possibly some celestite,filling vugs and replacing adjacent calcite, both single and numerous crystals. Porosity; matrix selective small-medium vugular 4-6%. Massive looking.

4142.4-4143.5

Dolomudstone-packstone: lt.gray-lt.brown gray, peloids, small intraclasts (recrystallized), pyritic, good intercrystalline, small vugular, and moldic porosity, patterned, grain rich locally.

4143.5-4145.5

Packstone-grainstone: lt.gray brown, peloids, small intraclasts, minor small vugular porosity, numerous fine grain laminations or crusts.

4145.5-4146.8

Packstone-wackestone: lt.yellow brown, calcispheres, ostracods, peloids, fair moldic and intercrystalline porosity, weakly laminated, type II stylolites, weak oil stain.

4146.8-4148.2

Packstone-wackestone: lt.gray brown, ooids, pisoids (many broken), anhydrite filling matrix selective vugular porosity, spar lining nonselective vugular porosity, fair small-medium vugular porosity, silt flooring vugs and draping over grains in layers, type II stylolites, pressure solution on grains.

TS 4147'

Oolitic/pisolitic peloidal packstone-grainstone: Allochems; ooids/pisoids 30-35%, peloids 30-35%. Orthochems; anhydrite 10-15%, micrite and some microspar 5-10%, spar 3-5%, dolomite 2-4%. Ooids and pisoids; gradational between the two, radially fibrous concentric laminations, many broken, some recoated, many small ooids or spherulites. Peloids; matrix, small, round. Anhydrite; filling large vugs, fenestrae, and stylolitic porosity, some replacement of adjacent carbonates. Micrite; matrix. Spar; blocky, partially filling small nonselective vugs. Dolomite; course, associated with stylolites and lining anhydrite filled vugs. Porosity; small-medium nonselective vugular 5-8%, interparticle 1-3%. Poorly sorted, massive, some pressure solution on grains.

4148.2-4155.5

Packstone and some grainstone: lt.brown-lt.gray brown, intraclasts, peloids, calcispheres, isolated anhydrite vug fill, brown anhydrite replacing some carbonates, blocky spar lining vugs, fair small nonselective vugular porosity, type II and some type I stylolites, isolated fine grain laminations or crusts.

TS 4153'

Intraclastic peloidal fossiliferous wackestone-packstone: Allochems; peloids 30-35%, intraclasts 20-25%, fossils 5-10%. Orthochems; micrite and some microspar 15-20%, anhydrite 10-15%, spar 3- 6%, dolomite 2-5%. Peloids; small-large, micritic, matrix. Intraclasts; peloidal/micritic, some large ones bored or possible oncoids, vague margins. Fossils; calcispheres 40%, ostracods 20%, possible dasycladacean algae 20%, tubular algae 5%, unID 15%. Micrite; matrix. Anhydrite; filling large vugs. Spar; blocky, partially filling small vugs. Dolomite; course, associated with stylolites. Porosity; small nonselective vugular 5-8%. Type II stylolites. Massive, poorly sorted.

NDGS# 7040

Depth Description

4039-4041

Nodular anhydrite and dolomudstone: med.gray-med.brown gray, anhydrite nodules and distorted thin beds, thin distorted dolomudstone laminations, some thin dark laminations.

4041-4042.3

Dolowackestone-packstone: lt.gray, scattered sulphate grains, argillaceous, anhydrite nodules, anhydrite filling short vertical fractures, minor intercrystalline porosity, weak wispy laminations.

4042.3-4042.6

Distorted argillaceous dolomudstone: lt.gray, possible peloid ghosts, minor intercrystalline porosity, uniformly distorted thin dolomudstone laminations, much like well# 2464-4068'.

4042.6-4043

Dolopackstone-wackestone: lt.brown, peloids, small intraclasts, anhydrite replacing grains and some matrix, minor intercrystalline porosity, alternating grain rich/poor thin beds.

4043-4045.8

Nodular anhydrite: lt.gray, small-large anhydrite nodules and dolomudstone stringers.

4045.8-4046.2

Dolowackestone: lt.gray brown, peloids, small intraclasts, anhydrite filling some vugs and replacing grains, minor intercrystalline porosity, thin laminations (possible algal), microstylolites, dessication cracks.

4046.2-4049.6

Nodular anhydrite: lt.gray, some sulphate grains within distorted dolomudstone stringers, small-medium anhydrite nodules.

TS 4047.9'

Nodular-massive anhydrite: Allochems; clay ?%. Orthochems; anhydrite 90-95%, dolomite 5-10%. Anhydrite; felted nodules, some compacted, some vertically elongate, massive subfelted thin bed. Dolomite; argillaceous, very fine grain, dark, distorted between nodules and thin near horizontal laminations. Porosity; none visible. Thin dolomudstone laminations dipping uniformly 20%.

4049.6-4050

Dolomudstone and nodular anhydrite: lt.gray, isolated sulphate grains, anhydrite nodules, minor intercrystalline porosity, patterned dolomudstone with anhydrite nodules within some of the patterns, small vertical fractures.

4050-4050.5

Dolomudstone and anhydrite sandstone: lt.gray-lt.brown gray, anhydrite sand concentrations, some anhydrite nodules, very minor intercrystalline porosity, cross-bedded anhydrite sand, alternating dolomudstone and sulphate grain laminations.

TS 4050.2'

Massive-cross-bedded anhydrite and argillaceous dolomudstone: silt 10-15%. Orthochems; anhydrite and some celestite 50-60%, dolomite 30-35%. Silt; anhydrite and dolomite grains, possibly some quartz. Anhydrite and celestite; most felted vertically oriented lathes, isolated nodules, cross-bedded silt and lathes. Dolomite; dark, fine grain, argillaceous, slightly calcitic. Porosity; vertical fractures 1-2%. Weakly laminated, crossbedded 30% dip.

4050.5-4052

Dolomudstone: lt.brown gray, minor intercrystalline porosity, weakly laminated-massive.

4052-4053.5

Calcitic dolowackestone-packstone: lt.gray brown, peloids (recrystallized), anhydrite replacing some grains, minor intercrystalline porosity, wispy laminations or microstylolites, locally steeply dipping, some fracturing.

4053.5-4055.3

Dolomudstone-wackestone: lt.gray, possible peloids (recrystallized), isolated anhydrite vug fill, fair intercrystalline and small vugular porosity, massive-weakly laminated.

Core missing for interval 4055.3-4061.5'

4061.5-4061.7

Wackestone-packstone: lt.brown, intraclasts, anhydrite replacing carbonates along small vertical fractures, fair intercrystalline porosity, wispy microstylolites, pressure solution on grains.

4061.7-4067

Nodular-massive anhydrite: lt.-med.gray, very minor intercrystalline porosity, nodular-massive, thin laminated seams (possibly algal).

4067-4068.8

Dolopackstone-wackestone: lt.gray brown, peloids, anhydrite filling fractures and adjacent porosity, anhydrite replacing some grains, fair intercrystalline porosity, massive with some thin laminated zones, microstylolites, steeply dipping.

4068.8-4069

Dolomudstone: lt.gray, fair intercrystalline porosity, patterned, anhydrite filling numerous horizontal and vertical fractures.

4069-4069.5

Anhydritic dolomudstone-packstone: lt.gray, sulphate grains within dolomudstone, anhydrite nodules, distorted.

4069.5-4070.5
Nodular anhydrite: lt.gray, thin distorted dolomudstone stringers.
4070.5-4073.5
Dolomudstone-wackestone: lt.brown gray, sulphate grains, possible peloids, anhydrite filling vugs and fractures, pyrite lining some vugs, fair intercrystalline and small vugular porosity, patterned-burrowed looking, some thinly laminated zones.
4073.5-4074.5
Dolomudstone-packstone: lt.-med.gray, sulphate grains (in lenses), fair intercrystalline and small vugular porosity.
4074.5-4075.5
Packestone-wackestone: lt.brown, intraclasts, peloids, anhydrite filling vertical fractures and replacing grains and matrix locally, minor small vugular porosity, type II stylolites and pressure solution on grains.
TS 4074.9'
Dolomitic oolitic intraclastic packstone: Allochems; ooids 25-35%, intraclasts 25-35%. Orthochems; anhydrite and possibly some celestite 20-30%, dolomite 5-10%, micrite 5-10%, spar 2-5%. Ooids; compacted, irregular shapes, both radially fibrous and micritic laminations, some dolomite replacement. Intraclasts; micritic and oolitic, some dolomitized, many with 1-2 outer radially fibrous coatings, poorly sorted. Anhydrite; restricted zones, many dolomite inclusions, replacing both calcite grains and matrix, odd yellow brown color, filling some vugs. Dolomite; scattered throughout matrix, course grains associated with pressure solution and stylolites. Micrite; matrix. Spar; blocky, filling some vugs. Porosity; small vugular 2-3%. Many type II stylolites, pressure solution on grains. Poor sorting, compaction.

NDGS# 7260
Depth Description

4134-4138.2
Wackestone-packstone: lt.gray brown, ooids, peloids, isolated pisoids and rip-up clasts, anhydrite filling interparticle, moldic, and fenestral porosity, fair moldic and vugular porosity, type II stylolites, fenestral looking, some pressure solution.
TS 4134'
Peloidal oolitic/oncolitic packstone: Allochems; peloids 20-25%, ooids/oncoids 15-20%, fossils 3-5%. Orthochems; anhydrite 45-55%, micrite and some microspar 5-8%, spar 4-6%, dolomite 2-4%. Peloids; small, micritic, some dolomitized. Ooids/oncoids; micritic, most with weak micritic laminations, some radially fibrous laminations, many dolomitized. Fossils; gastropod 95%, calcispheres 5%. Anhydrite; replacing calcite (both matrix and grains), incorporating dolomite and some spar, filling some vugs and molds. Micrite; matrix. Spar; blocky, filling vugs. Dolomite; large, scattered, many associated with anhydrite. Porosity; small nonselective vugular 2-4%.
4138.2-4138.6

Dolomitic wackestone: lt.gray, ooid ghosts, possible sulphate grains, minor vugular porosity, type II stylolites, thin silt rich laminations.

TS 4138.2'

Silty intraclastic peloidal wackestone-packstone: Allochems; intraclasts 20-25%, peloids 10-15%, silt 5-10%. Orthochems; micrite and some microspar 40-50%, spar 10-15%, dolomite 2-4%, opaques 1-3%. Intraclasts; small, micritic-microspar, very irregular shape, some weak internal structure, most with single outer lamination. Peloids; medium-large, micrite-microspar, irregular-round shape. Silt; quartz, dolomite, anhydrite. Micrite; matrix. Spar; small blocky-bladed, lining and filling fenestrae. Dolomite; some zoned crystals, some with opaque centers. Opaques; fibrous, dark, concentrated-scattered. Porosity; small vugular 2-3%, fenestrae 1-2%, fracture 1-2%. Strange fabric, numerous fenestrae, very uniform width, horizontal, vertical and diagonal directions as well as surrounding grains.

4138.6-4138.9

Wackestone-packstone: lt.brown, calcispheres, algae, ostracods, some intraclasts and ooids, spar filling moldic or shelter porosity, minor moldic and small vugular porosity, type I and II stylolites.

4138.9-4139.4

Wackestone-packstone: lt.brown, intraclasts, calcispheres, algae, ostracods, spar filling moldic or shelter porosity, fair moldic and small vugular porosity, type II stylolite zone, solution breccia.

TS 4138.9'

Intraclastic fossiliferous packstone-wackestone: Allochems; intraclasts 30-40%, fossils 20-30%, peloids 5-10%. Orthochems; micrite 15-25%, spar 5-10%, dolomite 5-8%, opaques 1-2%, chlorite? 1-2%. Intraclasts; small-medium, micritic. Fossils; calcispheres 50%, tubular algae 25%, ostracods 10%, brachiopod 5%, gastropod 5%, mollusc 5%, possible dasycladacean tr. Peloids; small, micritic. Micrite; matrix, micritization of some fossils. Spar; blocky, filling and lining vugs and intraparticle porosity. Dolomite; course, associated with stylolites, thin zone. Opaques; scattered. Chlorite?; filling small vugs. Porosity; small vugular (mostly matrix selective) 2-4%, stylolitic 2-4%, intraparticle 1-2%. Type I and II stylolites, poorly sorted, massive. Oil stained.

4139.4-4142.6

Wackestone-packstone: lt.gray brown, intraclasts, ooids, isolated pisoids and fossils, anhydrite filling porosity, blocky spar lining and filling vugular porosity, pyrite vug lining, fair vugular and moldic porosity, alternating course/fine grains, thin crusts, pressure solution.

4142.6-4143

Grainstone-packstone: lt.brown, peloids, ooids, intraclasts, spar lining vugs, minor nonselective vugular porosity, very good cross-bedding, some pressure solution.

TS 4142.6'

Spherulitic/oolitic grainstone: Allochems; ooids/spherulites

65-70%. intraclasts 2-4%. Orthochems; spar 25-35%. Ooids/ spherulites; 0.1-0.3 mm, most completely radially fibrous, some concentric laminations, isolated broken, slightly micritized locally. Intraclasts; isolated, with 1-2 radially fibrous outer laminations. Spar; blocky, filling vugs, small isopachous blocks filling interparticle porosity (intergrown). Porosity; interparticle 3-4%, small nonselective vugular porosity 3-4%. Well sorted, cross-bedded. Pressure solution on grains in micritized area.

4143-4143.5

Wackestone and some grainstone: lt.gray brown, ooids, small intraclasts, isolated pisoids, anhydrite filling fractures and vugs, blocky spar lining vugs, fair large-small vugular porosity, possible crusts or silt infill, pressure solution.

4143.5-4144.5

Dolomitic wackestone and some grainstone: lt.gray brown, small intraclasts, ooids, isolated pisoids, anhydrite filling fractures, spar lining and filling vugs, good-very good nonselective vugular and fenestral porosity, disrupted looking, sheet cracked, some pressure solution.

TS 4143.5'

Dolomitic oolitic peloidal grainstone-packstone: Allochems; ooids 35-45%, peloids 25-35%. Orthochems; micrite 15-20%, spar 5-15%, anhydrite 1-3%. Ooids; poorly sorted, both radially fibrous and micritic concentric laminations, locally micritized margins, some dolomitized. Peloids; possibly microspar, locally micritized margins, some dolomitized. Micrite; some matrix, thin micritic laminations coating large disrupted blocks or sheets. Spar; isopachous, blocky and bladed, filling and lining. Anhydrite; bladed, along small stylolite or crack. Porosity; small-medium nonselective vugular 5-10%. Vertical and horizontal cracks, fenestral looking blocks.

4144.5-4145.2

Wackestone: lt.gray brown, large ooids, pisoids, large intraclasts (3cm), some anhydrite vug fill, spar lining and filling vugs, pyrite lining some vugs, fair nonselective vugular porosity, type I stylolites, alternating course/fine grain, pressure solution on many grains.

4145.2-4148.1

Grainstone-packstone: lt.gray brown, poorly sorted ooids, isolated medium intraclasts, spar filling and lining interparticle and vugular porosity, fair moldic and nonselective vugular porosity, fairly massive, thin laminated zones, some pressure solution.

TS 4147'

Oolitic/oncolitic packstone-wackestone: Allochems; ooids/oncoids 45-55%, peloids 20-25%. Orthochems; micrite and some microspar 25-30%, spar 2-5%, dolomite tr. Ooids/oncoids; medium-large, both micritic and radially fibrous laminations, some dolomitized. Peloids; small, vague, matrix. Micrite; matrix. Spar; blocky, filling and lining vugs. Dolomite; associated with stylolites. Porosity; medium nonselective vugular 5-10%. Type I and II stylolites, pressure solution on grains.

4148.1-4149.5

Wackestone: lt.gray-lt.gray brown, ooids, small intraclasts, fair small vugular porosity, type II and I stylolites, pressure solution on grains, calcispheres.

4149.5-4150.5

Wackestone-mudstone: lt.gray brown, possible ooid and small intraclast ghosts, good vugular porosity, type I and II stylolites, pressure solution on grains, slight fenestral look.

4150.5-4151.8

Dolomudstone-wackestone: lt.gray-lt.brown gray, ooid sized grains (recrystallized), compacted oncoids, fair small vugular, moldic, and intercrystalline porosity, weak wavy pattern.

4151.8-4153

Grainstone-wackestone: lt.gray brown, intraclasts, ooids, blocky spar lining vugs, good nonselective vugular and fenestral porosity, alternating course/fine grain, fenestral looking.

4153-4157.8

Grainstone-wackestone: lt.gray brown, well sorted ooids, pisoids, anhydrite filling vugs, blocky spar lining vugs, good matrix selective vugular porosity, alternating course/fine grain, isolated thin fine grain laminations or crusts, type I stylolite, pressure solution on grains.

TS 4153'

Interbedded dolomitic oolitic grainstone and oolitic peloidal grainstone: Allochems; ooids 55-65%, peloids 10-15%, pisoids 2-5%. Orthochems; spar 25-35%. Ooids; radially fibrous concentric laminations, many dolomitized. Peloids; small, round, micritic. Pisoids; isolated, radially fibrous, broken, small. Spar; isopachous, fibrous, filling and lining interparticle porosity, some bladed intergrown, and blocky. Porosity; medium-large nonselective vugular 10-15%, interparticle 2-5%. Ooid grainstone cross-bedded. Sharp contact between two lithotypes. Diagonal fractures with compacted grains, some dissolution. Oil stained.

TS 4156.8'

Oolitic pisolitic peloidal packstone-grainstone: Allochems; ooids 30-40%, peloids 20-30%, pisoids 15-25%, fossils tr. Orthochems; micrite and microspar 10-15%, spar 5-10%. Ooids; small-medium, some grapestone, radially fibrous concentric laminations, some dolomite. Peloids; matrix, very small, microspar. Pisoids; radially fibrous concentric laminations, many broken and recoated several times. Fossils; calcispheres 100%. Micrite and microspar; matrix. Spar; blocky, partially filling vugs and fenestrae. Porosity; small-medium matrix selective vugular 5-8%, intraparticle 1-2%. Fenestral looking locally, poorly sorted.

4157.8-4161.3

Wackestone-grainstone: lt.gray brown, ooids, some pisoids, some anhydrite vug fill, blocky spar lining vugs, fair-good vugular (some vertically elongate) porosity, pressure solution on grains, type I stylolites, 1-3cm thick fine grain laminations or crusts.

TS 4157.8'

Peloidal oolitic packstone-grainstone: Allochems; peloids 35-45%, ooids 25-35%, intraclasts 5-10%. Orthochems; microspar and some micrite 5-10%, spar 5-8%, anhydrite 4-6%. Peloids; small, round, microspar locally. Ooids; small, radially fibrous concentric laminations, some micritic laminations, many broken. Intraclasts; small, peloidal/micritic, some with outer laminations. Microspar; matrix. Spar; bladed intergrown, lining and filling fenestrae and enlarged fenestrae, some blocky. Anhydrite; locally filling enlarged fenestrae, incorporating spar. Porosity; fenestral and enlarged fenestral (both horizontal and vertical) 8- 12%. Oil stained.

4161.3-4164

Grainstone-packstone: lt.brown, ooids, small intraclasts, small pisoids, isolated large intraclasts, spar lining and filling vugs, good vugular, interparticle, and fenestral porosity, alternating course/fine grain, algal structures (symetrical fenestrae patterns), pressure solution on grains, type II stylolites.

TS 4161.3'

Peloidal oolitic/oncolitic packstone: Allochems; peloids 55-65%, ooids/oncoids 15-25%, fossils 1- 2%. Orthochems; spar 10-15%, microspar and micrite 5-10%. Peloids; poorly sorted, round, micritic. Ooids/oncoids; weakly laminated, mostly micritic, some radially fibrous laminations, small-pisoid size. Fossils; calcispheres 95%, ostracods 5%. Spar; blocky, filling and lining fenestrae and vugs. Microspar; matrix. Porosity; fenestrae 5-8%, matrix selective vugular 2-4%. Concave symetrical fenestral zone, no large grains within the structure. Very fenestral.

<u>NDGS# 9679</u>
<u>Depth Description</u>

A very brief description of major lithologies and fossils. This core was not slabbed.

4157-4158.2

Quartz sandstone: med.gray, fairly massive.

4158.2-4159.4

Anhydrite: white-gray.

4159.4-4162

Silty anhydrite: dk.gray.

4162-4164

Dolowackestone-packstone: lt.gray brown, anhydrite replacing carbonates locally, some vugular porosity.

4164-4216

Packstone with varying amounts of wackestone and some grainstone: lt.gray-lt.brown, ooids, peloids, locally pisoids and large intraclasts, spar lining and filling vugular porosity, anhydrite filling vugs locally, fair-very good vugular and some interparticle porosity (large vugs at 4187'), medium bedded, isolated fine grain laminations or crusts, isolated fenestral zones, scattered type II and I stylolites, possible ostracods.

TS 4187'

Interbedded peloidal oolitic grainstone and oolitic pisolitic grainstone: Allochems; ooids 35-40%, peloids 30-35%, pisoids 5-10%. Orthochems; spar 15-20%, anhydrite 5-8%. Ooids; radially fibrous concentric laminations. Peloids; micritic, round, various sizes. Pisoids; radially fibrous laminations, many broken and recoated. Spar; isopachous fibrous and bladed filling interparticle porosity, blocky spar lining vugs. Anhydrite; locally filling vugs and replacing adjacent micritic grains and matrix, spar inclusions. Porosity; large nonselective vugular 10-15%, interparticle 1-2%. Sharp contact between two lithologies. Well sorted, slight fenestral look.

TS 4192'

Oolitic peloidal packstone-grainstone: Allochems; ooids 40-45%, peloids 25-30%, pisoid 2-4%, grapestone 2-4%. Orthochems; spar 10-15%, micrite and much microspar 5-10%. Ooids; small-large, radially fibrous concentric laminations, some micritic. Peloids; very small-large, micritic, moderate sorting. Grapestone; ooid. Pisoids; isolated, both radially fibrous and micritic laminations. Spar; coarse blocky filling and lining vugs, fine blocky filling interparticle porosity. Micrite; matrix, mostly associated with peloids. Porosity; nonselective vugular and enlarged fenestrae 4-6%, interparticle (possibly enlarged) 8-10%. Alternating course/fine grain laminations. Weakly fenestral looking.

TS 4214'

Oolitic/oncolitic packstone-wackestone: Allochems; ooids/oncoids 30-35%, intraclasts 10-20%, peloids 10-15%, silt 1-2%. Orthochems; micrite 15-25%, spar 8-12%, dolomite 1-2%. Ooids/oncoids; micritic concentric laminations, fairly uniform, dark replacement of some laminations (pyrite?), grain margins indistinct. Intraclasts; micritic, indistinct margins. Peloids; irregular shapes, small. Silt; possible quartz, scattered throughout. Micrite; matrix, possibly peloidal. Spar; blocky, filling vugs, partially filling fenestral or stylolitic porosity. Dolomite; course, associated with stylolites. Porosity; small vugular 2-4%, crack or enlarged fenestrae 1-2%. Micritic looking, dark, possibly argillaceous. Much pressure solution and type I and II stylolites. Brecciated looking.

APPENDIX D

Appendix D is a copy of a paper given at the Fifth International Williston Basin Symposium (1987), and published in the symposium volume. The paper is based on research done during the completion of my thesis and covers a portion of the research in some detail. Permission to reproduce granted by Roger N. Borchert, Symposium Committee chairman and President of the North Dakota Geological Society.

ENVIRONMENTAL SIGNIFICANCE OF A MEGASPORE FLORA FROM THE MISSION CANYON FORMATION (MISSISSIPPIAN), BOTTINEAU COUNTY, NORTH DAKOTA

MARK R. LUTHER[1], EDWARD N. STEADMAN[2] AND LEN V. HILLS[3]

[1] *Department of Geology and Geological Engineering, University of North Dakota, Grand Forks;*
[2] *Energy Research Center, University of North Dakota, Grand Forks;*
[3] *Department of Geology and Geophysics, The University of Calgary.*

ABSTRACT

Megaspores and unidentified plant fragments have been recovered from two thin (0.5 m - 1.5 m) zones within carbonates of the Frobisher-Alida interval of the Mississippian Mission Canyon Formation. This flora was found during a study of the Wiley Field, southwestern Bottineau County, North Dakota. At least five new forms of megaspores were found, and are believed to represent previously undescribed genera and species of arborescent lycopods. Arborescent lycopods are typically associated with fresh-water environments. The remarkable preservation, low diversity, and apparent areally restricted concentration of megaspores indicate growth at or near the place of deposition. This may provide evidence for local subaerial exposure and fresh-water lens development. Preserved organic fragments were deposited in nearby topographic lows. Organic plant and scolecodont material was preserved in an anoxic shallow water setting probably caused by saline brines. These brines dolomitized the sediments in which the organic material was preserved before significant compaction had occurred.

INTRODUCTION

Although plant fragments have been described from Mississippian rocks of the Williston Basin, these reported findings are rare. Webster (1982) and Thrasher (1985) found plant fragments in the Bakken Formation (Devonian and Mississippian) in North Dakota. Thrasher (1985) described blade-like "leaves", woody plant fragments, and possible plant stems. He considered the blade-like "leaves" to mark the base of the Mississippian in the Williston Basin.

Earlier, Fuller (1956) noted plant remains from Mississippian rocks in the Saskatchewan portion of the Williston Basin. He found nearly all the plant fragments in the Charles Formation, and a few "carbonized plant remains" in the Hastings-Frobisher Beds (upper Mission Canyon Formation). Fuller (1956) stated that some of these fragments resemble "equisetalian plants". To our knowledge, the above-mentioned descriptions of unidentified, poorly preserved plant fragments are the only documented occurrences of plants from the Mississippian of the Williston Basin.

Recently, however, extremely well-preserved plant remains have been recovered from Mississippian carbonates of the Mission Canyon Formation in the northeastern portion of the Williston Basin. Luther (in preparation), in a wireline log and core study of the Wiley Field (Township 161N. and Ranges 81W. and 82W. in Bottineau County, North Dakota, Fig. 1) found plant fragments while describing core from a well just south of the field boundary (Fig. 2). This well, NDGS# 3343, California Oil Company's O. C. Haugen #1, NE1/4NW1/4 Sec. 26, T. 161 N., R. 82 W., contained well preserved organic plant and animal fragments in two separate dolostone units just beneath the K2 (Kisbey) marker (LeFever and Anderson, 1986., Fig. 2).

METHODS

Core was slabbed and examined with a reflected light microscope and hand lens. Plant remains were first noted

STUDY AREA

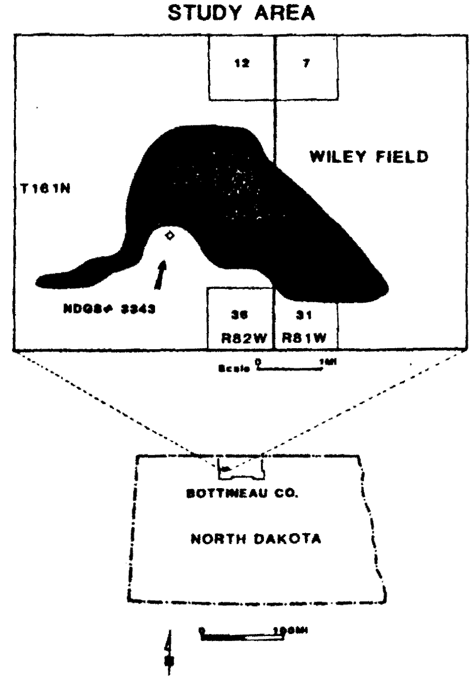


Fig. 1 Location of NDGS# 3343 relative to the Wiley Field.

visually on bedding planes of core sections. This led to examination of both slabbed and exterior core surfaces with a microscope. Several organic fragments were found by this process including several blade-like "leaves", possible plant stems, and numerous scolecodonts (Fig. 3), including at least one complete jaw assemblage. A few isolated, well-preserved fragments, later determined to be plant megaspores, were also found.

A small portion of the predominantly dolostone core from the interval in which organic fragments were found was then dissolved in dilute acetic acid (10%) to recover any organic or phosphatic floral and faunal elements. The resulting insoluble residue was washed through a 3-phi sieve to collect the larger fragments. This was dried, and then examined and sorted with a microscope. An SEM/Microprobe was used to analyze and photograph high-resolution images of selected organic fragments.

STRATIGRAPHY OF THE FROBISHER-ALIDA INTERVAL

The Wiley Field produces from carbonates of the Mission Canyon Formation in which hydrocarbons are trapped by updip laterally equivalent, and overlying evaporites of the Charles Formation. Since these carbonates are located beneath the K2 marker (Kisbey sandstone) and above the K3 marker, they are considered to be part of the Glenburn beds (LeFever and Anderson, 1986) (Fig 4). The Glenburn bed is approximately 50 ft. (15 m) thick within the study area.

Cores of the Glenburn bed to the south (basinward) of the Wiley Field contain increasing numbers and varieties of fossils. Well #3343, from which the plant fragments and scolecodonts were taken, occurs in a transitional area between predominantly coated-grain lithotypes (shoreward) and fossiliferous lithotypes (basinward).

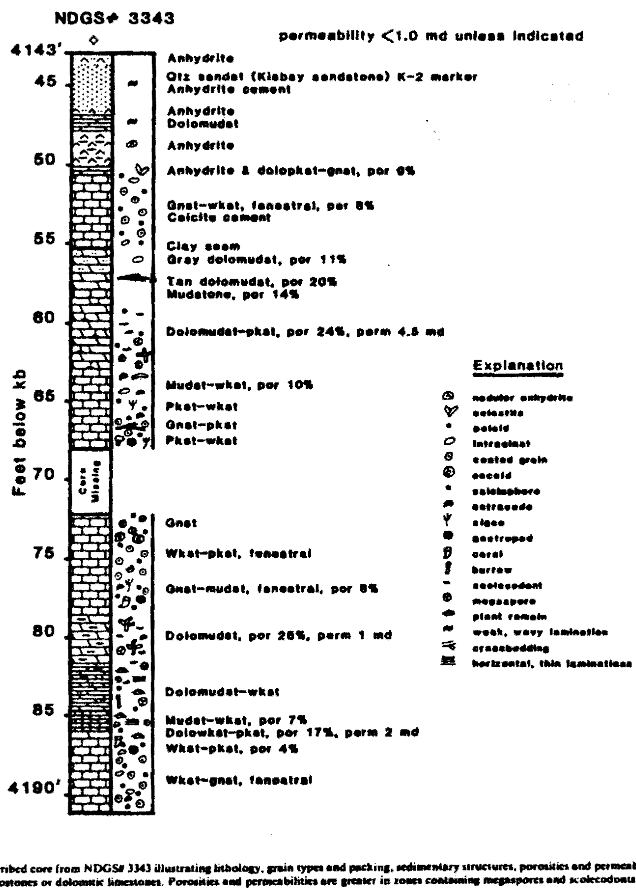


Fig. 2 Lithologic column for described core from NDGS# 3343 illustrating lithology, grain types and packing, sedimentary structures, porosities and permeabilities (millidarcy). Plant material and scolecodonts are found only in dolostones or dolomitic limestones. Porosities and permeabilities are greater in zones containing megaspores and scolecodonts.

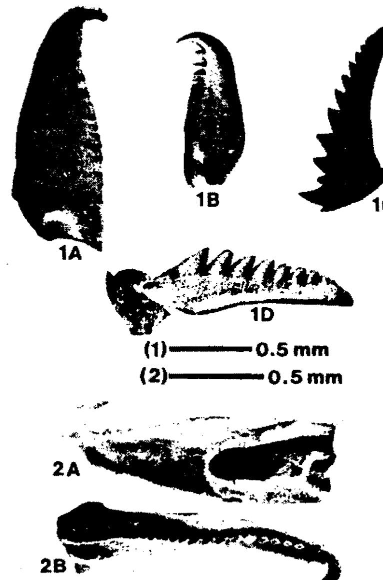


Fig. 3 Scolecodonts recovered from core taken at a depth of 4180 ft. from well #3343. Note hollow jaw (3-2A) which is typical for scolecodonts, but not for conodonts. Colour ranges from black to brown-black

Deposition of the Glenburn bed is here interpreted to have taken place during a time of equilibrium between relative sea level and sedimentation rates. This is indicated by the lack of lateral migration of predominantly inorganic allochems (basinward) and evaporites (shoreward) within the study area. This equilibrium ended at approximately the time of deposition of the K2 marker, when evaporite deposition abruptly extended basinward over the underlying carbonates.

Both isopach maps and core descriptions (Luther, in preparation) indicate that well #3343 was located in a NE-SW-trending topographic low extending to the shoreward evaporite-producing zones. This low is adjacent to coated-grain lithotypes that formed low relief (3 m) topographic highs in basinward portions of the Wiley Field. It is on these topographic highs that megaspore-producing plants are thought to have become established.

DESCRIPTIONS

Preliminary examination of the megaspores suggests that there are five distinct types. The following general descriptions and illustrations of the megaspores are intended to alert other investigators to these microfossils. No taxonomic determinations will be given here except to suggest that these types represent the megaspores of arborescent lycopods and represent both new genera and species. Further taxonomic treatment is forthcoming in future publications.

Type one (Figs. 8a through 8d) appears to be a trilete spore, and is roughtly triangular. Ornamentation consists of prominent spinae (Figs. 8c and 8d). The illustrated specimen is about 1.4 mm long in the long axis.

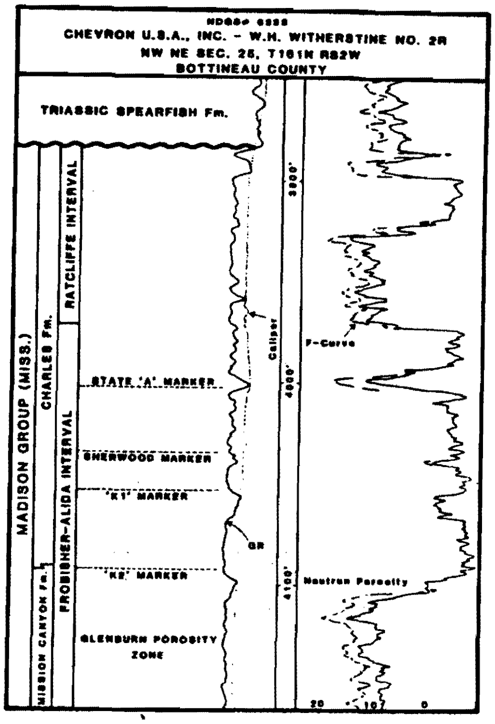


Fig. 4 A wireline log from a typical producing well in the Wiley Field, illustrating formations and informal intervals and markers. Nonporous anhydrites of the Charles Formation overlie porous carbonates of the Glenburn bed (Mission Canyon Fm.).

Type two (Figs. 9a through 9d) also appears to be a ·ilete spore, and is roughly triangular. Ornamentation is echinate to subechinate; spinae are less elongate and more rounded than those found in type one. The illustrated specimen is about 1.5 mm long in the long axis.

Type three (Figs. 10a through 10d) is spherical, and has prominent proximal architecture in the form of massa (or gula?). The exine surface appears smooth. The diameters are approximately 1.5 mm and 0.9 mm in the illustrated specimens.

Type four (Figs. 11a through 11c) is spherical and has prominent massa or gula on the proximal surface. This form is basically similar in overall morphology to type three except for the surface ornamentation. The surface of type four is covered with hair-like capilli (Fig. 11c) that are winding but not branched. The illustrated specimens are approximately 1.5 mm and 1.2 mm in diameter.

Type five (Fig. 12) appears to be a portion of a tetrahedral tetrad, and is roughtly spherical. The broken area is facing upward in the illustrated specimen. Several specimens of this type were encountered. The illustrated specimen is approximately 0.55 mm in diameter.

Fig. 5 Plant remain located on a bedding plane, and typical of those found in well #3343.

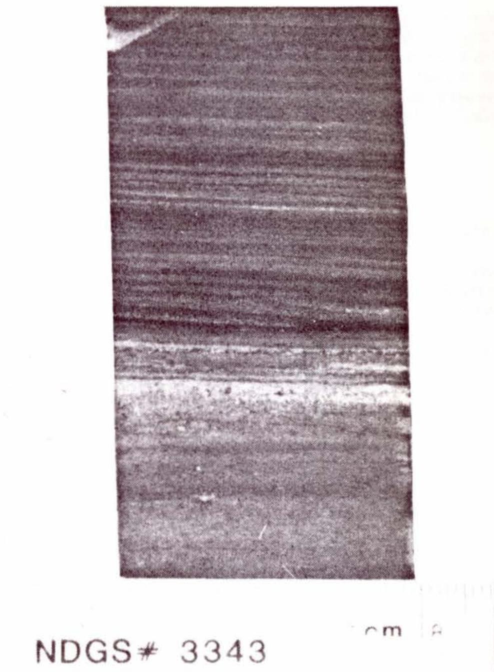


Fig. 6 Horizontally-laminated, dolomitic limestone to calcitic dolostone in which most plant fragments other than megaspores were found. Scolecodonts were not found in this type of deposit.

DEPOSITIONAL MODEL

Several factors indicate that plant fragments found in core from well #3343 originated near the place of deposition. These factors include: 1) the presence of previously undescribed forms of megaspores, representing new genera and species; 2) the relative abundance of megaspores with low diversity that were found (indicating a local, isolated origin), rather than the small number of very diverse megaspores that would be expected if transported from a continental source; 3) the apparent areal restriction of the organic fragments as indicated by the absence of preserved plant fragments in described core from 28 other wells generally located updip (shoreward) of #3343; 4) the excellent preservation and lack of abrasion observed in the organic fragments; 5) the presence of burrows and scolecodont assemblages in the upper portions of the megaspore-containing zone, thus precluding transport of all organics to the site of deposition; and 6) the presence of topographic highs composed of coated grains, on which plants may have become established adjacent to the place of deposition.

The coated-grain highs are the most likely area in which megaspore-producing plants might have become established. At least two different environmental settings may be envisioned. One setting involves coated-grain highs that were isolated, subaerially-exposed, positive features due to a small sea-level drop. A fresh-water lens could form in the exposed sediments, most likely underlain by the hypersaline marine brines that also filled the adjacent low. Plants, such as arborescent lycopods, generally thought to grow in fresh water, may have become established on these isolated highs and contributed plant material, including megaspores, to the immediate vicinity including the adjacent low.

In the other setting, arborescent lycopods became established in shallow marine waters, much like do modern mangroves. Once again the coated-grain highs would be the most likely areas in which this took place. The relative lack of current-produced sedimentary structures in the coated-grain highs suggests a stable substrate on which the arborescent lycopods could become established. As previously stated, arborescent lycopods are thought to have grown in fresh water environments. However, Schopf and Askin (1980) have suggested that the Triassic arborescent lycopod *Pleuromeia* may have formed mangrove-type associations.

PRESERVATION

To inhibit the oxidation and decomposition of the organic plant fragments found in well #3343, deposition in an anoxic or reducing environment is required. This environment may be caused by several conditions, including: very low-energy waters containing abundant organic material, rapid burial, or as Kinsman et al (1974) noted, saline brines capable of evaporate precipitation. Evidence found in the study area supports only the last (increased salinities) of these conditions.

Kinsman et al (1974) found that increasing the concentration of marine water brines led to gradually lower concentrations of dissolved oxygen. At the point at which halite-precipitation

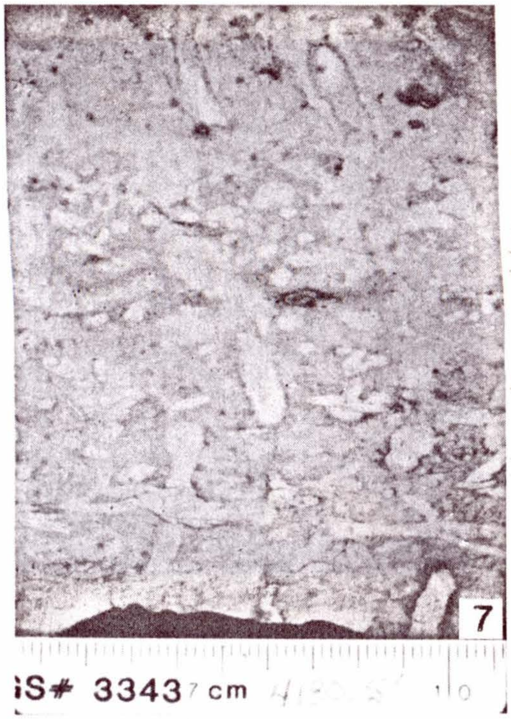


Fig. 7 Burrowed dolomudstone from which abundant scolecodonts were recovered.

could occur these brines were considered anoxic under all but the most turbulent conditions. Increased water temperatures reduced the amount of dissolved oxygen even more, to the point at which gypsum-precipitation brines would be nearly anoxic.

Anoxic conditions, due to the presence of concentrated brines in the topographic low in which the plant fragments are interpreted to have been deposited, can be supported in either of the previously discussed depositional settings. Dense saline brines would tend to concentrate in lows during a sea level drop (first setting), or may flow basinward through the NE-SW-trending low (location of well #3343) as an undercurrent from the shoreward, evaporite-precipitating, sublittoral flats (second setting).

Further evidence supporting this interpretation of organic preservation by anoxic saline brines is that organic fragments in well #3343 were found in thin dolostone sections not present in cores from adjacent coated-grain highs. Near-surface formation of this dolomite is indicated by the lack of compaction of both scolecodonts and megaspores and the presence of rhombic impressions on the exterior surfaces of some of these organic fragments (Fig. 12). This suggests that the dolomite formed before substantial compaction took place.

Dolomite formation by gypsum-precipitating brines is well documented. Many authors, including Sears and Lucia (1980), have called upon gypsum-precipitating brines to cause dolomitization of sediments. Brines with a high Mg/Ca ratio produced by evaporation of seawater and the precipitation of gypsum in shallow, shoreward flats could easily dolomitize sediments and preserve organic fragments.

CONCLUSIONS

Several conclusions and areas of possible future study are drawn from this research, including:

1) Identifiable organic remains were found including scolecodonts and previously undescribed forms of megaspores that originated at or near the place of deposition in Mississippian Mission Canyon carbonates of the Williston Basin.
2) A plant type (arborescent lycopod) generally associated with fresh-water environments was found in marine carbonates and may indicate subaerial exposure of coated-grain highs and formation of a fresh-water lens within these highs.
3) Nearly anoxic, shallow-water conditions were present in the vicinity of well #3343 during the deposition of plant material and burrowing of sediments by scolecodont-bearing polychaete worms. These conditions prevented the decomposition of organic fragments.
4) Saline brines that produced the anoxic conditions during the deposition of organic fragments also dolomitized the sediments in which they were found before significant compaction had begun. This indicates early, near surface dolomitization of sediments, or primary dolomite formation.

In addition, porosities and permeabilities are greater in zones in which saline brines preserved organics and dolomitized sediments than they are in underlying or overlying limestones. Porosity trends formed by similar brine movements may provide migration routes or reservoirs for hydrocarbons, and could be a target for exploration in the future. The possibility that land plants may have locally contributed to hydrocarbon accumulations should also be explored.

ACKNOWLEDGEMENTS

Core and logs were supplied by the North Dakota Geological Survey, whose personnel have provided much assistance. Partial funding of the study that led to this paper was provided by Tenneco Oil Exploration and Production. Dr. Robert Stevenson of the University of North Dakota Natural Materials Analytical Laboratory is thanked for his assistance with SEM/Microprobe analyses. Dr. Francis M. Hueber of the Smithsonian Institution provided initial identification of the megaspores as well as helpful comments. Dr. Howard J. Fischer (University of North Dakota) contributed valuable observations and discussions, although the responsibility for interpretations rests with us. The manuscript benefited from critical comments by Dr. Alan M. Cvancara and Jean Hoff (University of North Dakota).

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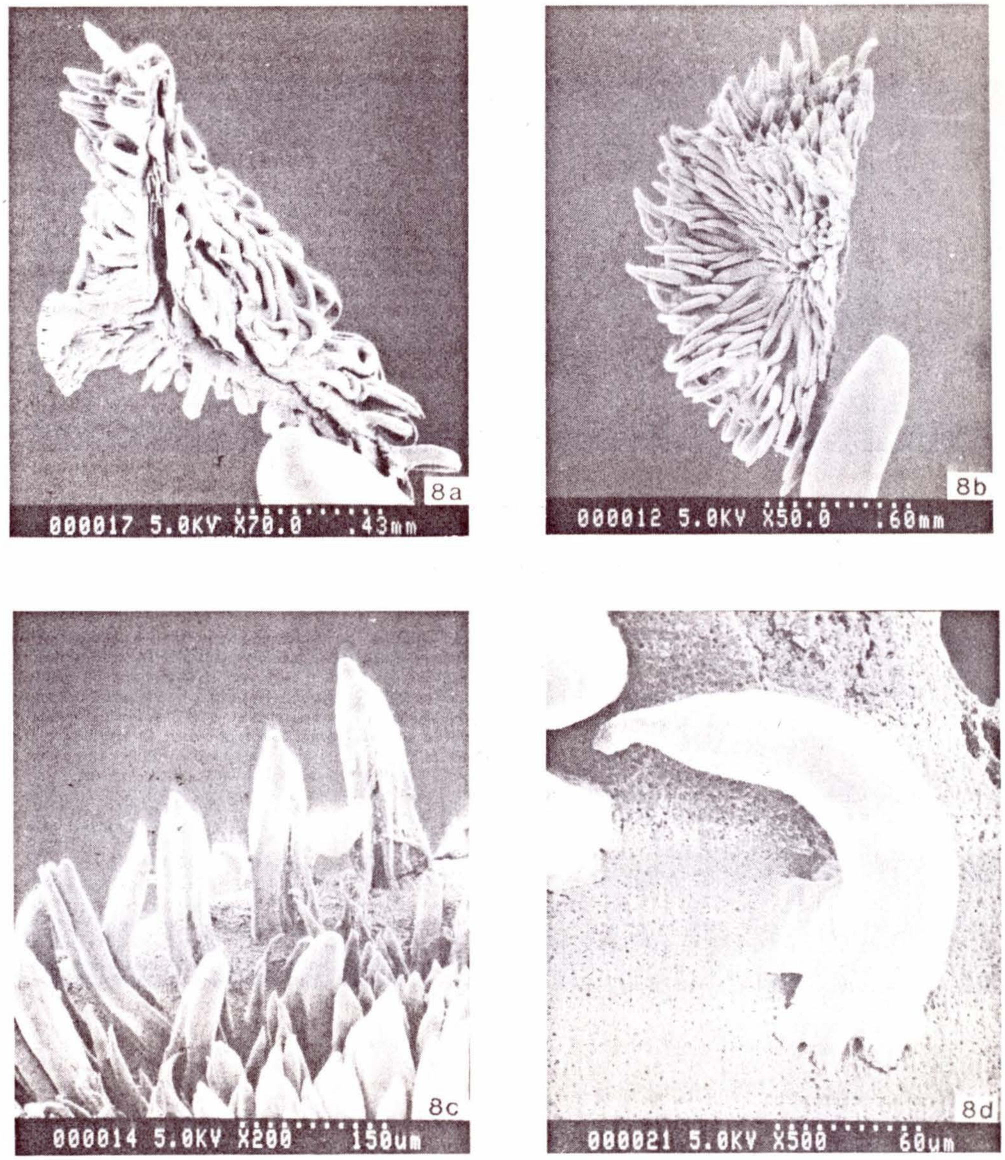


Fig. 8 A trilete megaspore (Type 1) recovered from 4182 ft depth. a) looking at cut surface and hollow interior. b) straight edge on the right is the result of a saw cut during core slabbing. c) and d) note well preserved spinae.

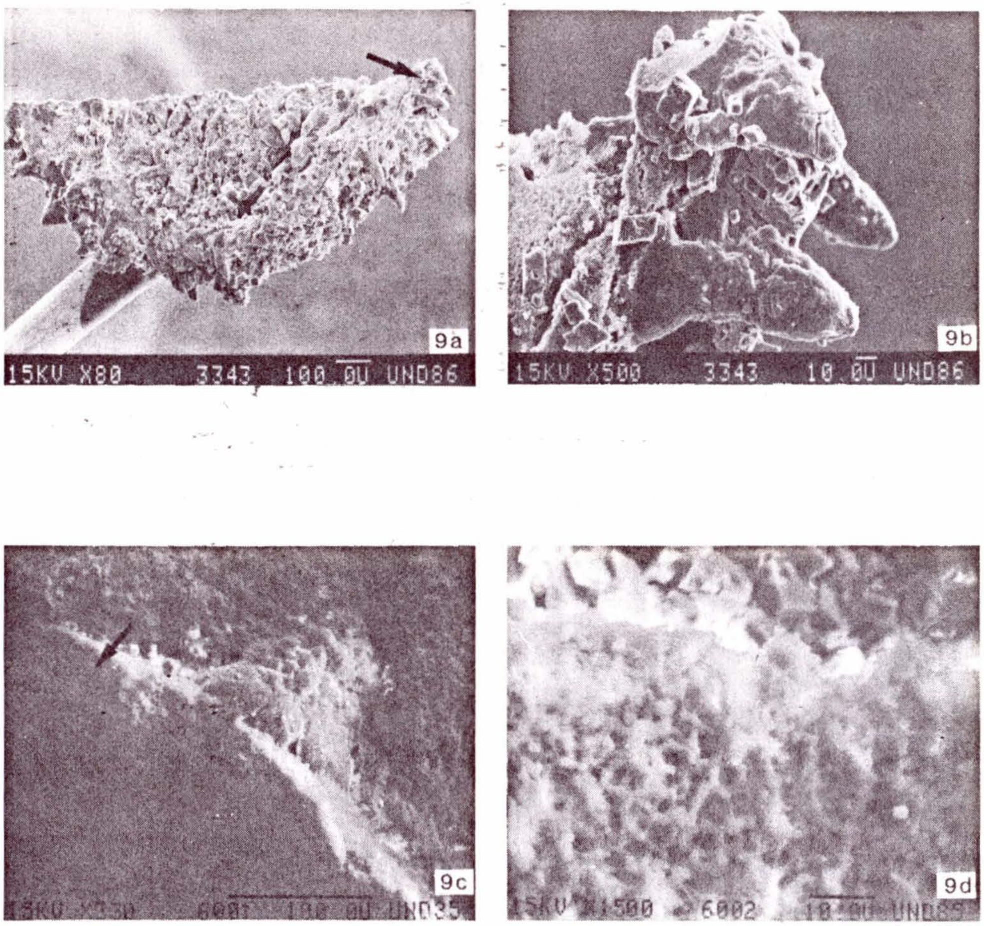


Fig. 9 A trilete megaspore (Type 2) recovered from 4183 ft depth. Megaspore has short, blunt spinae. a) arrow points to location of 9b. b) note dolomite which wasn't totally removed by acid. c) Megaspore within dolostone. Arrow points to location of 9d. d) close-up of exine (spore wall). Scale bars in microns.

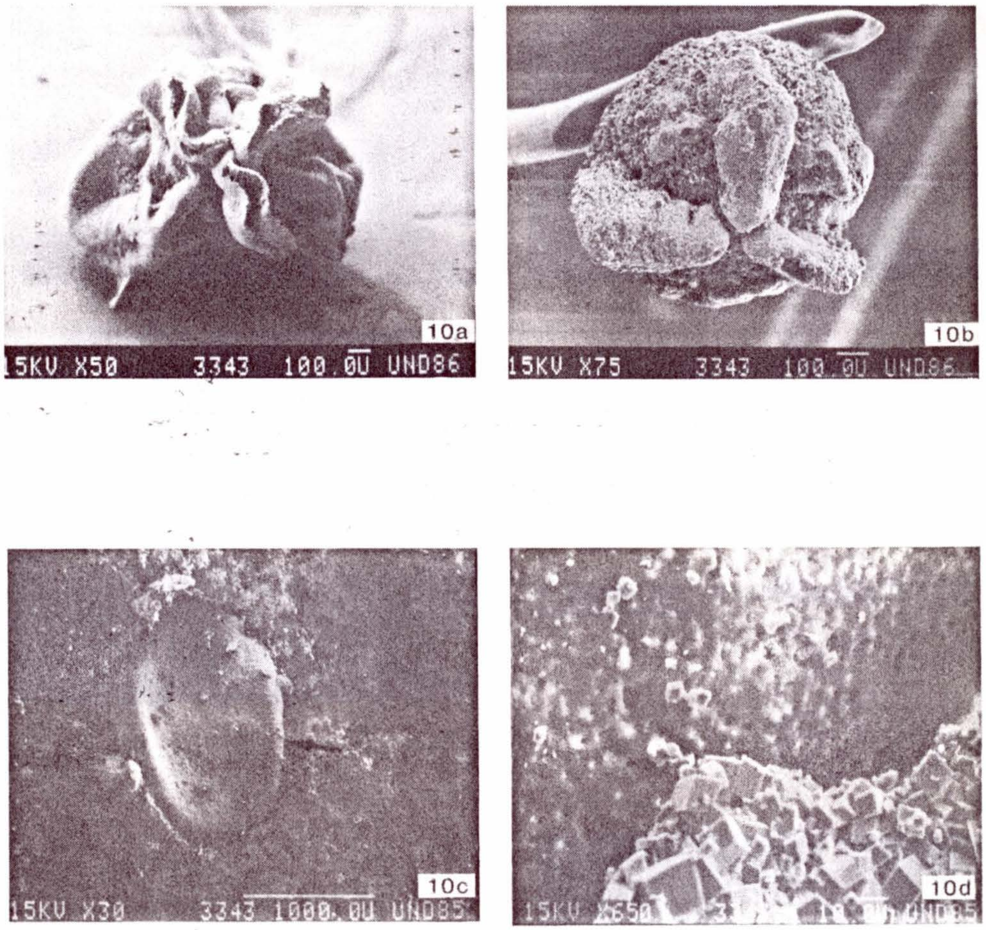
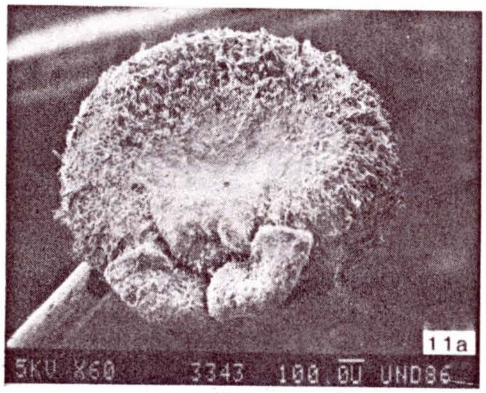
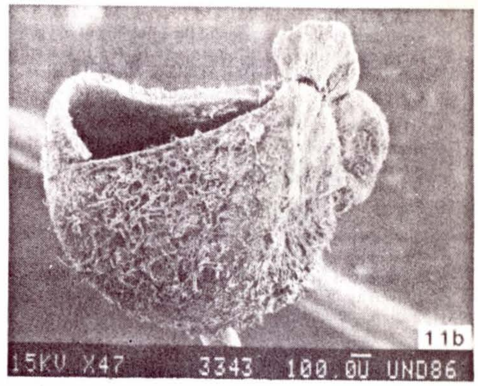


Fig. 10 Megaspores (Type 3). a) and c) from 4182 ft depth. b) from 4162 ft depth. Notice the lack of capilli or spinae. c) megaspore in dolostone matrix, arrow points to location of 10d. Scale bars in microns.





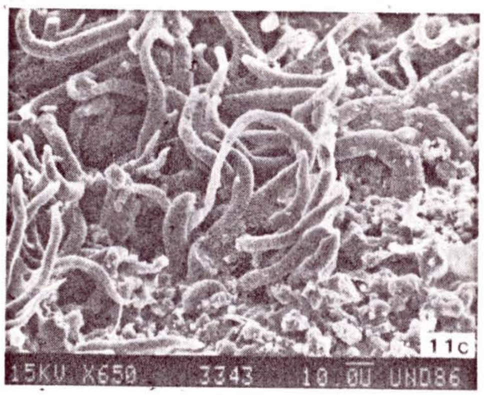


Fig. 11 Megaspores (Type 4) recovered from 4181-4182 ft depth. Very similar to Type 3, but covered with hair-like capilli. 11c is a close-up of capilli on 11b. Note partially dissolved dolomite. Scale bars in microns.

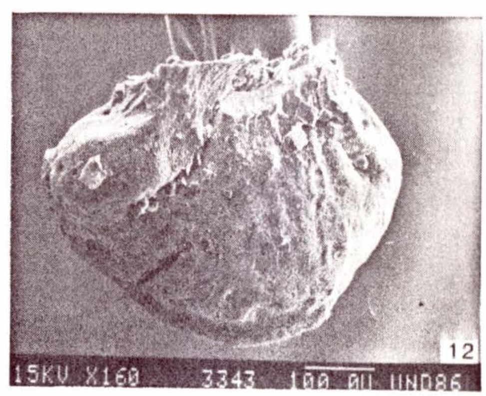


Fig. 12 Megaspore (Type 5). Possibly a portion of a tetrahedral tetrad. Recovered from 4183 ft. depth. Arrow points to rhombic impressions formed during compaction with dolomite.

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Organic floral and faunal specimens recovered from well NDGS #3343 (The California Oil Co., O. C. Haugen #1, NE 1/4 NW 1/4 Sec. 26 T161N R82W) are stored in the University of North Dakota Department of Geology and Geological Engineering's paleontological collection. The following accession numbers are given for the cored intervals from which the specimens were recovered.

Accession No.	Cored Interval (feet below KB)
A2660.1	4160.5 - 4161.5
A2660.2	4161.5 - 4162.5
A2660.3	4179.5 - 4180.5
A2660.4	4180.5 - 4181.5
A2660.5	4181.5 - 4182.5
A2660.6	4182.5 - 4183.5
A2660.7	4183.5 - 4184.5
A2660.8	4184.5 - 4185.5

APPENDIX E

Appendix E is a copy of a paper given at the Fifth International Williston Basin Symposium (1987), and published in the symposium volume. The paper is based in part, on research conducted during the completion of this thesis. This author's contribution to the paper primarily deals with brine circulation, salinity gradients, and their relation to lithofacies development and distribution. Permission to reproduce granted by Roger N. Borchert, Symposium Committee chairman and President of the North Dakota Geological Society.

SALINITY, OXYGENATION, AND TOPOGRAPHIC CONTROLS ON MISSISSIPPIAN SUBTIDAL SEDIMENTATION IN A PORTION OF THE MISSION CANYON FORMATION, WILLISTON BASIN, NORTH DAKOTA

HOWARD J. FISCHER, MARK R. LUTHER, KURT E. EYLANDS AND CHRISTOPHER F. QUINN

Department of Geology and Geological Engineering,
University of North Dakota
Grand Forks ND 58202

Our model for the deposition of sublittoral rocks from the Mississippian Mission Canyon Formation is derived from the examination of cores and wireline logs from hydrocarbon-producing fields in Billings County and the Bottineau-Renville County area of North Dakota. During the past four years, seven Master of Science theses at the University of North Dakota have focused on the deposition and diagenesis of the Mission Canyon Formation. In addition to the contributions by the writers of this report, information collected in those studies has been helpful in developing this model. The ideas presented herein are therefore somewhat preliminary, and represent our present understanding of the Mission Canyon depositional setting. An earlier version of the model was presented by Fischer et al (1986).

The model outlined in this report calls for salinity to be the major factor controlling sedimentation patterns throughout "Mission Canyon time". The carbonate section developed in response to a general increase in salinity through time that was punctuated by rapid, periodic fluctuations in salinity that controlled lithofacies distribution within the carbonate succession. Local changes in salinity, sedimentation rate, oxygenation above and below the sediment-water interface, and bottom topography accentuated the effects of the broad salinity changes and controlled the local variations in lithologies, organism distribution, sedimentary structures, and evaporite mineral distribution within the Mission Canyon section.

The majority of the Mission Canyon carbonates from Billings, Bottineau, and Renville Counties show characteristics that suggest formation in a shallow sublittoral setting. The rocks from Billings County are mainly mudstones and wackestones containing the remains of a relatively low-diversity epifauna of both stenohaline and euryhaline organisms, low numbers of stenohaline forms, a low to moderately oxygen tolerant infauna, and abundant organic material. Local accumulations of echinoderms and corals in packstone textures are also found. The rocks in Billings County are extensively dolomitized and contain a littoral facies and abundant evaporite minerals at the top of the section (Stephens, 1986; Fischer et al, 1986).

Rocks in Bottineau and Renville Counties contain lithologies similar to those in Billings County, although inorganic allochems and particularly coated grains are more common. Increasing amounts of evaporite minerals and littoral sediments are also found upward in the section (Quinn, 1986, Luther and Quinn, 1985).

In epeiric seas, bottom waters may become more saline through time as evaporation, particularly at the margin of the sea, produces seaward-flowing, bottom-hugging brines of elevated salinity (Scruton, 1953). It has been demonstrated that as salinity increases in marine water, the ability of the water column to contain dissolved oxygen decreases (Kinsman et al, 1974). Thus bottom waters, in addition to becoming brines, may also contain low concentration of dissolved oxygen.

The brines, being more dense than the remainder of the water column, would have accumulated on the sea bottom and flowed away from the sea margin due to a difference in head between the brine (greater head) and less saline water in the seaward direction. Closed topographic lows on the sea floor would have retained the brines, while linear lows, elongated in the flow direction may have acted as conduits for the movement of the brines seaward. In addition, the lack of oxygen in the topographic lows would retard the growth of carbonate-shelled epifauna, and produce a mudstone texture with very few fossil allochems. Lack of oxygen would also produce a sediment with abundant preserved organic material and an ichnofauna indicating low levels of oxygen below the sediment-water interface (Byers, 1977).

The drag on seaward moving brines caused by friction with the sea bottom and overlying, shoreward-moving, fresher marine waters, would have been capable of forming a dynamic barrier to circulation within the sea. The barrier would have restricted the free exchange of water from more open marine environments with the more stagnant, interior and shoreline waters (Scruton, 1953). This dynamic barrier would also have barred the outward flow of the brines until a reduction in drag, caused by reduced inflow of overlying, shoreward-moving waters or increased head of the accumulating brines allowed the dynamic barrier to collapse periodically and the bottom brines to flow seaward.

The elevated salinity created throughout the sea by these processes is the major controlling factor in the chemical and biological evolution of Mission Canyon lithofacies. Reduced levels of oxygen, coupled with elevated salinities, easily explains the lower levels of productivity (numbers of organisms) of such stenohaline groups as the brachiopods, bryozoans, trilobites and in many places the corals and echinoderms. Where euryhaline forms such as green algae and ostracods are found they occur in higher, but still not excessive, numbers.

Increased salinity and decreased oxygenation also explain the low diversity found within taxa in the Billings County area. In both stenohaline and euryhaline groups, the numbers of taxa are lower than those found in sections from more open marine environments. In addition, a succession of ichnofacies, preserved mainly in topographic lows and adjacent flat areas of the bottom, indicates variable, low to moderate levels of oxygenation in the bottom sediments and the water column (Fischer et al, 1986). The predominantly dark-colored, organic-rich rocks that comprise the majority of the Mission Canyon succession in Billings County confirm that low oxygen levels (reducing conditions) existed within the accumulating sediments. Since much of the section in the Billings Anticline area is rich in carbonate mud, with only local concentrations of bioclasts, and because of the evolving chemical composition of the water column, it is reasonable to suggest that the majority of the carbonate mud in that area was produced by inorganic precipitation.

A factor that must be addressed in evaluating sedimentation rates, biodiversity and population density is the affect of compaction on the section. With the abundance of stylolites and mechanical compaction features found in the Mission Canyon succession representing thickness reduction and packing enhancement, it is likely that in many cases, allochems within the compacted rocks are closer together and therefore appear more abundant than they were during deposition. In the same way, the total sediment thickness is reduced, and any attempt to evaluate sedimentation rates must be modified to account for the effects of compaction. For the sake of simplicity, in trying to remove the influence of compaction, we have doubled the thickness of the section. We have also modified the apparent packing by suggesting that in many cases, packstones have been compacted from wackestones and wackestones have been compacted from mudstones. This significantly modifies the interpretations that can be drawn from the rocks now preserved. If the fossil content of a wackestone is reduced to that of a mudstone, and the number of organisms preserved in a packstone is reduced to that of a wackestone, then the biological productivity of the area is seen to have been much lower than that determined from examining the compacted rocks. Thus, only rarely were there enough organisms present to accumulate in a wackestone, much less a packstone texture. The uncompacted sediment pile may have been at least 1500 feet (457 metres) thick by this reasoning. If a value of seven million years is assumed for the duration of Mission Canyon sedimentation, we can derive a maximum sedimentation rate of 0.21 feet (0.06 metres) per thousand years. This is a slow rate for any marine environment, especially when compared with rates of sedimentation in modern areas of carbonate production.

This model explains the formation of the sublittoral portion of the existing Mission Canyon stratigraphic succession by a combination of variations in salinity, oxygenation, and topography. Interactions between the evolving marine water, developing brines, brine movement, and the biological and chemical components in the various depositional environments can account for the entire preserved sediment package. Therefore, rather than calling on a physical barrier to account for the restricted conditions that produced some of the lithologies developed across the area, the lateral, "band-like" distribution of the facies is explained by bodies of water with different salinities and oxygen values forming across the study area. Since salinity gradients would be established away from the margin of the epeiric sea, concentric bands of progressively less saline water would develop from Bottineau (shoreward) to Billings County (seaward). The lateral migration of the salinity bands would cause the vertical stacking of sediments showing different degrees of restriction as a particular chemical environment caused a specific lithofacies to form in a given area.

Episodic changes in levels of salinity and oxygenation in the water covering the study area, possibly caused by the periodic flow of brines in response to the collapse of a dynamic circulation barrier, would therefore cause the lateral distribution and vertical succession of the facies. In addition, topography, brine movement or concentration, and oxygenation would become important local controls on sublittoral sedimentation.

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