DEPOSITIONAL SYSTEMS IN THE ATOKA AND MORROW SERIES (PENNSYLVANIAN), HALEY FIELD AREA, LOVING COUNTY, TEXAS

By

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Introduction

Haley Field, located in Loving County, Texas has produced over 300 billion cubic feet (bcf) of gas since the discovery well was drilled in 1983. However, only one in four wells drilled in the field is economic (PI/Dwights, 2007). The reservoirs are deep, making the wells expensive to drill, and the targets remain elusive, even after 25 years of drilling in the area. The reservoirs are complexly interbedded and consist of interfingering carbonate and clastic strata deposited during the Early and Middle Pennsylvanian (Morrowan and Atokan) some 318 million years ago. The productive zones are at depths of 16,000 to 18,000 feet and individual wells cost 10 to 15 million dollars to drill. A clear understanding of the geologic controls on the makeup and distribution of reservoir rocks in the field would decrease the cost of development by increasing the success of infill drilling. A study of the depositional environment of the Morrowan and Atokan strata in the Haley Field area elucidates the geologic controls on the composition, geometry and orientation of the reservoir rocks in the field.

To accomplish this, over 300 wells were correlated over an area of more than 3,000 square miles in Loving, Ward, Winkler, Reeves, and Culberson Counties, Texas, and Eddy and Lea Counties, New Mexico (Fig. 1). The Lower and Middle Pennsylvanian section was subdivided into the Atoka and Morrow Series (Fig. 2). The Morrow was further subdivided into three units called here the upper, middle and lower Morrow. Structure, isopach, and sand percent maps were made for each series and unit. The middle Morrow was then divided into four intervals for more detailed mapping. Structure and isopach maps were also made for the Barnett Shale (Mississippian).

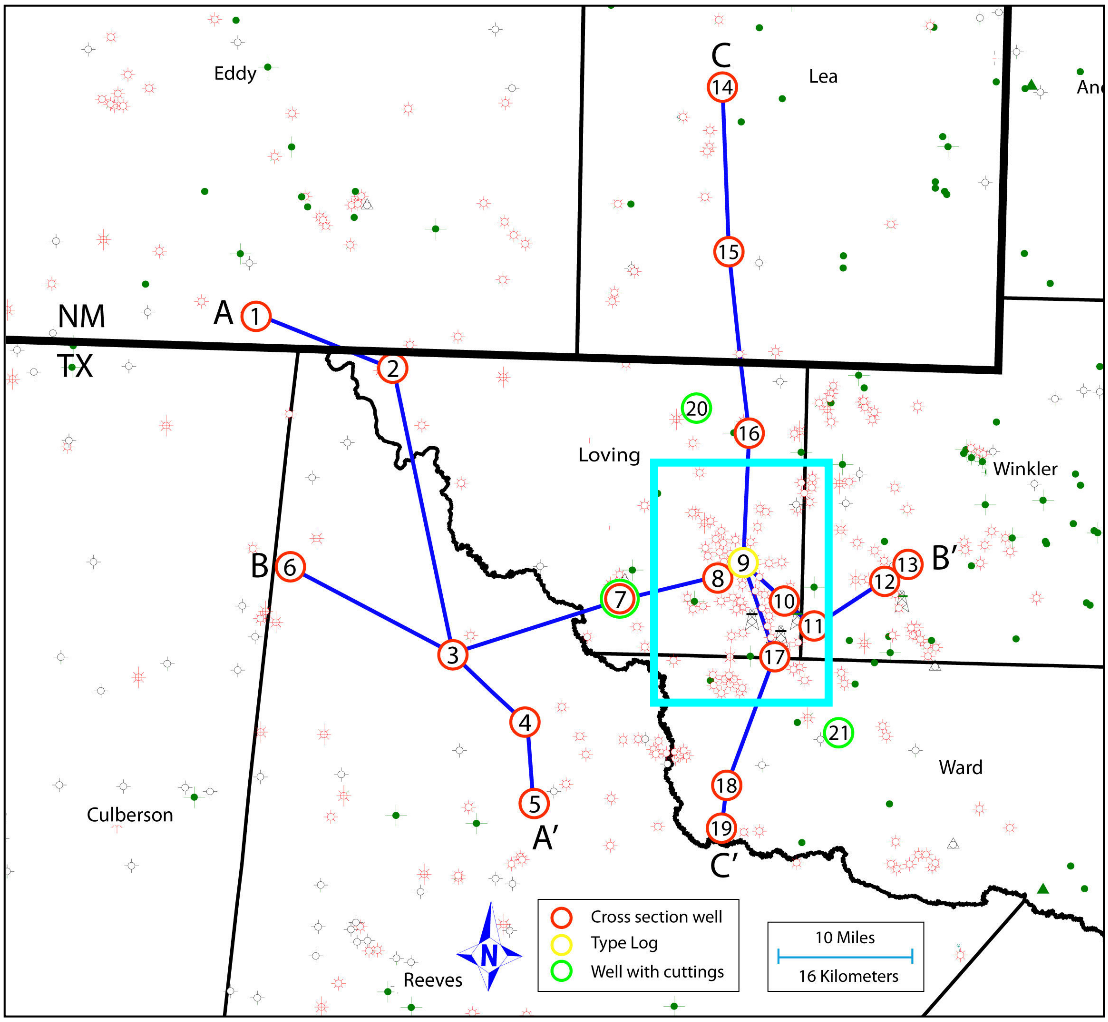


Figure 1. Map showing location of Haley Field area (box) and regional well control. Dark blue lines are cross sections made in this study. See Table 1 for names of numbered wells.

Map #	API #	Well #	Operator	Well Name	Well Description	County	Measured Depth (ft)
1	3001521398	1	HAMON JAKE L	STATE LG-1175	Abandoned Oil	Eddy	14,572
2	4230130225	1	BROWN H L JR	RED BLUFF /DEEP/	Gas	Loving	17,077
3	4238931391	1	R K PETROLEUM CORP	DIXIELAND `3`	OIL	Reeves	19,475
4	4238931133	1	BTA OIL PRODUCERS	8008 JV-P ARNO	Dry	Reeves	18,493
5	4238931228	1	HNG OIL COMPANY	BIGGS UNIT `22`	Dry	Reeves	15,465
6	4238931112	1	TENNECO OIL CO	TENNECO V P	Gas	Reeves	16,500
7	4230130020	1	SUN OIL COMPANY	MOORE-HOOPER ETAL	Gas	Loving	21,893
8	4230130500	1	WESTLAND OIL DEV CRP	AVNT FRST ET AL`39`	Gas	Loving	22,800
9	4230130642	2	AMOCO PROD CO	HALEY `36`	Gas	Loving	23,012
10	4230131228	1	CHESAPEAKE OPERG INC	UNIVERSITY 20-8	Gas	Loving	18,000
11	4249531442	1	GETTY OIL COMPANY	UNIVERSITY `27-20`	Abandoned Oil	Winkler	22,700
12	4249530229	1	HNG OIL COMPANY	UNIVERSITY 21-15	Gas	Winkler	16,973
13	4249530865	1X	UNION TEXAS PET CORP	UNIVERSITY /21-12/	Abandoned Oil	Winkler	19,185
14	3002528119	1	AMOCO PROD CO	FEDERAL `CW` COM	Gas	Lea	13,538
15	3002527083	1	ENSERCH EXPL INC	BATES T G	Gas	Lea	17,501
16	4230130072	2	EXXON CORPORATION	LINEBERY GAS UN NO1	Gas	Loving	20,200
17	4230130356	WD-1	TEXACO PROD INC	UNIVERSITY `26-19`	Service Well	Loving	20,200
18	4247534390	2	ENRON OIL & GAS CO	CHINA LAKE `205`	Gas	Ward	16,867
19	4247534337	2	ENRON OIL & GAS CO	WORSHAM `42`	Gas	Ward	17,700
20	4230110313	1	PENNZOIL CO INC	ANDERSON MRS OP	Abandoned gas	Loving	22,643
21	4247530700	1	HUNT HASSIE INC	UNIVERSITY /18-39/	Abandoned gas	Ward	19,132

Table 1. Names of wells used in making cross sections. Numbers correspond to those in Figure 1. Type log highlighted in yellow. Cuttings obtained from wells indicated in green.

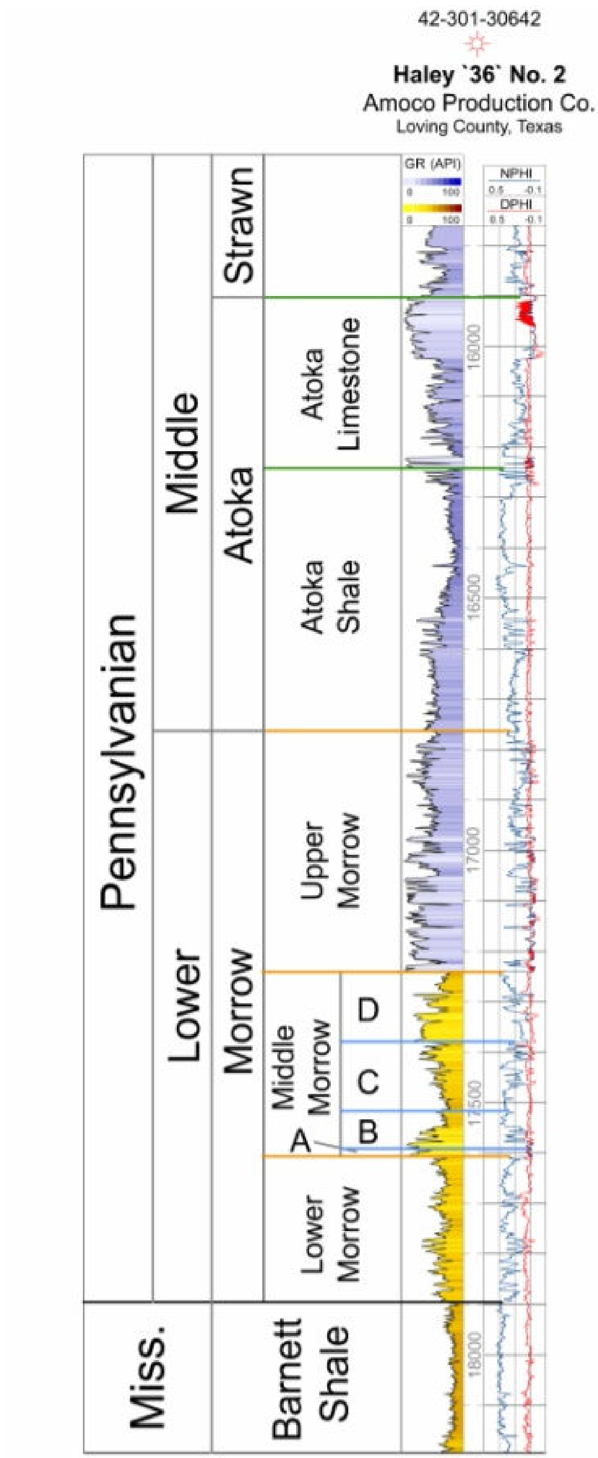


Figure 2. Type log Amoco Haley 36 #2. The Gamma Ray (GR) log is on the left, and Neutron-Porosity (NPHI) and Density Porosity (DPHI) logs are on the right. Yellow shading on Gamma Ray indicates predominantly clastic rocks; blue shading indicates predominantly carbonate rocks. NPHI and DPHI crossover is highlighted red, indicating potential gas bearing zones.

Cuttings from three wells were described over the entire Morrow and Atoka section and thin sections were made from key intervals.

Haley Field History

The discovery well for Haley Field, Amoco Hill A.G.–Haley #1A (API 42-301-30339), was drilled in 1983, in section 35, block 29, Public School Lands, Loving County, Texas (IHS Energy, PI/Dwights, 2007). The field comprises the correlative interval between 12,682 feet and 18,342 feet as shown on the type log, from the Amoco Haley 36 #2 (API 42-301-30642) drilled three years later (Byram and Co., 2007) (Fig. 2). The zone of interest consists of complexly interbedded and interfingering carbonate and clastic rocks ranging from Lower Pennsylvanian through Lower Wolfcamp (Permian) (Byram & Co., 2007). This zone is highly overpressured and produces thermally mature gas.

Haley Field has produced over 300 bcf of gas, as mentioned previously, and more than 80,000 barrels (bbl) of oil since the first well was drilled in 1983 (IHS Energy, PI/Dwights, 2007). Currently about 100 wells are producing from the field. A total of 127 wells have been drilled in the field by various operators since its discovery in 1983. Of those 127 wells, only 49 have produced over 1 bcf of gas needed to cover the cost of drilling. Only 12 have produced enough gas, 10 bcf, to make a significant profit (IHS Energy, PI/Dwights, 2007). A well producing 10 bcf or greater is drilled about once in every ten attempts.

Geologic Setting

A broad, shallow depression formed on the southwestern edge of the Laurentian craton during the Cambrian as a result of rifting between Laurentia and a craton to the south (Walper, 1977; Keller et al., 1980). This depression, known as the Tobosa Basin, persisted through the Cambrian to Late Mississippian (Galley, 1958). It was broken up into the Midland and Delaware Basins by Late Paleozoic tectonism (Fig. 3).

The Marathon-Ouachita orogeny, caused by the collision of the South American and North American plates, generated only mild tectonic activity in the Tobosa Basin during the Mississippian (Keller et al., 1980). During the Pennsylvanian, tectonic activity intensified and caused structural movement along Proterozoic lines of weakness. This tectonism divided the Tobosa Basin into the shallow Midland Basin to the east and the deeper Delaware Basin to the west, separated by the Central Basin Uplift (Fig. 3). Mountain building produced significant topographic relief to the south and east of the Delaware Basin (Wright, 1979, his Fig.14). Sediment shed from these highs filled the adjacent Val Verde and Marfa foredeep basins and then overflowed into the southern Delaware Basin (Fig. 3) (Galley, 1958). Orogenic sediment did not reach the study area in the northern Delaware Basin at this time. The orogeny created intraforeland uplifts within the Permian Basin and surrounding region, forming a composite foreland basin (Yang and Dorobek, 1995). Several basement-involved structures that would influence later sedimentation formed within the basin at this time.

Compression brought on by the Marathon-Ouachita orogeny caused the Central Basin Uplift to rise along nearly vertical faults and generated other basement-involved faults and folds in the Delaware Basin (Walper, 1977; Hills, 1984; Yang and Dorobek,

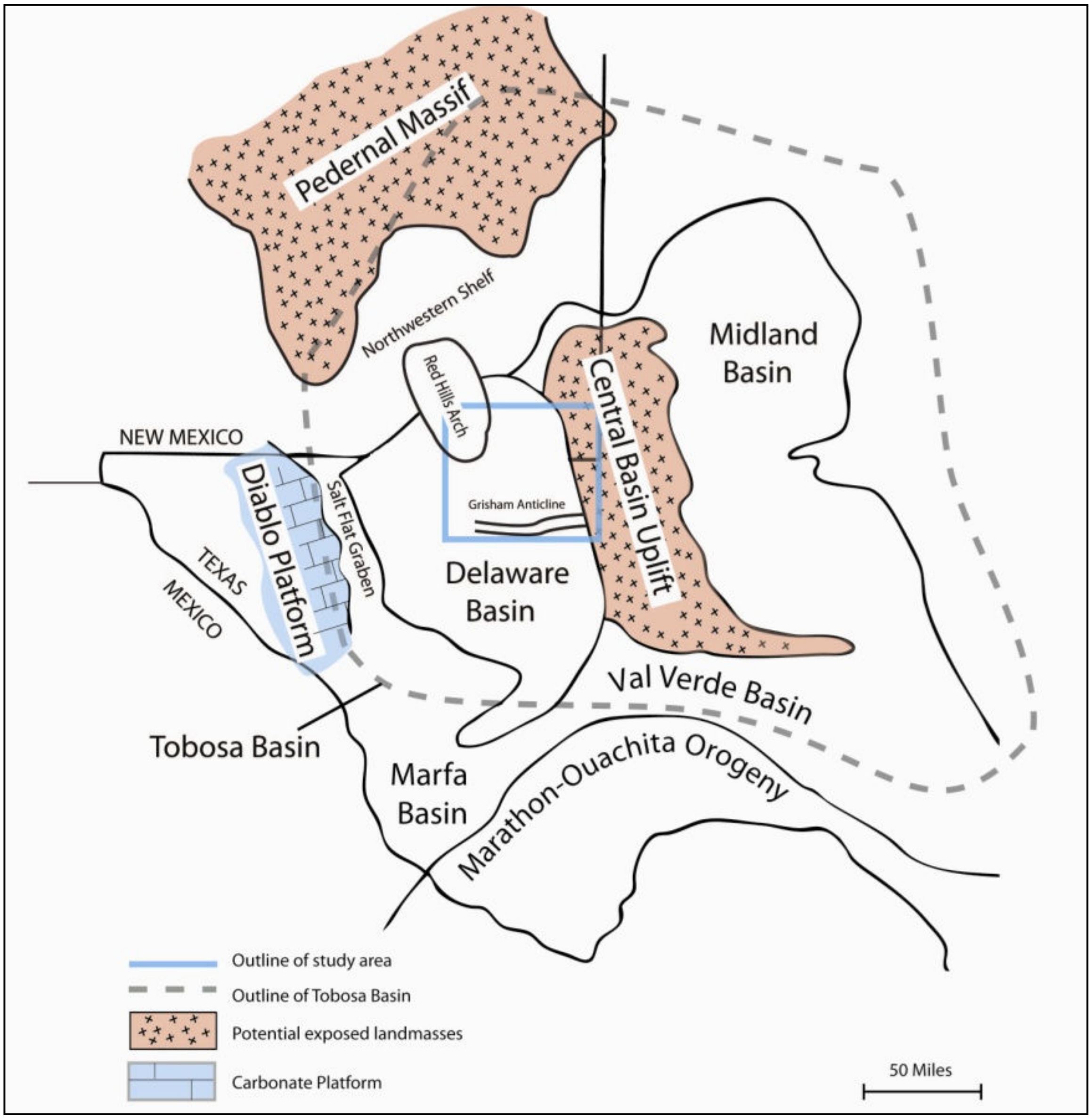


Figure 3. Map of features affecting deposition in the Delaware Basin during Early and Middle Pennsylvanian, modified from Wright (1979) and Frenzel and others (1988). The Red Hills Arch and the Grisham Anticline affected deposition within the study area. The Pedernal Massif and Central Basin Uplift were likely source areas for the Delaware Basin.

1995). In addition to the Central Basin Uplift, the already exposed Pedernal Massif to the north and the Diablo Platform to the west were potential sources of sediment for the Delaware Basin during the Pennsylvanian. The Diablo Platform was a stable carbonate shelf that bordered the western margin of the Delaware Basin throughout this period (Frenzel et al., 1988). The highest rates of subsidence and the greatest water depths occurred in a north-south trend on the eastern side of the basin along the Central Basin Uplift. Pennsylvanian strata are thickest here, ranging in thickness from 2000-2500 feet. The strata are predominantly shales and limestones with interbedded sandstones and siltstones (Frenzel et al., 1988).

Basement-involved folding and faulting associated with the Marathon-Ouachita Orogeny affected the patterns of sediment distribution in the Delaware Basin during the Pennsylvanian. Of particular note is the east-west trending Grisham Anticline, also known as the Grisham Fault or the Mid-basin fault in the center of the Delaware basin (Fig. 3) (Walper, 1977; Shumaker, 1992; Yang and Dorobek, 1995). This fault separates a structurally more complex area in the southern part of the basin from the more stable area in the north. The Red Hills Arch of Wright (1979) was also a positive feature that likely also affected sedimentation during the Pennsylvanian (Fig. 3).

The Delaware Basin, and particularly the Haley Field area, was surrounded by emergent or nearly emergent positive features during the Pennsylvanian. The Haley Field area subsided in response to basement-involved movements which raised the Central Basin Uplift. As the basin deepened and the surrounding highlands were uplifted and eroded, the sedimentary fill evolved in response to a complex interplay of structure and sediment supply, as shown in the present study.

Previous Work

Previous work in southeastern New Mexico on the Northwestern Shelf of the Delaware Basin provides both context for, and constraints on, the interpretation of the depositional setting of contemporaneous Lower and Middle Pennsylvanian basinal strata in the Haley Field area.

Stratigraphy

Broad, regional studies of Lower and Middle Pennsylvanian strata in the Delaware Basin of West Texas can be found in Galley (1958), Adams (1965), Wright (1979), Hills (1984, 1985) and Frenzel et al. (1988), among others. James (1985), Casavant and Mallon (1999), and Walsh (2007) provide detailed subsurface studies of the Morrowan and Atokan strata in the northern portion of the Delaware Basin in Eddy and Lea Counties, New Mexico. This detailed work has been conducted some 50 to 100 miles north of the Haley Field area (Fig. 4).

Morrowan strata in southeastern New Mexico have been subdivided in different ways but are generally broken into three parts: an upper limestone interval and two lower clastic intervals (James, 1985; Casavant and Mallon, 1999; Walsh, 2007). Morrowan clastic sediments rest unconformably on Mississippian strata below. The lower Morrowan clastics consist of fluvial-deltaic channel deposits trending predominantly south-southeast (James, 1985) (Fig. 5). A shale interval called the Morrow shale separates the lower and middle clastic intervals in the region of the Northwest Shelf (Worthington, 1999). Casavant and Mallon (1999) interpret the middle clastic interval as distributary channel and distributary mouth-bar deposits. Walsh (2007) interprets these

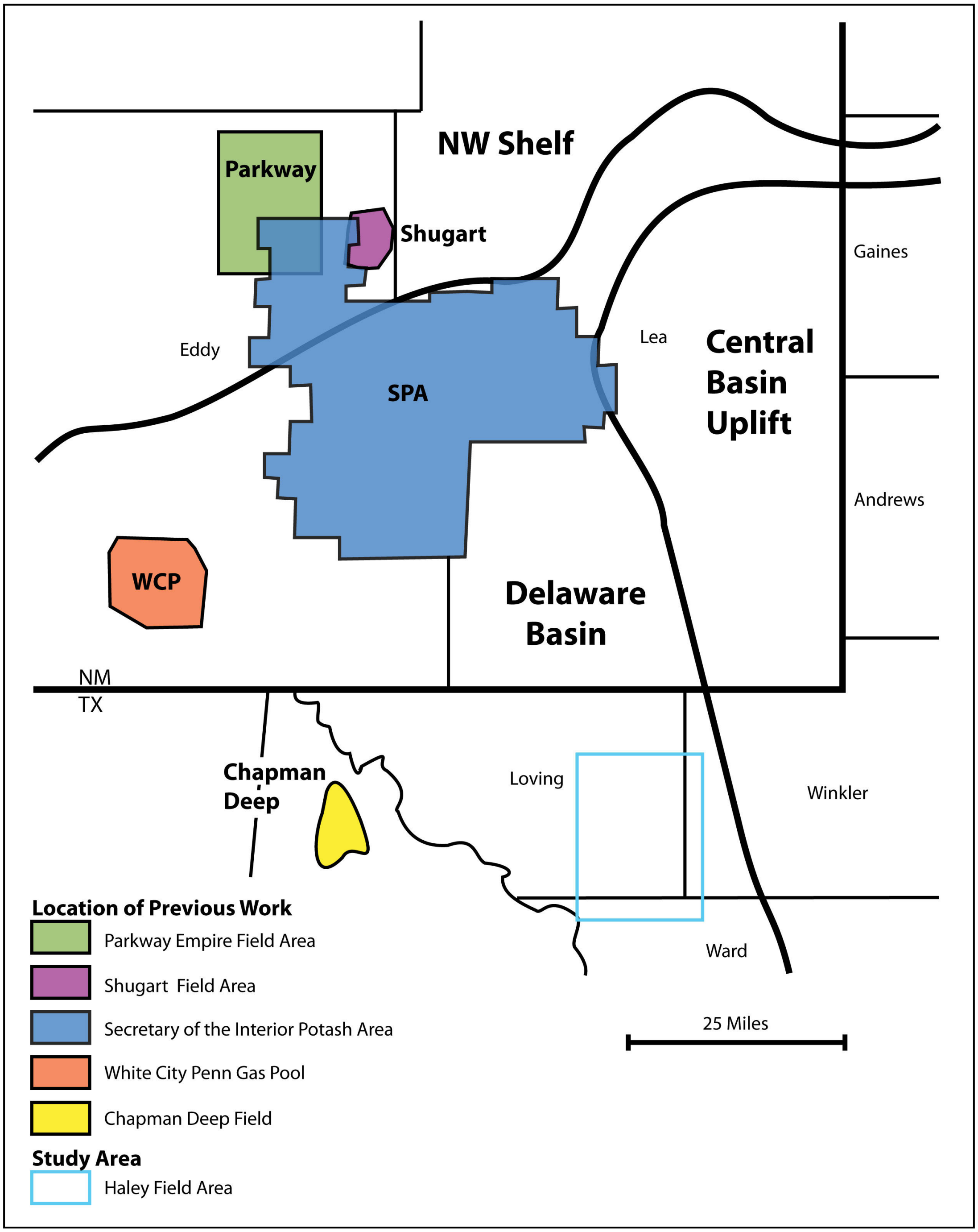


Figure 4. Map showing the location of previous studies in relation to the study area and geological provinces of the Delaware Basin. The Parkway Empire Field area was studied by James (1985); the Shugart Field area was studied by Worthington (1999); the Potash area (SPA) was studied by Walsh (2007); the White City Penn Gas Pool (WCP) was studied by Casavant and Mallon (1999); and Chapman Deep Field was studied by Mazzullo (1981).

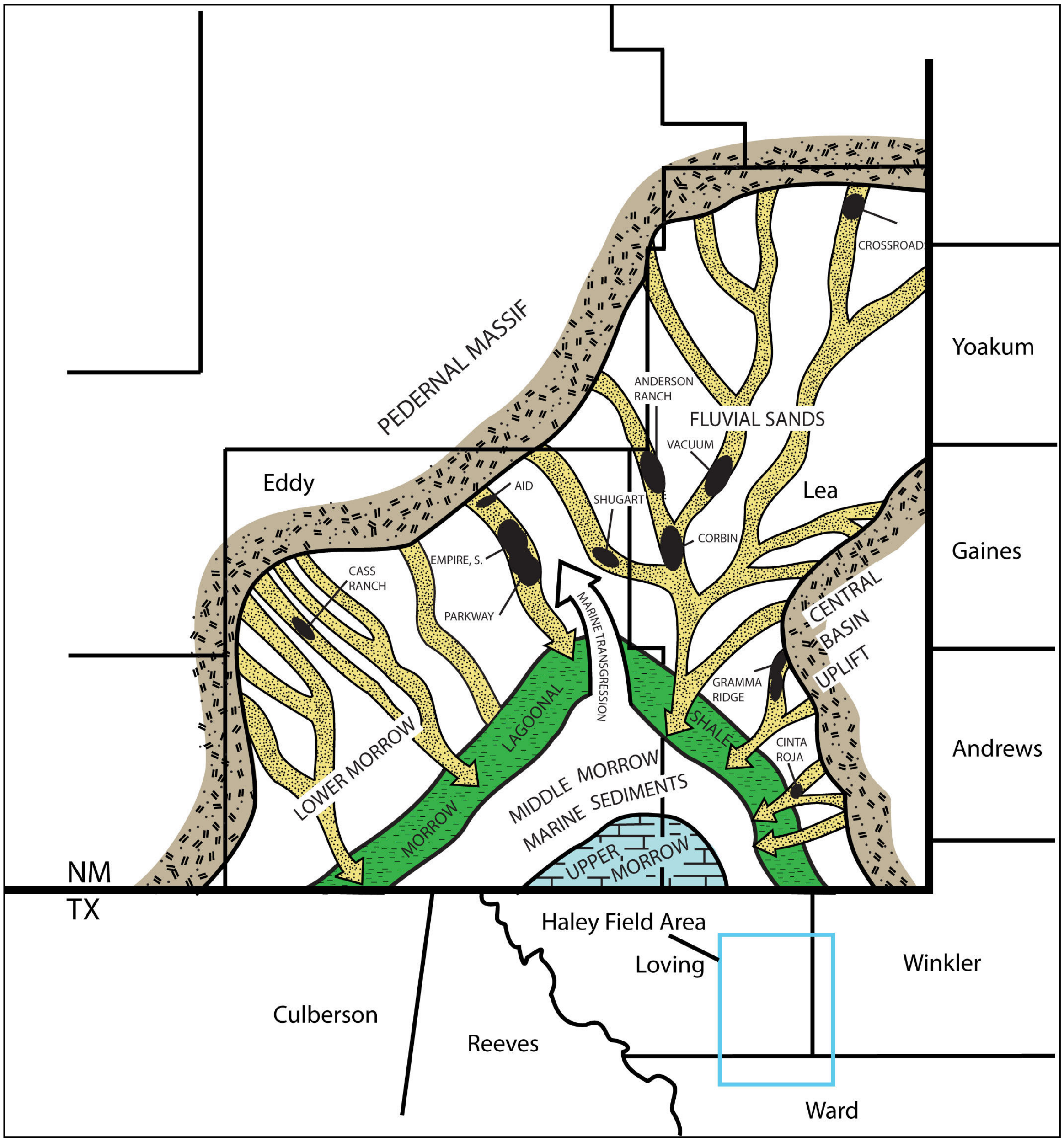


Figure 5. Map showing the interpretation of the depositional environment of the lower Morrow in southeast New Mexico from James (1985). The lower Morrow was interpreted as a southeast-prograding system of fluvial and deltaic deposits. The lower Morrow was covered by a marine transgression which deposited the middle and upper Morrow sediments, indicated by the white arrow. The exposed Pedernal Massif and the Central Basin Uplift were sediment sources. The Haley Field area is highlighted with a light blue box. Oil fields producing from the Morrow are shown in black.

same sediments as reworked delta or beach deposits. The upper Morrow, or Morrow limestone, contains interbedded limestone, marine shale, and thin sandstone beds. The Morrow-Atoka boundary likely lies within these limestones, but the boundary cannot be consistently identified on borehole logs. Atokan strata in the Delaware Basin of southeastern New Mexico are divided into a lower clastic unit and an upper limestone unit, separated by an unconformity. James (1985) interprets sandstones in the lower Atoka in the Parkway-Empire area in central Eddy County as barrier islands cut by surge channels (Fig. 6).

Environment of Deposition

Lower Morrow sediments in southeastern New Mexico and West Texas were deposited in point bars, fluvial-deltaic channels, and delta mouth bars (James, 1985; Casavant and Mallon, 1999). The sediments were derived predominantly from the Pedernal Massif to the north and west. The shoreline prograded from northwest to southeast, toward the Haley Field area. This regressive sequence was subsequently flooded during a large-scale transgression that deposited the upper Morrow limestone as well as landward-stepping deltaic deposits (Bay and Baltensperger, 1990). A similar fluctuation in relative sea level deposited the overlying lower Atoka clastics during its regressive phase and upper Atoka carbonates during its transgressive stage.

Braided fluvial deltaic systems dominated lower Morrow deposition in southeast New Mexico (James, 1985; Worthington, 1999). James (1985) explained the distribution of sandstone reservoirs in the lower Morrow using a meander belt model. A structure map on the base of the Morrow shale shows northwest-southeast trending features

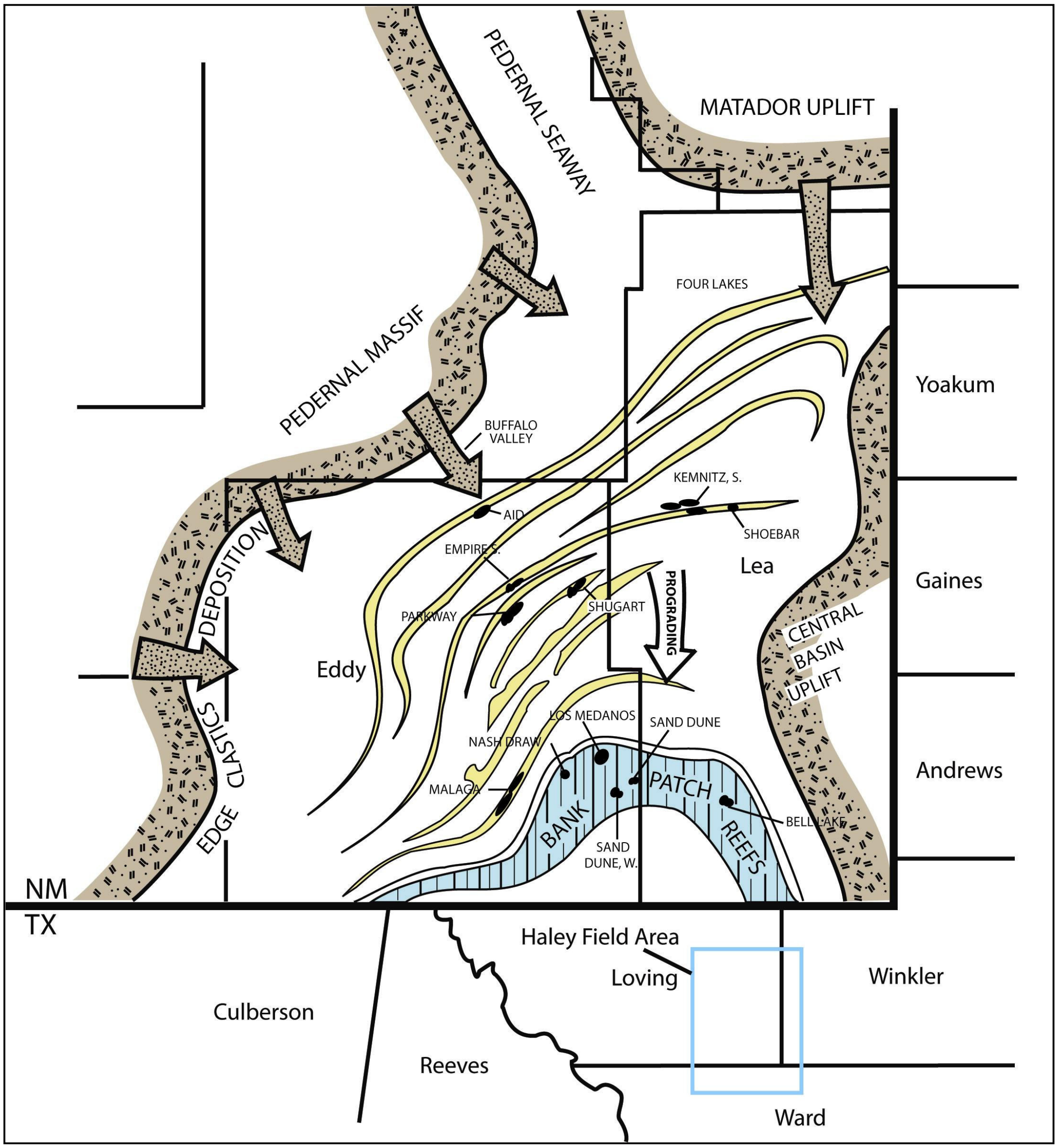


Figure 6. Map showing the interpretation of the depositional environment of the Atoka "B" sand after James (1985). James interpreted this sand as a system of barrier bars (yellow) prograding to the southeast. A subsequent transgression covered these sediments and deposited highstand bank patch reefs (blue) in southeast New Mexico. Both the Pedernal Massif and the Central Basin Uplift continued to serve as sources of sediment during this time. Oil fields producing from the Atoka are shown in black.

(James, 1985, his Fig. 5). These features result from differential compaction of sand and shale in the underlying lower Morrow clastics and reveal the orientation of river channels in that interval. Casavant and Mallon (1999) interpreted the lower Morrow strata as prodelta distal deposits of river-dominated deltas prograding south-southeast. Borehole geophysical logs through the lower Morrow show log curve shapes typical of point bars and channels (James, 1985; Walsh, 2007).

Clastic strata in the middle Morrow seem to have been deposited farther down paleoslope, to the south and southeast, than the lower Morrow strata. The middle Morrow clastics consist of thick, stacked sands. The lowermost sands have been interpreted as distributary channel and distributary mouth-bar deposits. The overlying sands have been interpreted as delta-front, prodelta, and delta-margin deposits (Casavant and Mallon, 1999). The middle Morrow represents deltaic and fluvial systems reworked by marine processes during subsequent transgression of the sea (Bay and Baltensperger, 1990). Oolitic marker beds are present in the middle Morrow (Casavant and Mallon, 1999).

Renewed uplift brought an influx of clastic sediment to the Northwestern Shelf of the Delaware Basin during the early Atokan. James (1985) interpreted the lower Atoka sands as barrier islands cut by surge channels. Shoreline-parallel sands trended northeast-southwest (Fig. 6) and the system prograded basinward to the southeast. The shoreline sands occur near the base of a predominantly clastic section overlying the shallow marine carbonates of the upper Morrow (Worthington, 1999). Terrigenous marine sediments of the lower Atoka were derived from the northwest, as were the fluvial sediments of the lower Morrow. Carbonate bank sediments, including reef deposits, accumulated farther basinward along the slope break (Hills, 1985) (Fig. 6).

Methods

271 digital and raster logs spread over more than 3000 square miles were correlated in this study, covering almost the entire northern portion of the Delaware Basin of southeastern New Mexico and west Texas (Figs. 1 and 4). The logs were correlated using Petra® version 3.1.9.9, IHS Energy software. Sixty-one wells had digital logs. The remaining 210 logs were raster images. The gamma ray curve was digitized on the remaining 210 logs to permit more efficient calculations from the logs.

Isopach, structure and sand percent maps were created from the log database. Net sand was determined using a gamma ray cutoff of 45 API units. The maps were contoured by hand and then gradient fills were generated from the contour lines. Cuttings were described for each ten-foot interval from three wells (Fig. 1, Table 1). The cuttings were made available by the Bureau of Economic Geology, University of Texas-Austin. For complete descriptions of the cuttings see Appendix A.

Lithologic Determination

From Logs

Limestones, dolomites, sandstones and shales are all present in the Lower and Middle Pennsylvanian strata in the Haley Field area. Lithologic determinations were made using combinations of responses from gamma ray, neutron-porosity (NPHI), density-porosity (DPHI), bulk density and resistivity logs. Shales were identified as having a gamma ray reading greater than 45 API units and a normal NPHI and DPHI separation greater than 10 percent porosity. Intervals with gamma ray readings less than 30 API units, NPHI and DPHI between 0 and 5 percent, and no more than 5 percent porosity separation between NPHI and DPHI were interpreted as limestone. A gamma ray cutoff of 30 API units and a normal NPHI and DPHI separation of greater than 5 percent but with less than 10 percent porosity was taken to indicate dolomite. NPHI and bulk density from intervals with gamma ray counts less than 45 API units were then plotted on a porosity/lithology crossplot (see Schlumberger, 2000). Points that plotted to the left of the quartz sandstone line were interpreted as quartz sandstones

Using these criteria, less than 5 percent of the entire Morrowan interval in the study area is sandstone. The vast majority of Morrow sediments are carbonate rock and shale. Shale makes up 60-70 percent of the lower and middle Morrow, sandstone makes up 10-20 percent and carbonate rock, the remainder. Carbonate rock comprises some 50-60 percent of the upper Morrow on the Northwestern Shelf, but increases to 80-90 percent at the shelf edge. Thin sandstones occur throughout the upper Morrow, but the majority of the sediments in this interval are carbonates and shales. The Atoka is similar to the upper Morrow: carbonates comprise 50-60 percent of the interval and the remaining 40-50 percent is shale. Only a few thin sandstones are present in the Atoka in the Haley Field area.

From Cuttings and Thin Sections

Cuttings reveal most of the rock in the Lower and Middle Pennsylvanian to be limestone, dolomite or shale, as determined from log interpretation. Abundant quartz-rich siltstone and very fine-grained, quartz-rich sandstones with secondary dolomite rhombs are present in the lower and middle Morrow. A few pieces of poorly sorted, coarse-grained arkosic sandstone were recovered from cuttings from all three wells from the lower Morrow. Fragments of chalky and micritic carbonates are also present throughout the entire Morrow interval. Light brown to tan ooids and pieces of oolitic limestone are present in cuttings from the interval at the top of the middle Morrow. Operators in the area use this oolitic limestone to mark the top of the middle Morrow. Ooids were present in cuttings from all three wells, but were most abundant in the Hunt Hassie University 18-39 #1 at the southern edge of Haley Field.

Pieces of clean, well-rounded, well-sorted, fine-grained quartz-rich sandstone were present in small amounts in cuttings from all three wells over the entire interval. Fragments of fine-grained quartz sandstones with quartz overgrowths are present in a few samples from the Atoka. Cuttings from the limestone interval above the Atoka shale contained some fossils but were mainly micritic. This limestone interval marks the top of the Atoka.

Fifteen thin sections were made from cuttings impregnated with epoxy resin and stained for carbonate. Potentially productive zones in the Atoka and Morrow were chosen for thin sections to determine lithology and porosity. Zones that appeared to be porous and quartz-rich were chosen to verify the nature of the rock. Other zones were chosen in which the lithology was difficult to determine using a binocular microscope.

The thin sections revealed additional petrographic detail about productive intervals within the study area (Fig. 7). Porous intervals in the lower and middle Morrow are primarily quartz siltstone with scattered dolomite rhombs, and very little limestone is present (Figs. 7A, 7B). Both of these thin sections came from the same interval in

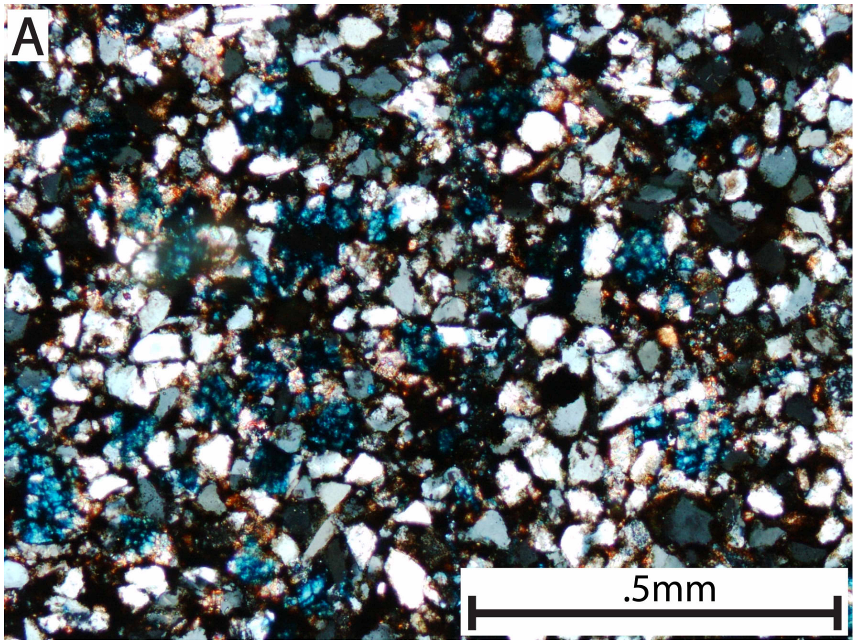


Figure 7A. Photomicrograph of thin section made from cuttings from the Pennzoil Mrs. O.P. Anderson #1 located in Loving County at 17,630 feet in the lower Morrow. Quartz siltstone with secondary dolomite rhombs (blue staining). Cross-polarized light.

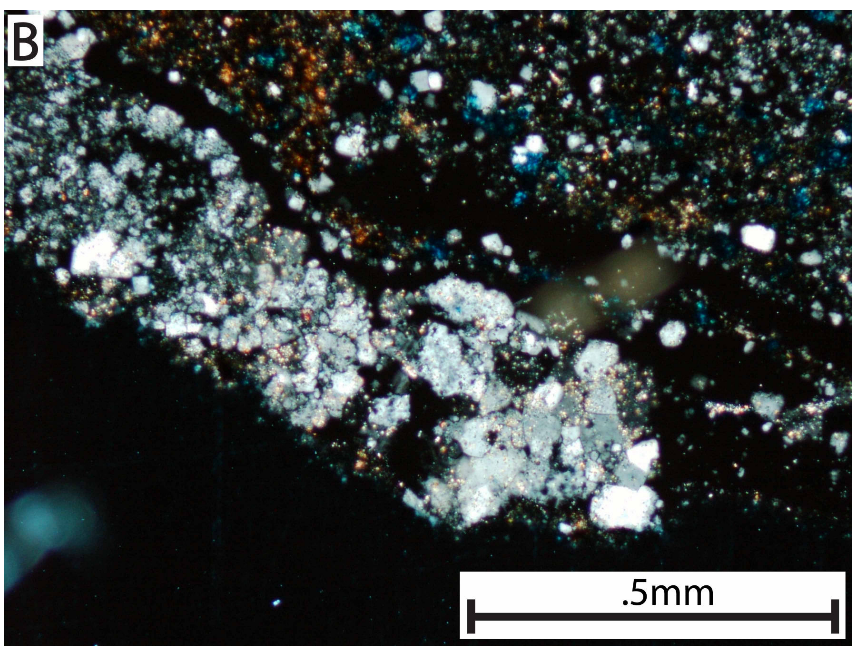


Figure 7B. Photomicrograph of thin section made from cuttings from the Hunt Hassie University 18-39 #1 well located in Ward County at 16,660 feet in the middle Morrow, showing siltstone layer within shale. Quartz grains are well sorted and have overgrowths. Cross-polarized light.

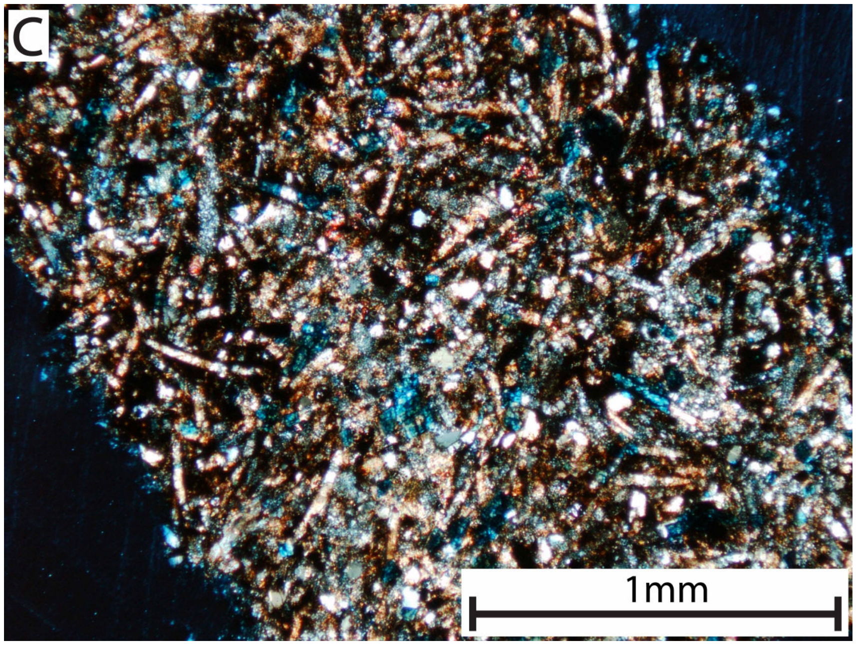


Figure 7C. Photomicrograph of thin section made from cuttings from the Hunt Hassie University 18-39 #1 located in Ward County at 17,020 feet. Abundant sponge spicules in the lower Morrow are visible as well as some calcite (red) and some dolomite rhombs (blue). Cross-polarized light.

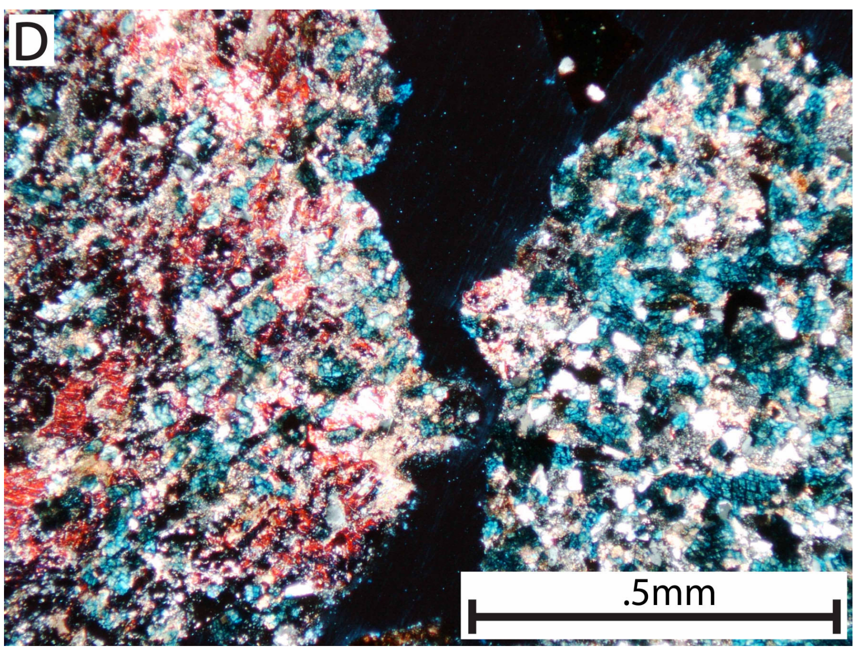


Figure 7D. Photomicrograph of thin section made from cuttings from the Pennzoil Mrs. O.P. Anderson #1 located in Loving County at 17,230 feet in the lower Morrow showing limestone and dolomite fragments. Calcite is stained red and dolomite is stained blue. Cross-polarized light.

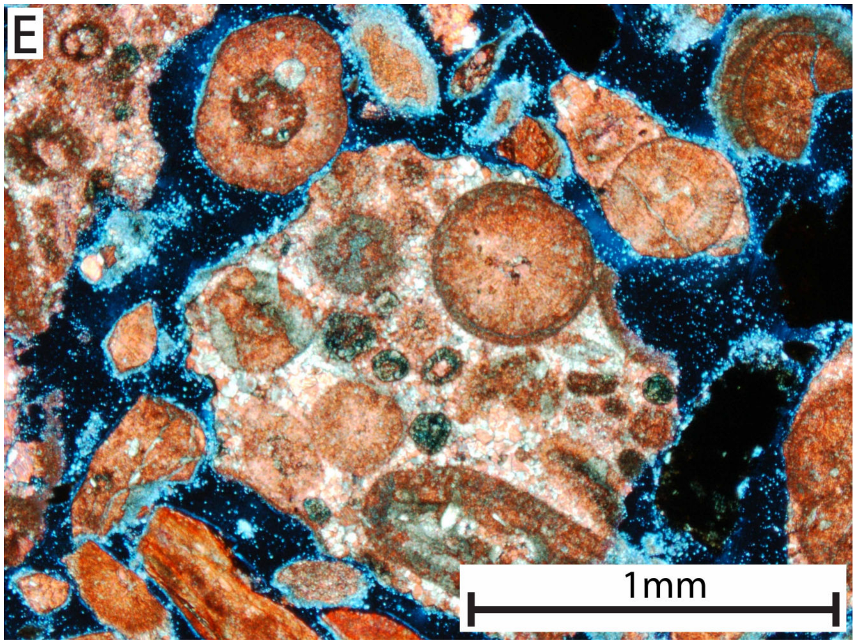


Figure 7E. Photomicrograph of thin section made from cuttings from the Hunt Hassie University 18-39 #1 located in Ward County at 16,460 feet. The interval immediately overlies the middle Morrow. It is an oosparite and oolites have nucleated primarily around quartz grains. Cross-polarized light.

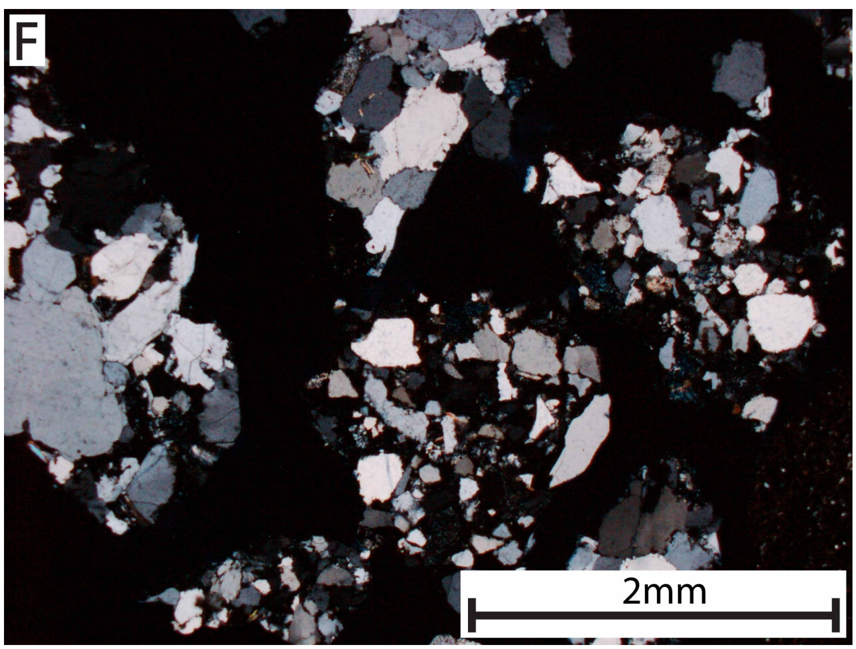


Figure 7F. Photomicrograph of thin section made from cuttings from the Sun Oil Moore Hooper et al. #1 located in Loving County at 15,850 feet in the Atoka, showing quartz sandstone with quartz overgrowths. The sandstone is poorly sorted and has angular quartz grains. Cross-polarized light.

different wells. Similar lithologies are present throughout the lower and middle Morrow. The presence of dolomite may suppress log curves over intervals containing this quartz siltstone and should be considered when interpreting lithology from logs in the area. Siliceous sponge spicules are present in many samples but were most abundant in the lower Morrow (Fig. 7C). Dolomite and limestone are present throughout the lower and middle Morrow as well (Fig. 7D). Oolites immediately above the middle Morrow are cemented by sparry calcite and nucleated around quartz grains (Fig. 7E). Quartz sandstone in the Atoka contains overgrowths and very little porosity, and almost no carbonates were present in this interval (Fig. 7F).

The thin sections showed that quartz-rich cuttings are predominantly siltstone, some of which are rich in sponge spicules. Nearly all samples contained diagenetic dolomite rhombs. Carbonates were present but were most abundant in the upper Morrow and Atoka.

Structural Geology of the Haley Field Area

Tectonic movements associated with the Marathon-Ouachita Orogeny took place in the Delaware Basin throughout the deposition of the Morrow and Atoka. Faulting and folding affected the Central Basin Uplift, Grisham Anticline, Red Hills Arch, Pedernal Massif, Diablo Platform and other more subtle basement-involved folds and faults (Galley, 1958; Walper, 1977; Shumaker, 1992) (Figs. 3, 8). These structures were active during deposition and created complex patterns of sediment distribution in the Lower and Middle Pennsylvanian.

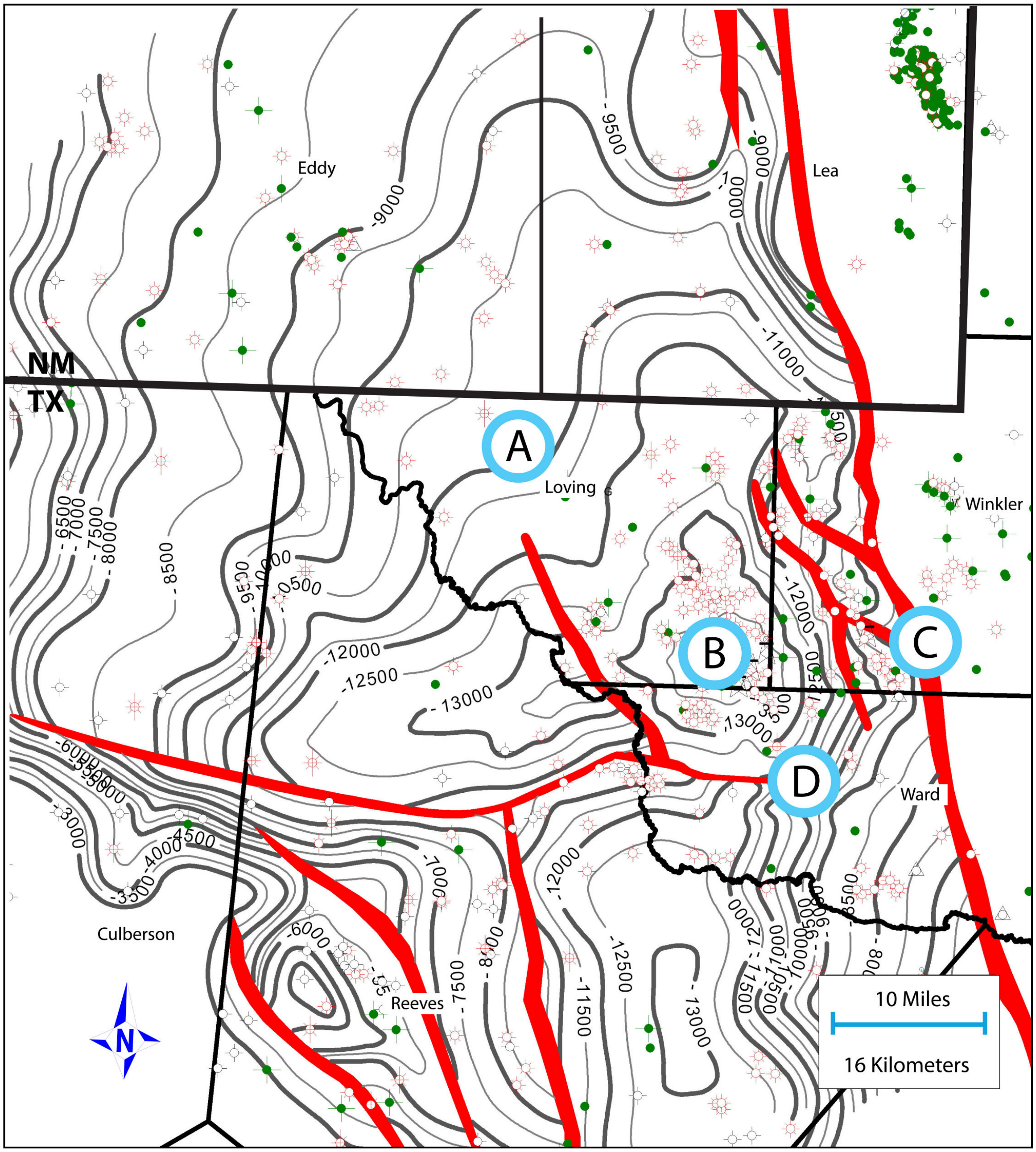


Figure 8. Structure map on the Atoka shale, faults are indicated by thick red lines. Features of interest include: A, southern extension of the Red Hills Arch (Wright, 1978); B, Depocenter & Haley Field Area; C, Central Basin Uplift Fault Zone; D, Grisham Anticline. Contour interval, 500 ft.

The Central Basin Uplift is the nearest positive element to Haley Field. It began rising during the Mississippian (Schumaker, 1992), but underwent significant uplift during the Pennsylvanian. It provided sediment to the basin and developed sufficient relief to affect the distribution of sediment around its margins (Frenzel et al., 1988; Shumaker, 1992). Not until the Wolfcampian (Early Permian) did carbonate reefs begin to develop on the high (Frenzel et al., 1988).

A faulted anticline is present in the southern portion of the study area. This feature has been called the Grisham Anticline by Walper (1977), the Mid-basin fault by Shumaker (1992) and the Grisham Fault by Yang and Dorobek (1995). Morrowan and Atokan strata thin over the eastern portion of the feature, suggesting it was a positive element at the time of deposition. The amount of thinning decreases to the west, indicating the structure grew westward through time. At present, a nearly vertical strike-slip fault exists in the location of the anticline.

Another positive feature in the study area is the southern extension of the Red Hills Arch of Wright (1979), which extends into the northwest corner of Loving County (Figs. 3, 8). This feature can be seen on structure maps of the lower, middle, and upper Morrow as well as the Atoka shale. The Red Hills Arch is clearly seen on an isopach map of the Barnett Shale (Mississippian) (Fig. 9), indicating it formed either before or during the Pennsylvanian. Wright (1979) suggests it was present during the Mississippian. There are virtually no coarse clastics on the Red Hills Arch in the lower and middle Morrow suggesting the presence of an unconformity. The arch was likely an area of non-deposition during the Morrowan and Atokan. Carbonates appeared on the Red Hills Arch as the upper Morrow shelf prograded over this high.

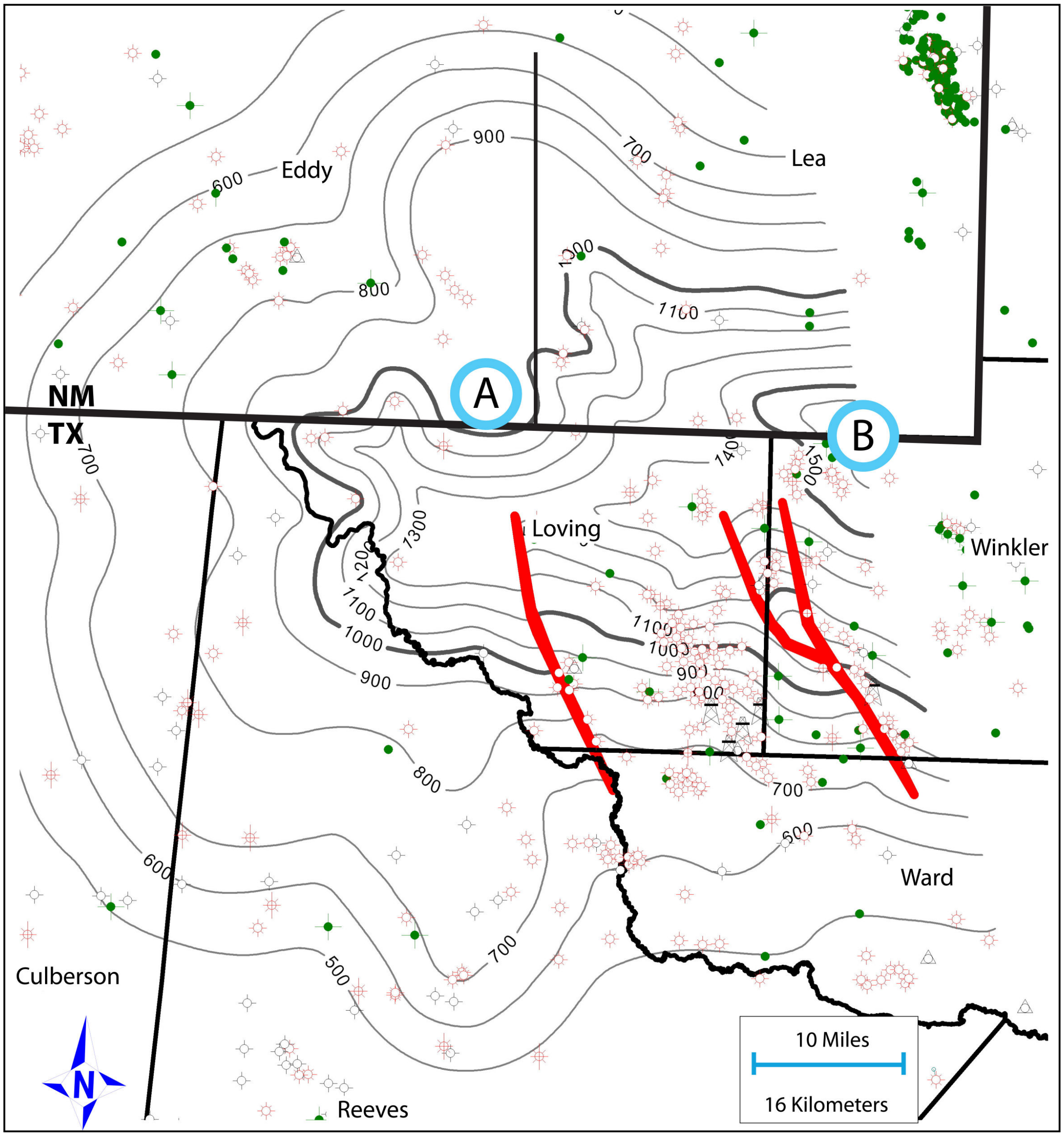


Figure 9. Isopach map of the Barnett Shale. This map represents paleostructure during the Mississippian. Important features include: A, southern extension of the Red Hills Arch; B, Depocenter of the Tobosa basin. Contoured interval, 100 ft.

The structure of the Delaware Basin formed during the Pennsylvanian was modified when the Laramide orogeny tilted the western side of the Delaware Basin to the east (Ewing, 1991). A structure map on the Atoka shale shows that all sides of the basin dip toward the basin center at present day (Fig. 8). However, Morrowan and Atokan strata were deposited in a southwest trend around the western edge of the Grisham Anticline. When tilting due to the Laramide orogeny is taken into account, the dip on the western side of the basin decreases significantly (Nelson, 2008, personal communication). When these factors are considered, paleoslope changes during the Pennsylvanian and is oriented to the southwest.

Stratigraphy

The Morrow strata in the Haley Field area can be subdivided into three zones, informally called the lower, middle, and upper Morrow (Fig. 2). The lower Morrow is predominantly shale with some limestone and about 10 feet of sandstone at the top. The thickness of the lower Morrow is relatively uniform throughout the study area, about 200 to 300 ft (Figs. 10A-C and 11A).

The middle Morrow in the study area consists mainly of shale, limestone, quartz sandstone and quartz siltstone. Quartz sandstones make up less than 5 percent of the interval. Log responses within this interval vary substantially, making log correlation difficult. The middle Morrow is also of relatively uniform thickness, about 400 to 500 ft (Fig. 11B). This interval can be further subdivided into four units (A, B, C, and D) (Figs. 2 and 10C). Shale at the top of the middle Morrow marks the boundary with the upper Morrow.

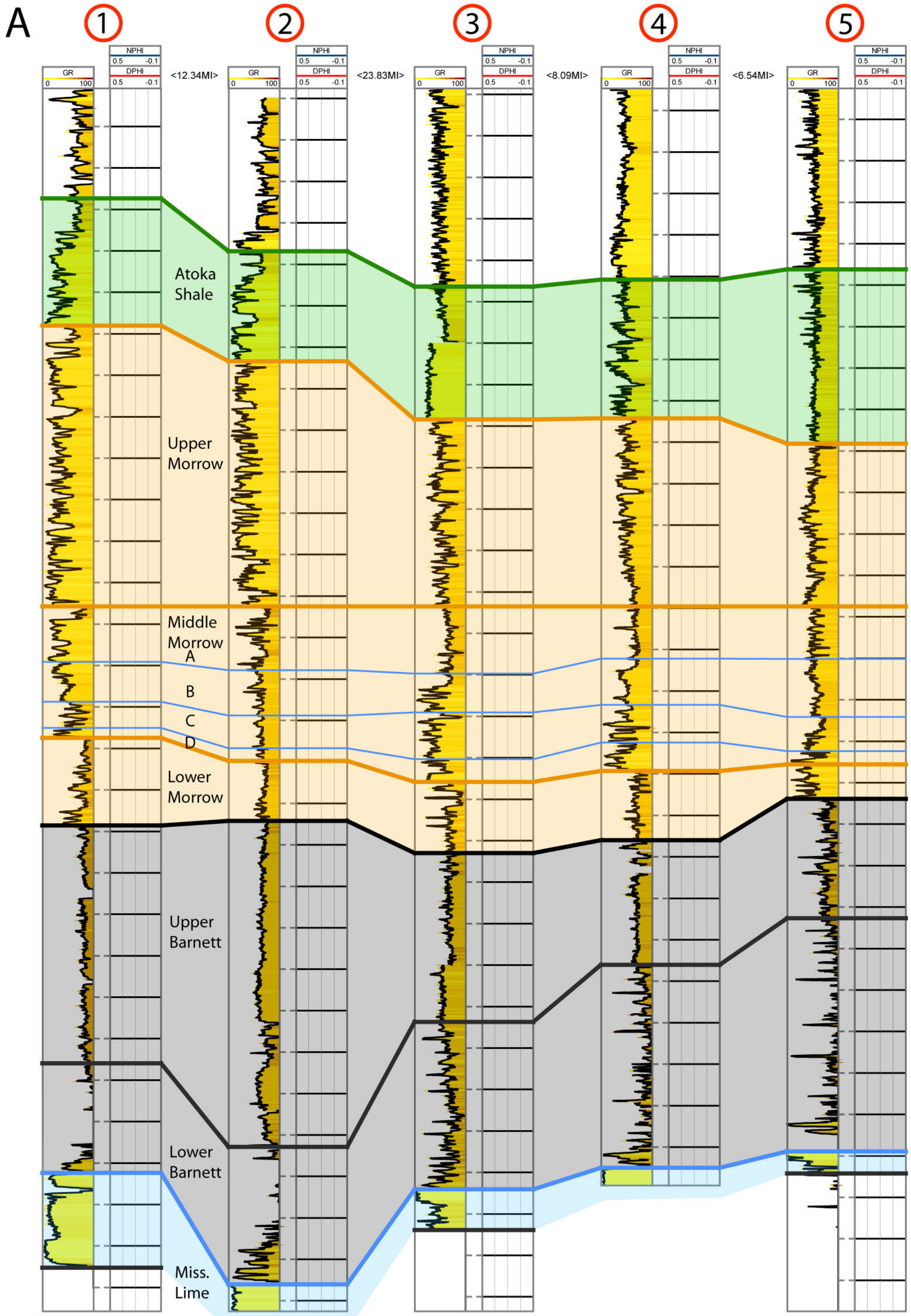


Figure 10A. North-south cross section across the study area (Fig. 1). The lower Morrow is mostly shale, the middle Morrow is a combination of carbonates and coarse clastics, and the upper Morrow is mostly carbonate. The transition of the predominantly carbonate upper Morrow in the north to predominantly shale in the south is clearly seen in the increase of shale in the upper Morrow from left to right. The datum is the top of the middle Morrow.

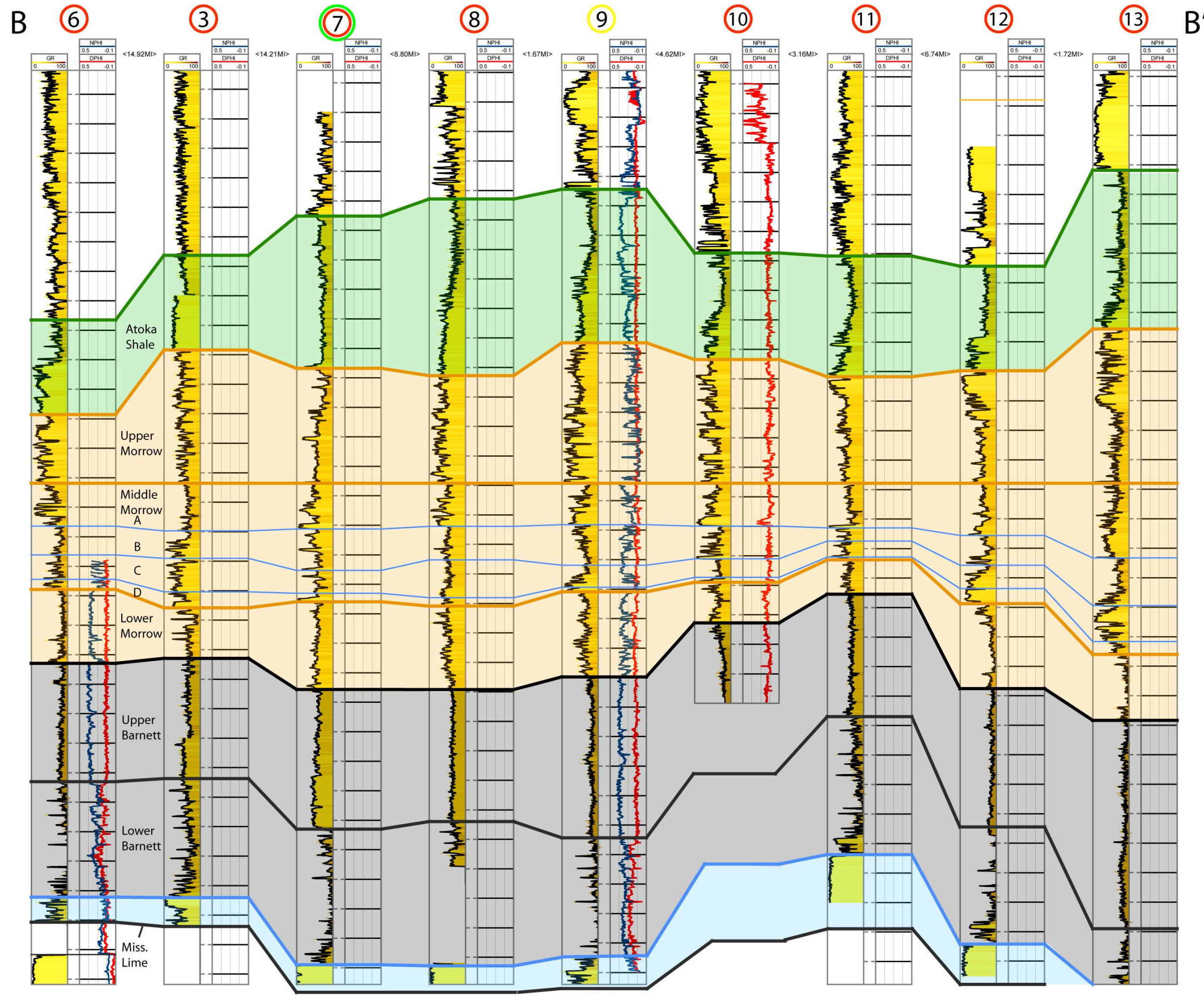


Figure 10B. **W-E cross section through the study area. The change from carbonates to shale into the basin is clearly visible here as well. The lower and middle Morrow maintain relatively uniform thickness while the upper Morrow and Atoka vary dramatically as a result of carbonate deposition. The lower Morrow thins over a northern salient of the Grisham Anticline. Datum is the top of the middle Morrow. Colored circles around well numbers correlate to those found in**

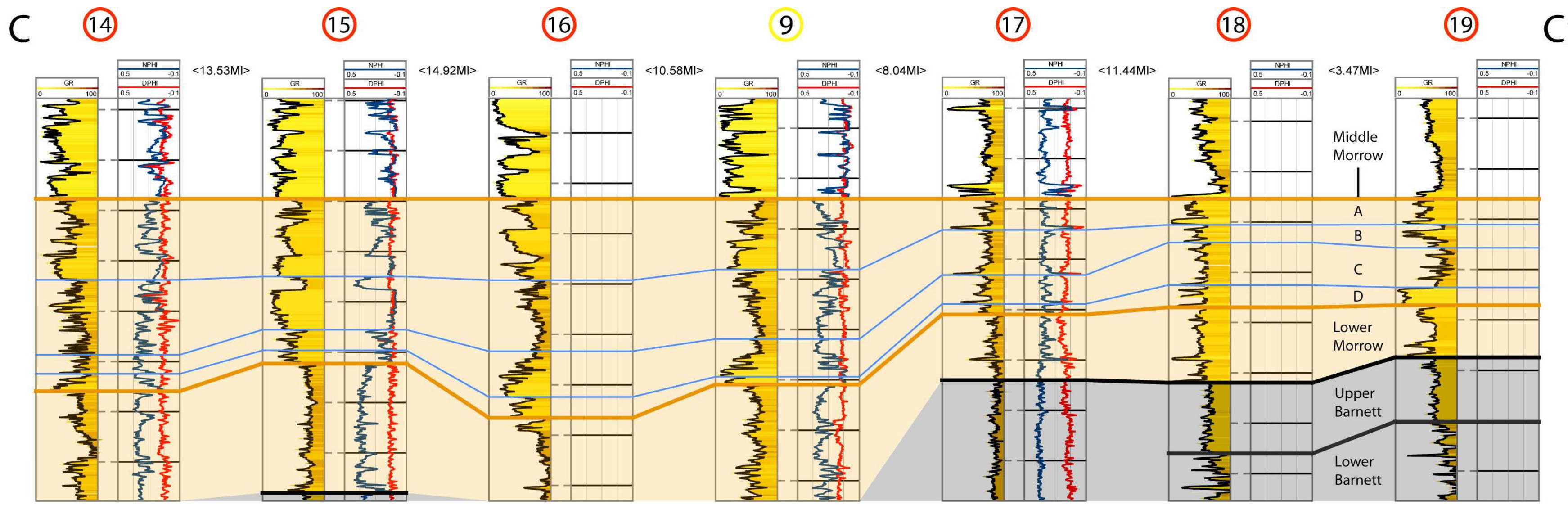


Figure 10C. North-south cross section of the middle Morrow highlighting the four intervals mapped in additional detail. The middle Morrow is highly channelized.

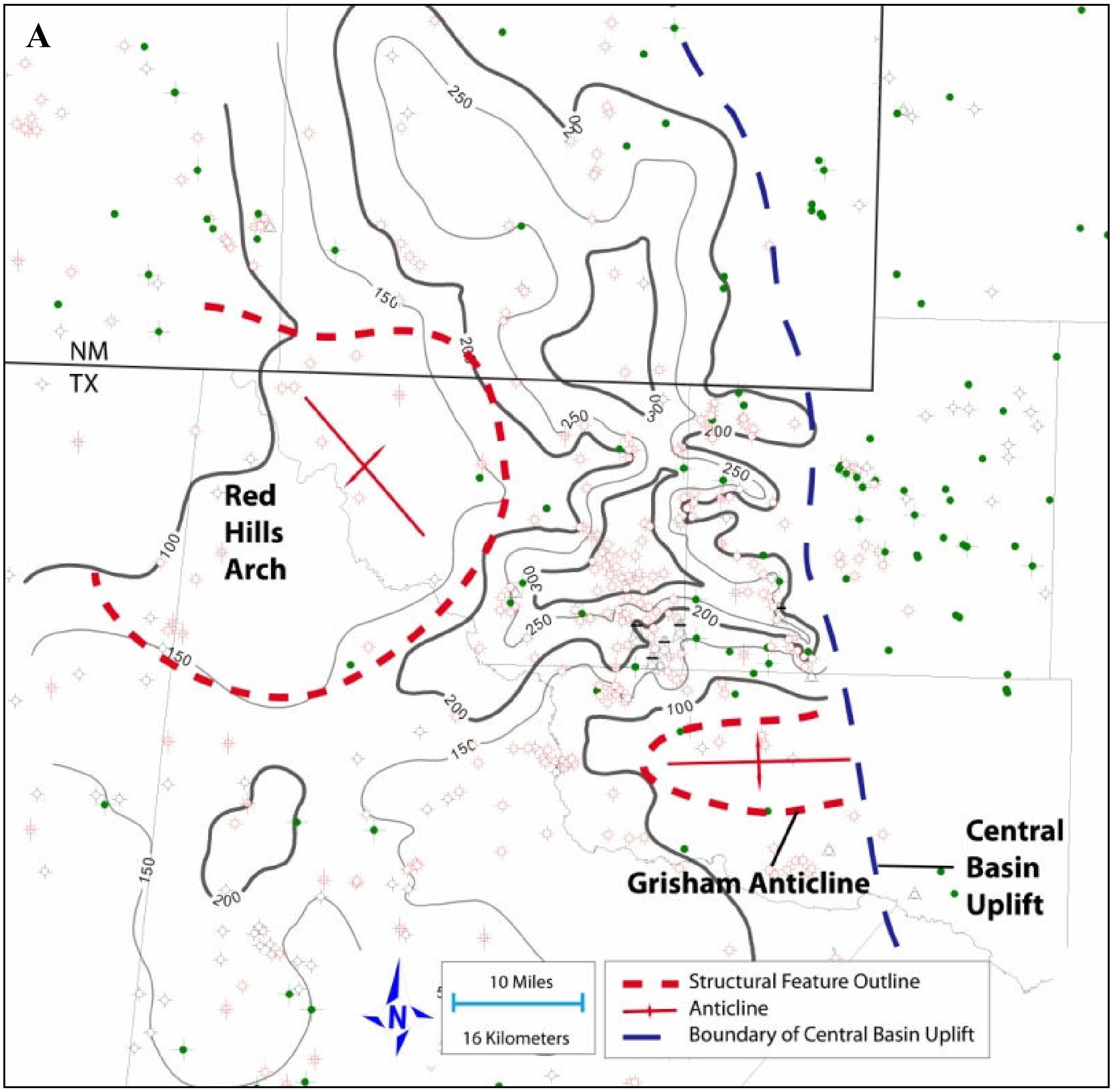


Figure 11A. Isopach map of the lower Morrow. Two primary depocenters are apparent as well as restricted deposition on and around structural highs. Structural highs are enclosed by red dotted lines, and the western flank of the Central Basin Uplift is denoted by a blue dotted line. Contour interval, 50 ft.

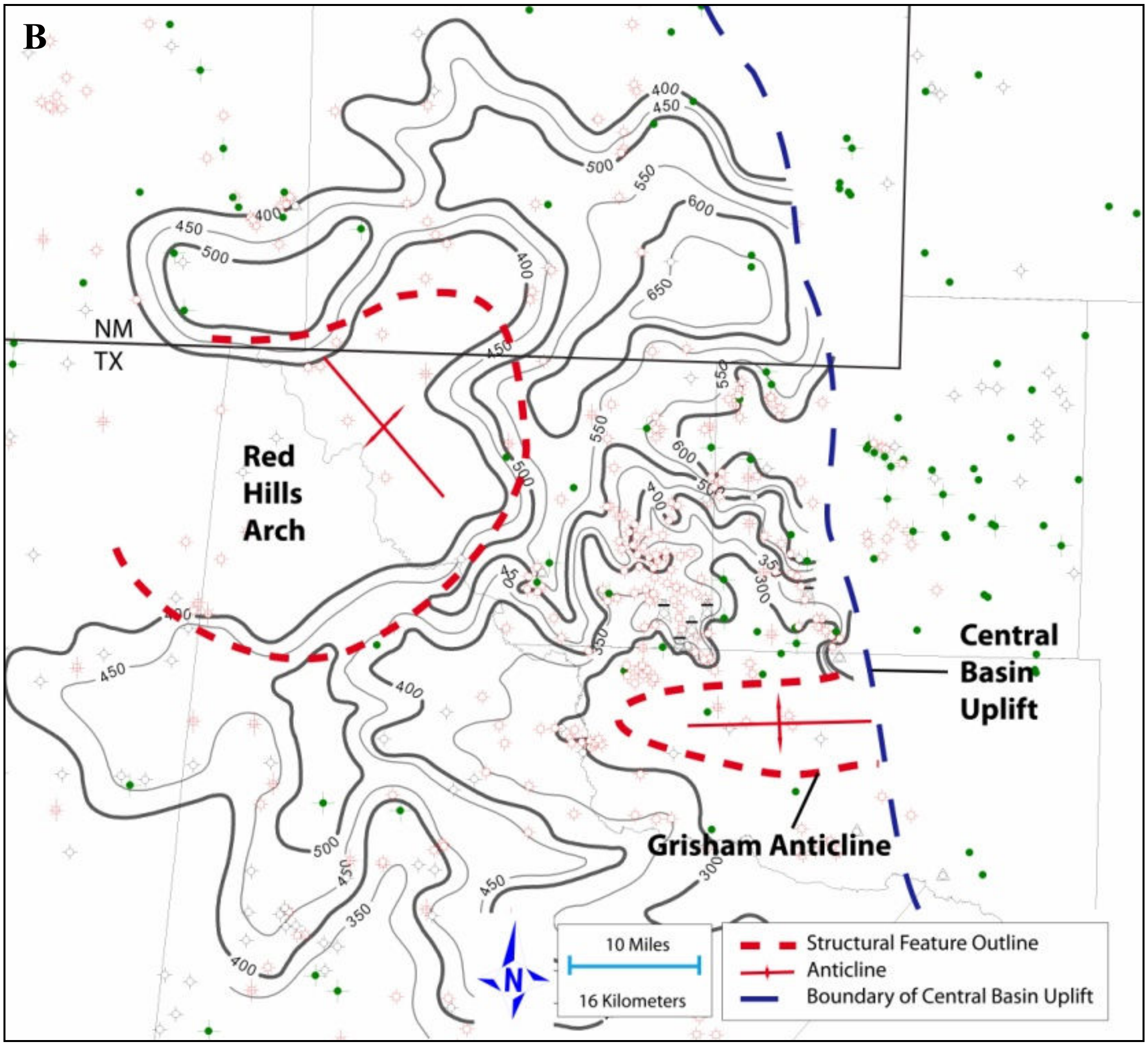


Figure 11B. Isopach map of the middle Morrow. Several depocenters are apparent as well as the structurally controlled geometry of deposition. The Grisham Anticline and Red Hills Arch both strongly controlled deposition. Contour interval, 50 ft.

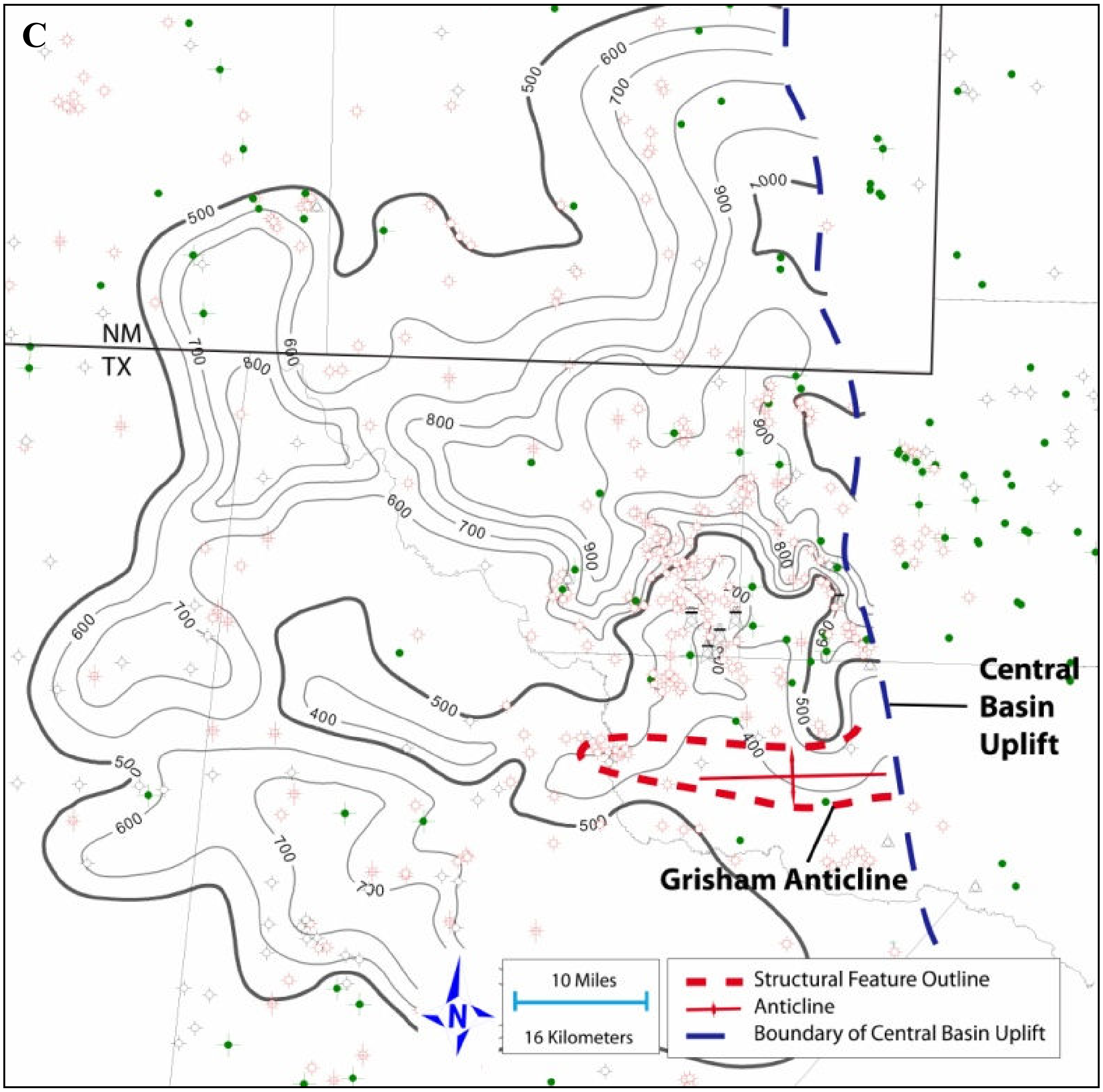


Figure 11C. Isopach map of the upper Morrow. The upper Morrow is thickest in an east-west direction through Loving County and northern Reeves County. It is also thick to the south. The upper Morrow thins across the Grisham Anticline high. Contour interval, 100 ft.

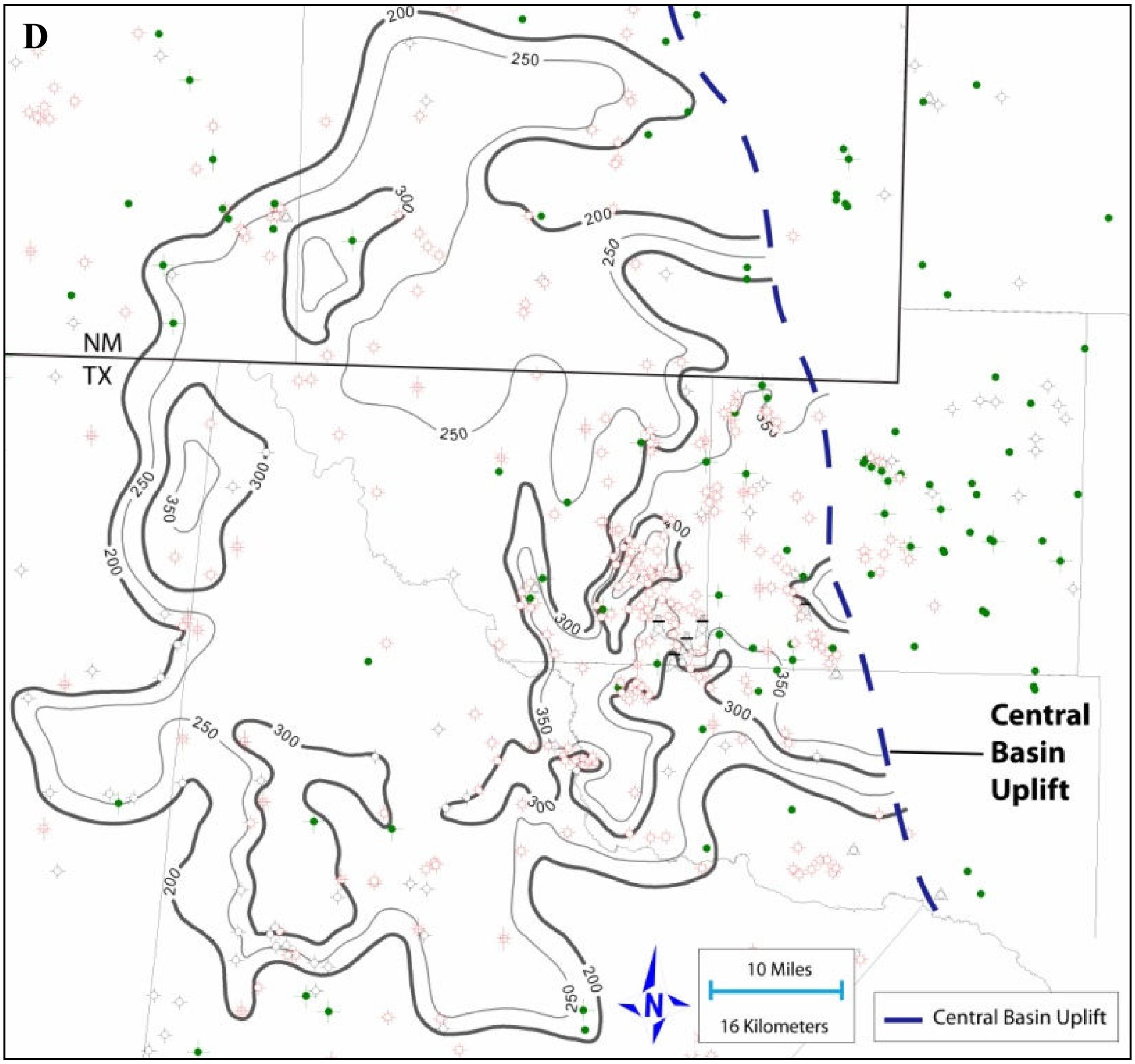


Figure 11D. Isopach map of the Atoka. The Atoka is thickest in the south in a northeast – southwest direction. Note that the Grisham Anticline is no longer present and does not affect deposition during the Atoka. Contour interval, 50 ft.

The upper Morrow represents the greatest part of the Morrow Series. It is 700 to 900 ft thick (Fig. 11C). The upper Morrow consists primarily of carbonates in the northern portion of the study area, but is almost entirely shale with minor amounts of sandstone in the southern portion. A sharp line delineates the area of mainly carbonate deposition in the north from the area of mainly shale deposition in the south.

The Atoka is 200 to 300 ft thick in the study area (Fig. 11D). It consists of a lower section composed mainly of clastics and an upper section composed mainly of limestone (Fig. 2). The clastics are predominantly shale with some quartz sandstone. In southeastern New Mexico, the Atoka is also divided into a lower clastic section and an upper carbonate section (James, 1985; Worthington, 1999; Casavant and Mallon, 1999).

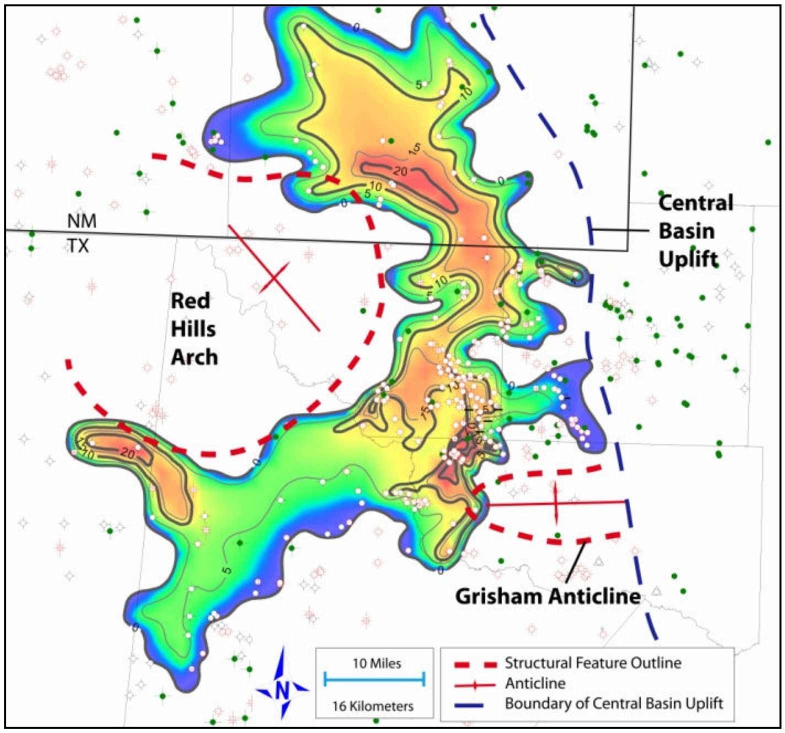
Sediment Distribution

During the Early and Middle Pennsylvanian, the Delaware Basin was surrounded by exposed land masses, as stated previously (Galley, 1958; Wright, 1979, his Fig.14). The distribution of source areas and depositional sites in this intracratonic basin was largely controlled by structural activity. The Pedernal Massif was the primary source of sediment for the Northwestern Shelf and the Delaware Basin throughout the Pennsylvanian (Galley, 1958, Casavant and Mallon, 1999). However, the Central Basin Uplift also contributed sediment to the basin, especially in the Haley Field area. The emergent Central Basin Uplift influenced sediment distribution in the ancestral Tobosa Basin during the Mississippian as well, but most likely had only low relief (Shumaker, 1992). The Central Basin Uplift was rising during the Pennsylvanian and portions of it were exposed and eroded. The evidence for this is thinning of Mississippian strata across portions of the uplift (Galley, 1958). In the Late Pennsylvanian and Permian, the Central Basin Uplift was largely exposed and erosion took place over large areas. By Late Pennsylvanian, erosion formed a flat surface on which reefs developed in the Permian (Galley, 1958; Frenzel et al., 1988; Shumaker, 1992).

Sand percent maps of the lower and middle Morrow and limestone percent maps of the upper Morrow and Atoka show two distinct patterns of sediment distribution in the basin (Fig. 12A-B). Sand percent maps and limestone percent maps were used to identify the depositional environment by removing variations in sand and limestone thickness in this structurally active area. The first pattern of sediment distribution was predominantly southward into the basin center. Upon reaching the center of the basin, the sediment was then carried in a west-southwest direction (Fig. 12A). Following the middle Morrow, the pattern of sediment distribution changed. The second pattern of sediment distribution, which characterizes the upper Morrow and Atoka, is dominated by progradation of carbonates forming along the edge of the Northwestern Shelf (Fig. 12B). Carbonates make up 80-90 percent of this interval in some locations, particularly to the north of the Haley Field area. The Red Hills Arch is less apparent during the deposition of the upper Morrow and Atoka, suggesting sediment prograded southward over it. In contrast, the Grisham Anticline and the Central Basin Uplift continued to influence deposition.

High percentages of sand on the sand percent map of the lower Morrow coincide with isopach thicks (compare Figs. 11A and 12A). The sediment trend turns southwest at the basin center suggesting either multiple sources or structural controls, or both. A similar pattern of sediment distribution is seen on maps of the middle Morrow (Figs. 11B

Lower Morrow



Middle Morrow

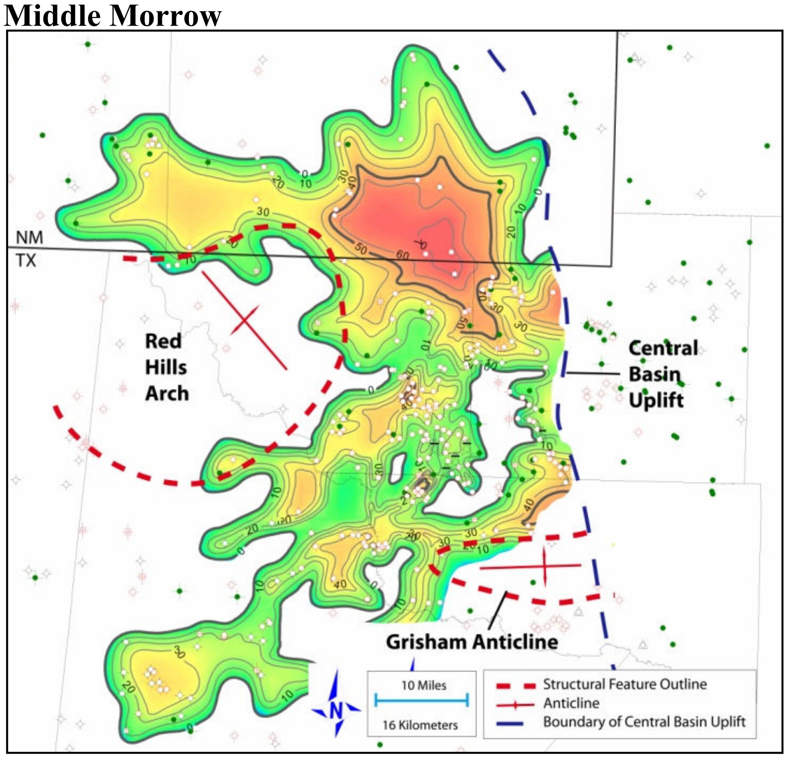
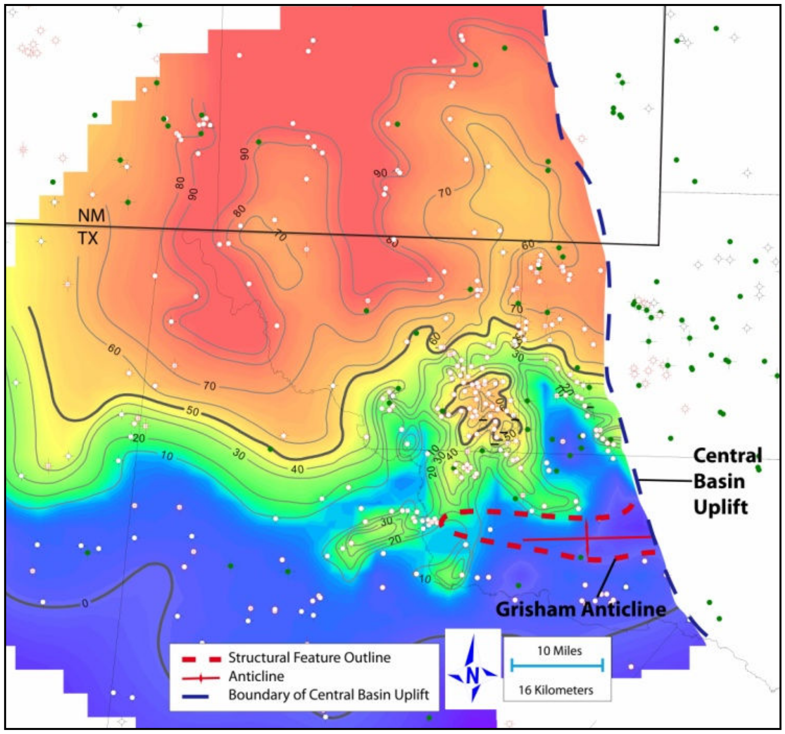


Figure 12A. Sand percent maps generated on the lower and middle Morrow. These maps were contoured on a 10% contour interval. Warm colors represent high percentages of sandstone and cool colors represent lower percentages of sandstone.

Upper Morrow



Atoka

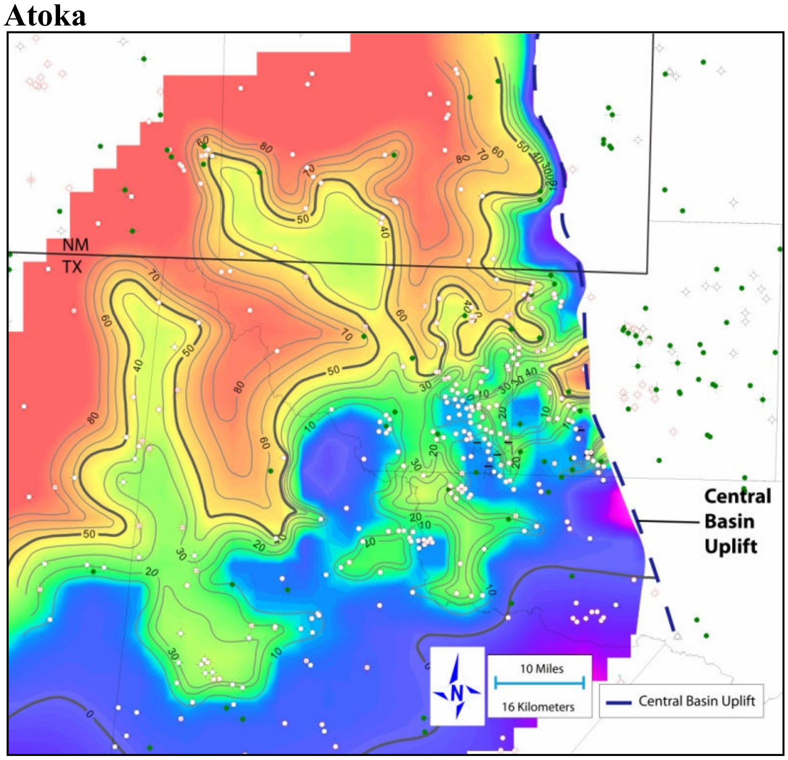


Figure 12B. Limestone percent maps generated on the upper Morrow and Atoka. These maps were contoured on a 10% contour interval, warm colors represent high percentages of limestone and cool colors represent lower percentages of limestone.

and 12A). During the lower and middle Morrow the Red Hills Arch in the northwest corner of Loving County must have deflected sediment derived from the Pedernal Massif to the east. In the center of the basin, this sediment delivery system was joined by sediment derived from the Central Basin Uplift and deflected to the southwest. The scarcity of sand in the lower Morrow suggests the shelf edge was some distance removed to the northwest.

Both the lower and middle Morrow thin across the Grisham Anticline, suggesting it was either already established or beginning to form. The structure began forming on its eastern end, then grew to the west, and was later faulted. The western portion of the anticline apparently had no influence on the deposition of lower and middle Morrow sediment, indicating that it did not yet extend that far.

The upper Morrow is thickest at the shelf edge, where carbonate deposition dominated (Figs. 11C and 12B). Sediment derived from or transported across the shelf was deposited to the south and east of the shelf edge in lobes on the basin floor. These patterns of sediment accumulation and sediment distribution persisted through the Atoka (Figs. 11D and 12B). Most of the sediment was apparently derived from the north and west, but the Central Basin Uplift to the east also provided sediment to the basin.

Depositional Setting

Depositional setting was inferred from lithology, patterns of sediment dispersal, and knowledge of the regional geologic setting. The fine-grained nature of the Morrowan and Atokan strata suggests that relatively low-energy conditions prevailed in the Haley Field area. On occasion, however, higher energy conditions existed. The presence of silt-sized quartz at most depths in the wells from which cuttings were described suggests terrestrial sources provided sediment to the basin throughout deposition of the Lower and Middle Pennsylvanian. The sandstones and siltstones are texturally and compositionally mature (well-sorted, well-rounded, fine-grained and quartz-rich). High textural maturity suggests considerable time in the sedimentary mill under rigorous conditions, and perhaps a long transport distance. Coarse, angular grains of orthoclase suggest a second, more proximal source. Crystalline basement rocks were exposed in the Pedernal Massif during the Pennsylvanian (Wright, 1978; James, 1985; Casavant and Mallon, 1999). However, the size and angularity of the grains suggest a much closer source, most likely the Central Basin Uplift. Mississippian strata thin over the uplift, indicating erosion may have occurred, possibly to the basement in some areas (Galley, 1958). Abundant ooids at the base of the upper Morrow indicate a shallow, high-energy carbonate environment. Few quartz grains are found in the cuttings that contain ooids suggesting the latter have not been resedimented. Sponge spicules present in cuttings from the lower and middle Morrow are also indicative of marine sedimentation.

I interpret the lower and middle Morrow sediments in the Haley Field area as the deposits of submarine ramps fed by turbidites flowing off the Northwestern Shelf and the Central Basin Uplift. Reading and Richards (1994) classified basin-margin turbidite systems by grain size and sediment source. According to this classification, deep-water deposits off the Northwestern Shelf are multiple-source submarine ramp systems with mud to sand-sized sediment. Sediment was supplied to the basin from the Northwestern Shelf by five major sources in the middle Morrow (Fig. 13). Source areas for ramp systems are typically small to moderate size, have moderate gradients, and are close to

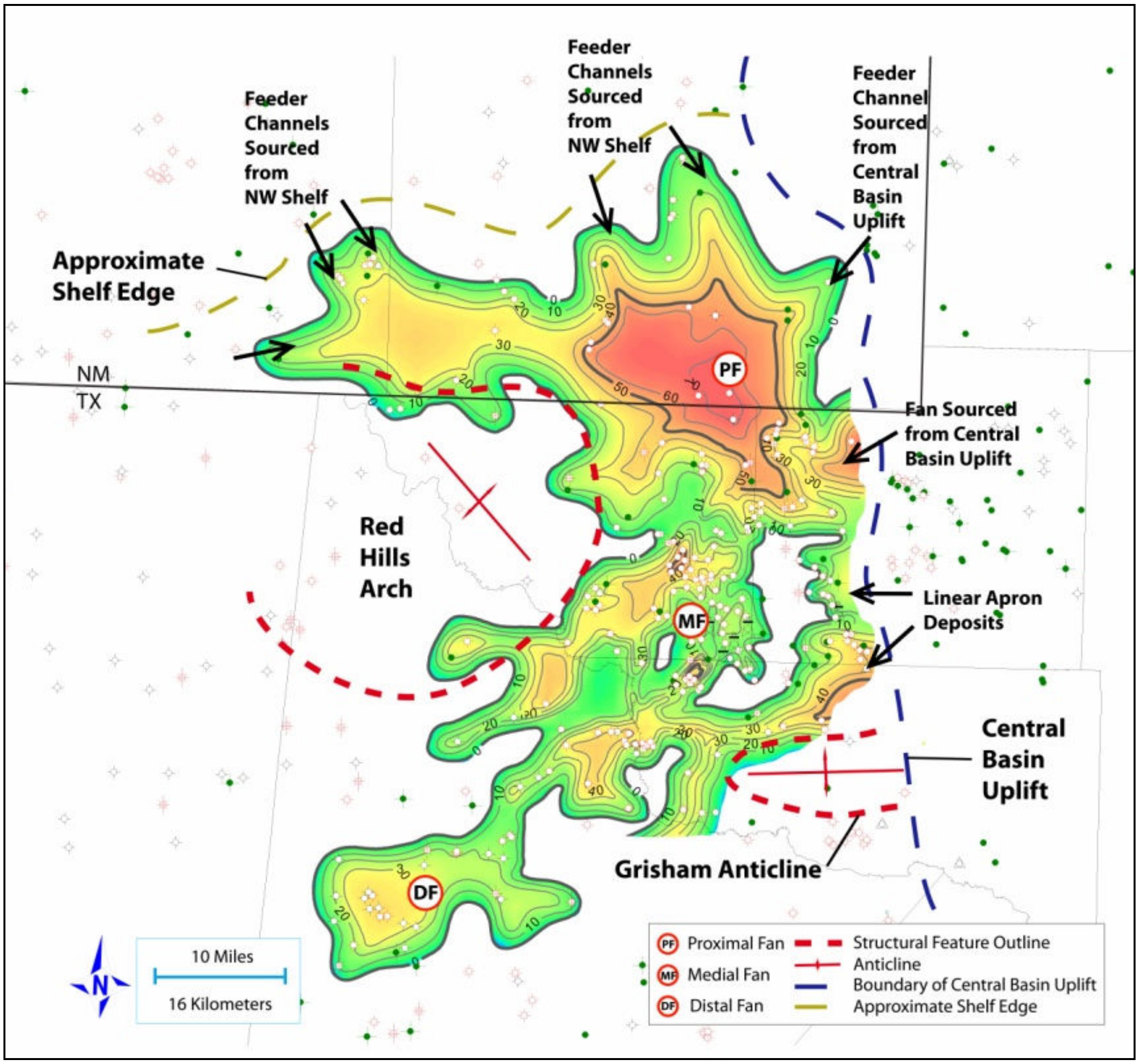


Figure 13. Sand percent map of the middle Morrow contoured on a 10% contour interval. Warm colors indicate thick deposits and cool colors indicate thin ones. This map shows the geometry of the inferred submarine fan complex as well as the orientation of feeder channels sourcing the system. Turbidites fed by the Northwest Shelf and the Central Basin Uplift coalesced in the basin center and were forced to the southwest by the Red Hills Arch and the Grisham Anticline, as well as by sediment derived from the Central Basin Uplift.

the site of deposition (Reading and Richards, 1994). The deposits are lobate and extend tens of miles into the basin.

Systems sourced by the Central Basin Uplift were a combination of multiple-source submarine ramps and linear-source slope aprons with mud- to sand-sized sediment. Ramps developed in the northern portion of the study area and slope aprons in the southern end of the study area. Source areas for apron systems with this size of sediment are small to moderate in size, have moderate to high gradients, and are close to the site of deposition (Reading and Richards, 1994). Sediments were transported shorter distances into the basin by less efficient currents. The deposits formed linear belts along the flank of the rising platform (Fig. 13). Small, short-lived chutes provided clastic sediment and perhaps some carbonates from the Central Basin Uplift.

Sand percent maps for each of the four subdivisions of the middle Morrow show patterns of sedimentation similar to those on the map of the entire interval (Figs. 14A-14D). Feeder channels from the Northwestern Shelf avulsed over time. A persistent topographic low at the junction of the Northwestern Shelf and rising Central Basin Uplift allowed sediment to pond. This area is marked by high sand percent values and is interpreted to contain proximal ramp deposits. From this location, currents continued first south and then west, joining with currents flowing off the Central Basin Uplift to form medial and distal ramp deposits.

These deep-water deposits probably formed during a highstand of relative sea level. They correlate with fluvial-deltaic sands higher on paleoslope, indicating these areas were not sites of erosion or sediment bypass. As the basin filled, accommodation space decreased and a relative fall in sea level ensued. Upper Morrowan carbonate

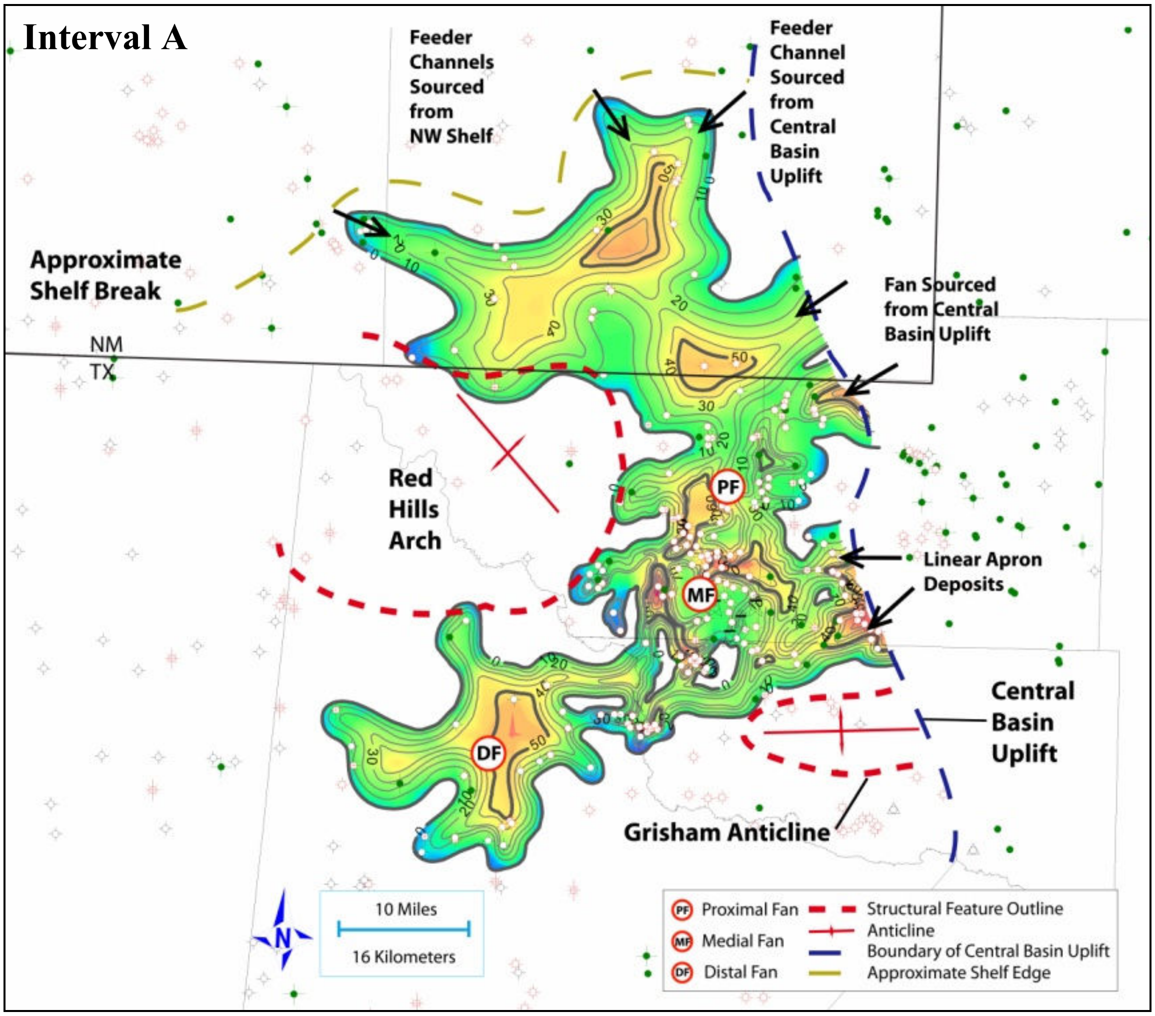


Figure 14A. Sand percent map of interval A of the middle Morrow. A similar geometry is apparent as shown by the entire middle Morrow sand percent map (Fig. 13). Proximal, medial, and distal fan deposits are present. Structural highs including the Red Hills Arch, the Grisham Anticline, and the Central Basin Uplift continued to control sediment input in the basin. Feeder channels existed on the Northwest Shelf and from the Central Basin Uplift. Linear slope aprons were also deposited in the southern end of the study area and were derived from the Central Basin Uplift. Faulting controlled deposition in the northern portion of the study area, just north of the NM-TX border, as noted by the irregular deposition.

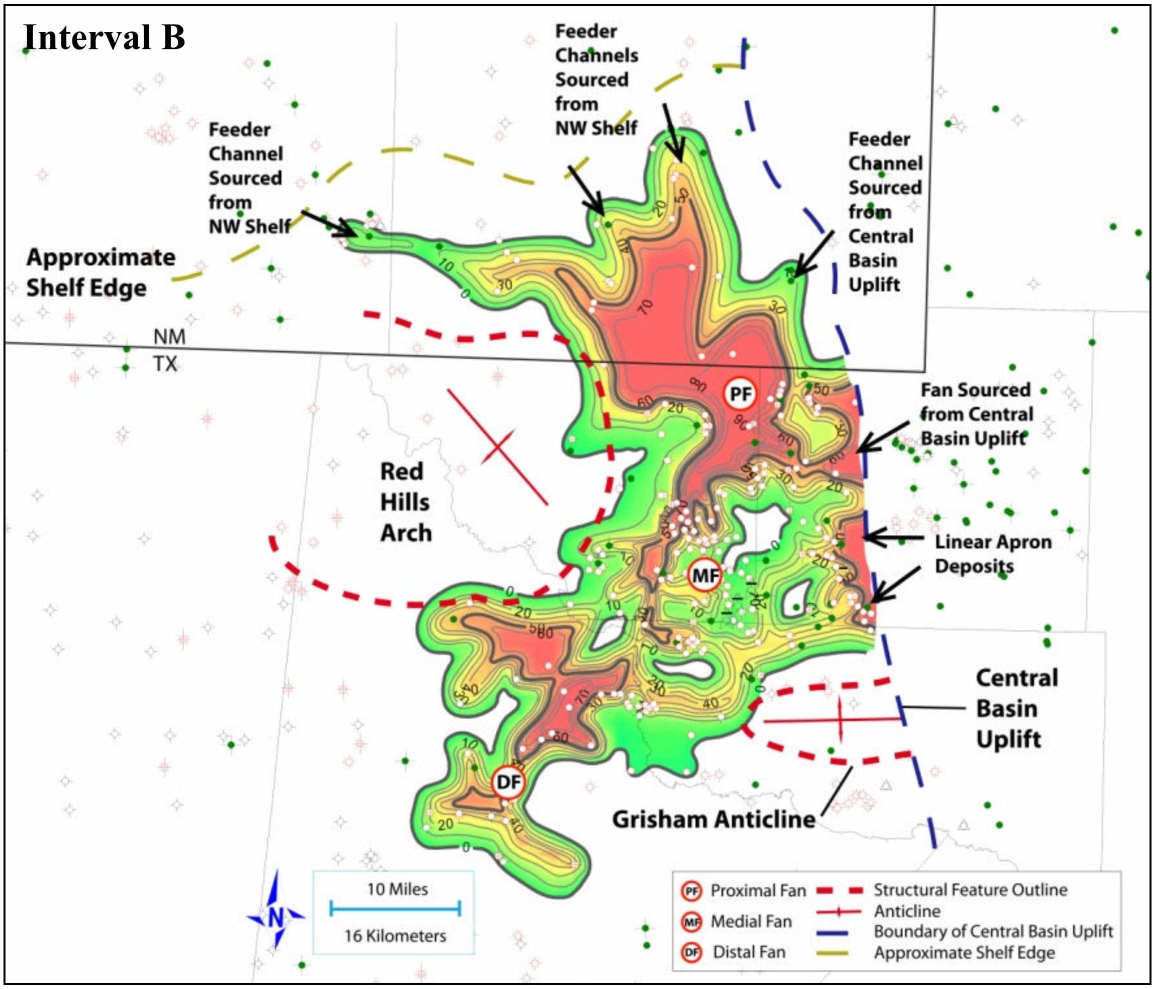


Figure 14B. Sand percent map of interval B within the middle Morrow. A similar geometry is apparent to that of interval A. Proximal, medial, and distal deposits are more defined in this interval. Structural features are noted as well as the shelf edge. Faulting controlled deposition in the northern portion of the study area, along the NM-TX border, creating a side-stepping appearance of deposition. Fans, channels, and slope apron deposits derived from the Central Basin Uplift are more pronounced. The Grisham Anticline and the Red Hills Arch continued to control sediment distribution.

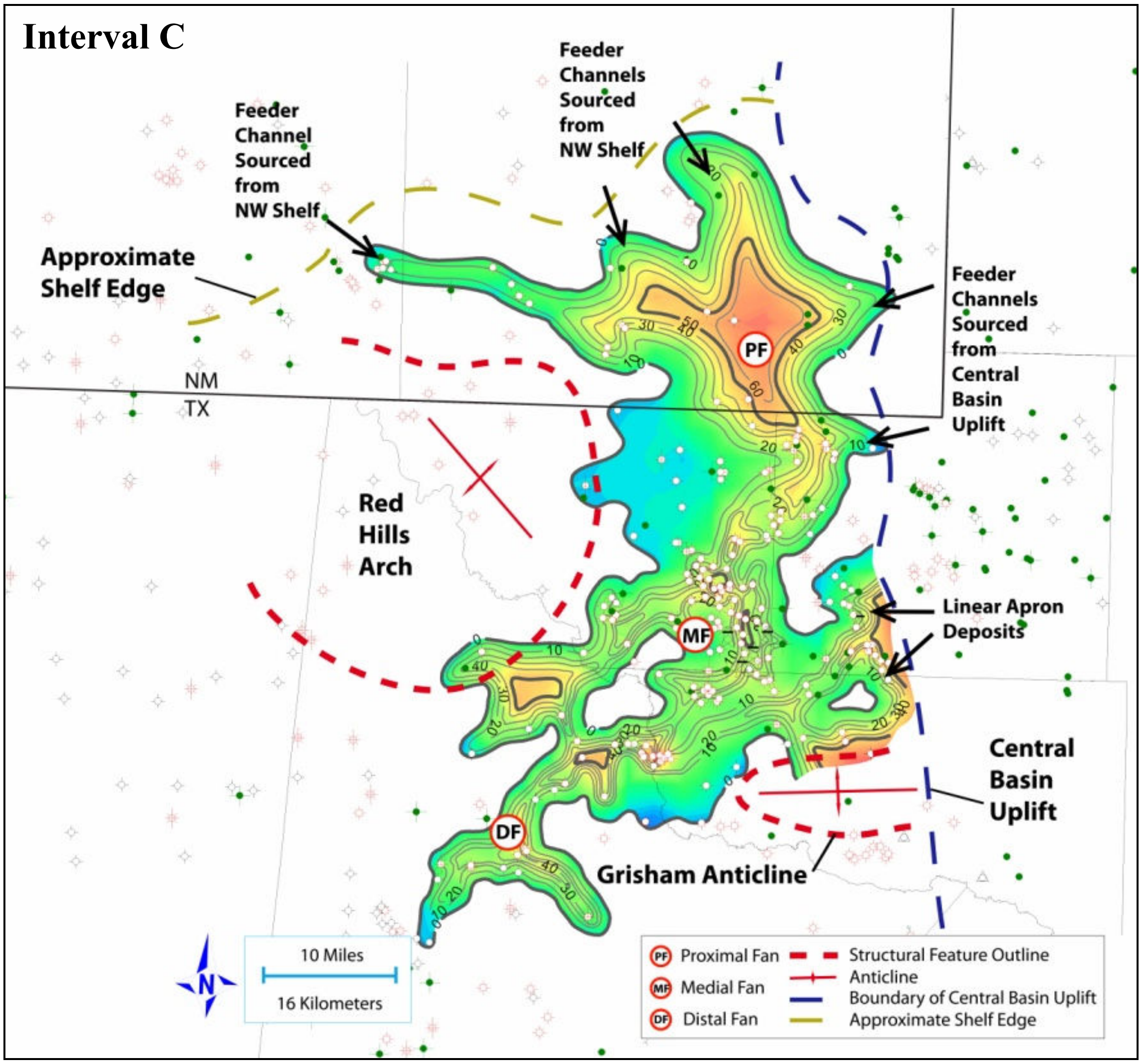


Figure 14C. Sand percent map of interval C in the middle Morrow. Overall, decreased sand deposition with significantly lower sand percentages occurred during this time. The system is more channelized than the previous interval. Structural features are displayed as well as the location of the Northwestern Shelf break. Feeder channels and fans continue to avulse on both the Northwest Shelf and the Central Basin Uplift.

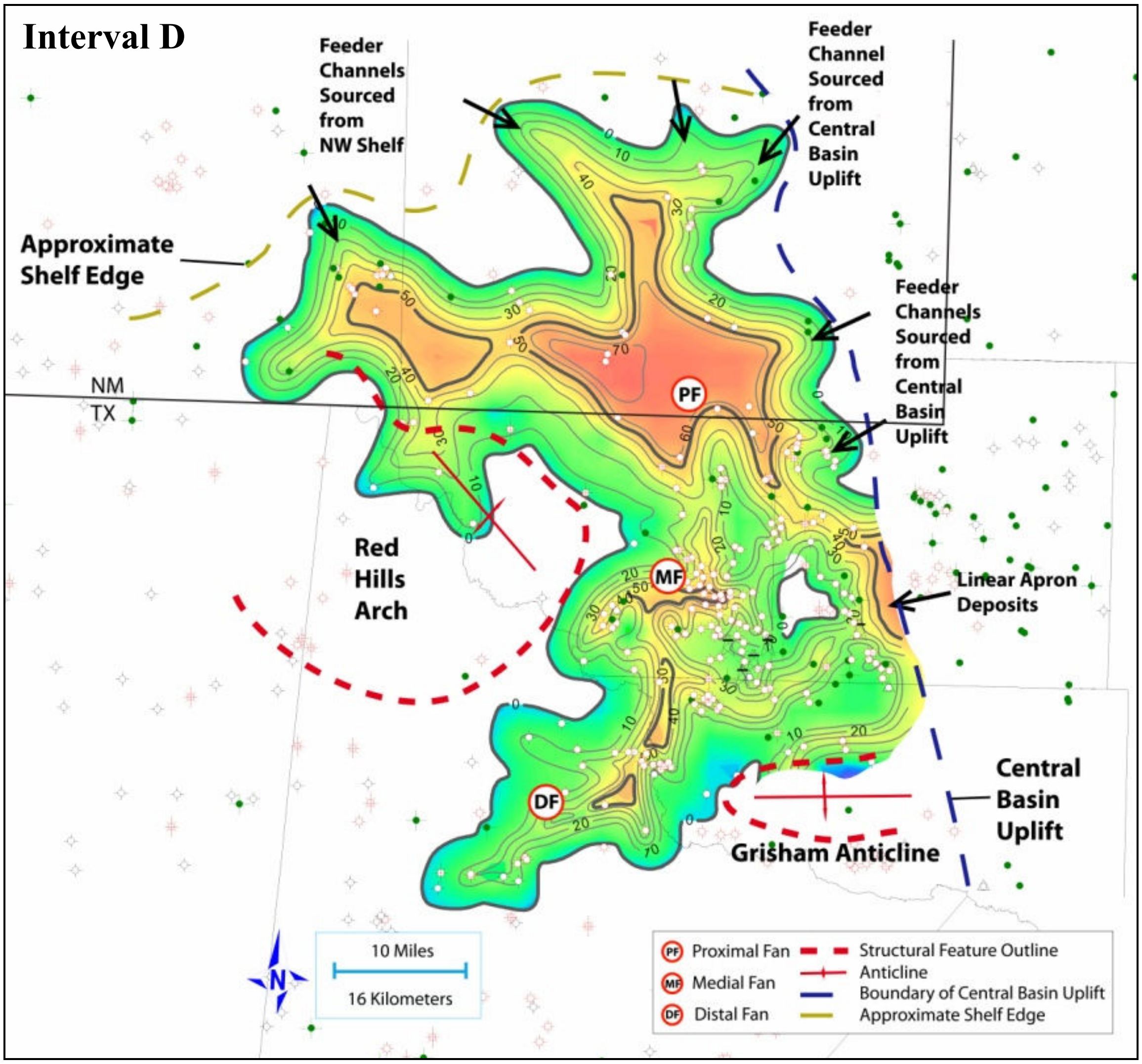


Figure 14D. Sand percent map of interval A in the middle Morrow. Sand percent increases dramatically in this interval, possibly due to an increase in accommodation space. Multiple feeder channels from the Northwest Shelf develop into two primary feeder systems. Feeder channels off of the Central Basin Uplift continue to develop and linear slope apron deposits are more extensive. Proximal, medial, and distal deposits are better defined. Structural highs continued to control deposition. Faulting continued to control deposition in the northern end of the study area, creating an irregular pattern of deposition.

deposition began at this time, mainly on the Northwestern Shelf, but also around basinal highs such as the Grisham Anticline, as evidenced by the abundance of oolites in cuttings from the Hunt Hassie University 18-39 #1, and their absence in wells farther north of the anticline.

A pronounced carbonate shelf edge developed along the Northwestern Shelf during the late Morrowan and migrated basinward during the Atokan (Figs. 15 and 16). Atokan strata in Chapman Deep Field in Reeves County form a progradational sequence of basinal shales overlain by shales and lime mudstones representing distal slope facies (Mazzullo, 1981). The distal slope deposits are overlain by proximal slope deposits (crinoidal wackestone and calcareous siltstone), which are succeeded in turn by a shallow-water limestone bank facies. Mazzullo (1981) suggests that water depths off the shelf edge may have reached as much as 700 ft in the Atokan. The carbonate buildups and associated facies on the shelf described by Mazzullo (1981) formed in water depths of 50-100 ft.

Turbidite deposition most likely continued throughout the Morrowan and Atokan in deeper waters. Relief on the shelf edge increased and channels cut through the limestone bank margin. The deep-water deposits accumulated in ramp settings fed by deep channels. The deposits were probably sand-rich, as the shelf edge was much closer and had more relief than during the early and middle Morrow. The Central Basin Uplift continued to rise and supplied more sand to the basin, which built both point-source fans and linear-source aprons.

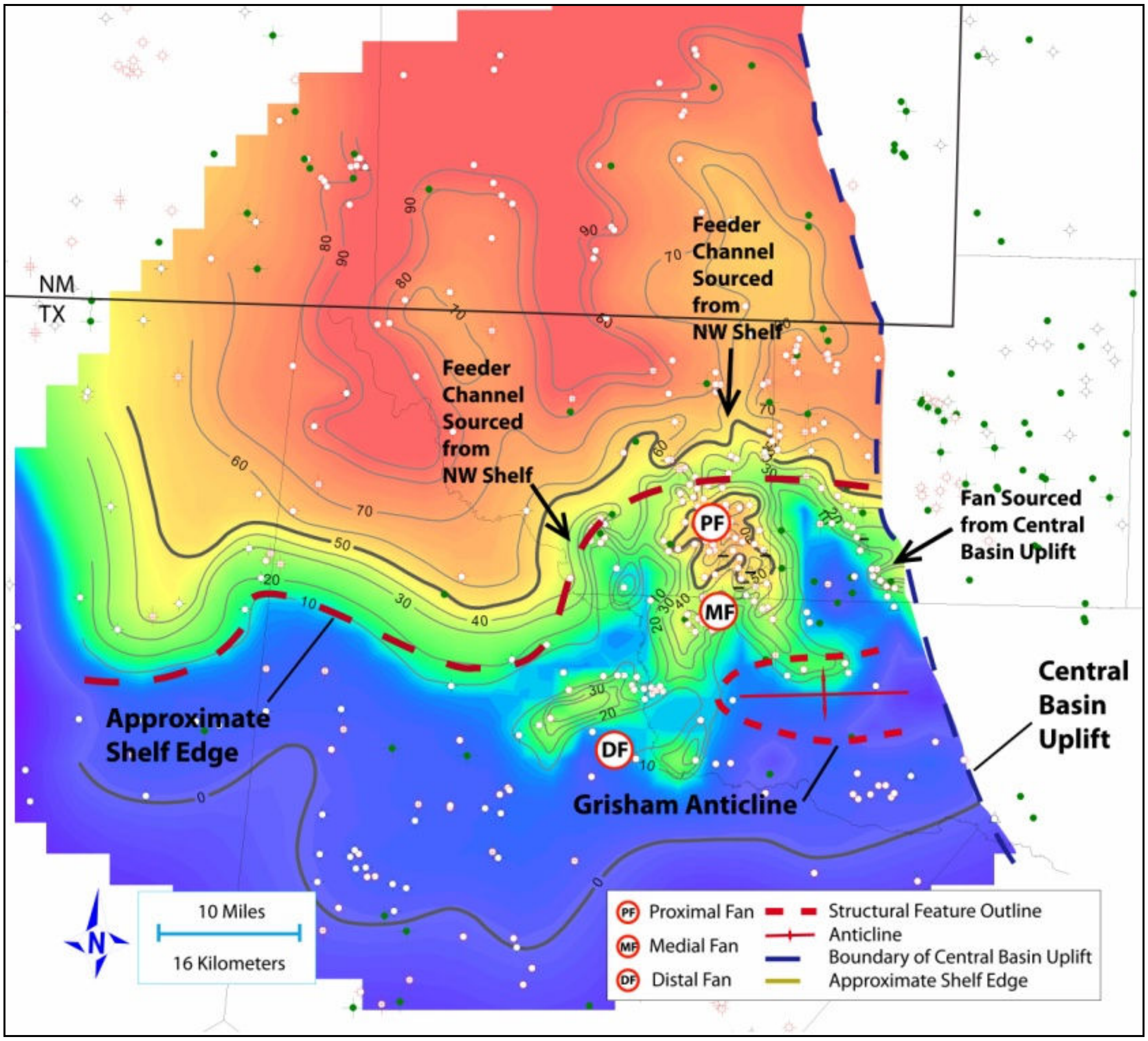


Figure 15. Limestone percent map of the upper Morrow contoured on a 10% contour interval. Hot colors represent high percentages of limestone and cool colors represent low percentages of limestone. The shelf edge is visible at the transition from thick carbonates (hot colors) to the sediment-bare basin plain (cool colors). The shelf edge is further denoted with a red dashed line. Turbidites deposited on the basin floor were fed by at least two feeder systems from the Northwest Shelf. At least one significant turbidite complex was deposited during the upper Morrow, consisting of proximal, medial and distal deposits. These turbidites are a mixture of carbonate and clastic sediment.

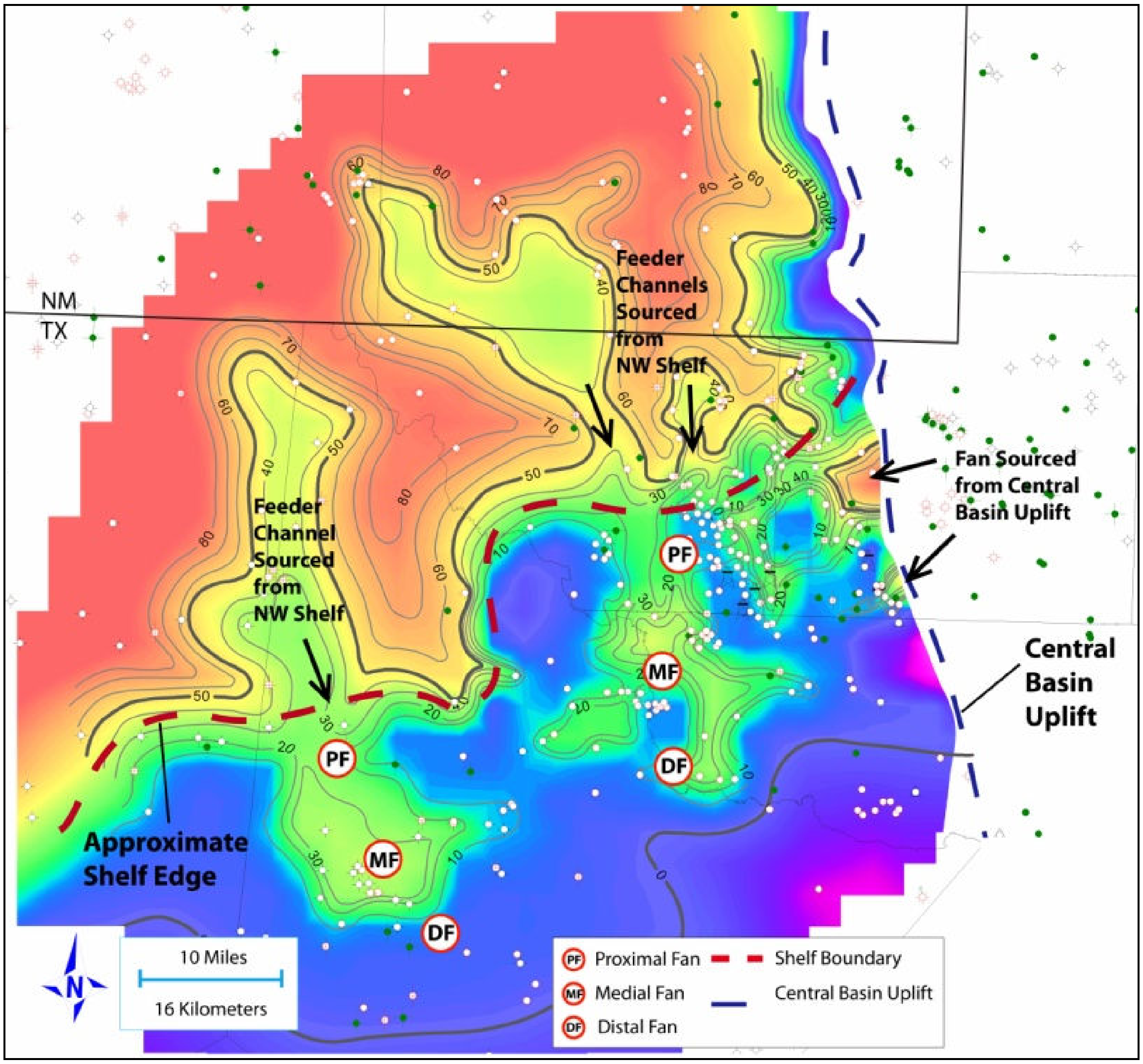


Figure 16. Limestone percent map of the Atoka contoured on a 10% contour interval. Hot colors represent high limestone percentages and cool colors represent low limestone percentages. The carbonate shelf edge during the Atoka is visible at the transition from green to blue on the map and has also been delineated by a red dashed line. Turbidites were deposited during the Atoka and at least two significant feeder systems developed, denoted on the map. These turbidites consisted of proximal, medial, and distal deposits. Fans continued to feed the system derived from the Central Basin Uplift as well. The Grisham Anticline continued to serve as a bathymetric obstacle.

Discussion

Basin-margin complexes rarely represent single point-source depositional systems (Reading and Richards, 1994). For example, the Mississippi Fan has one feeder channel at the present day, as do many modern fans. However, the Mississippi Fan has had 17 sources over the past 3.5 million years (Weimer, 1990). Ancient basin-margin complexes most often appear as ramp systems with more than one source because their entire history is present in the rock record. Turbidite systems in the Tyee Formation (Eocene) of Oregon were fed by multiple channels linked to a single delta (Chan and Dott, 1983), as was the Sweetwater Slope System (Cisco Group, Pennsylvanian) of north-central Texas (Galloway and Brown, 1973). Martin et al. (1986) interpreted Morrow sandstones in Pitchfork Field, Lea County, New Mexico, as submarine fans supplied from the Central Basin Platform some 12 miles to the east.

Turbidite fans, ramps and aprons will have distinctive shapes when deposited on broad, flat basin plains (Reading and Richards, 1994). This is seldom the case, however, because many turbidite systems develop in small, constricted, structurally active basins. In these settings, the shape of the turbidite complex is determined by bathymetric obstacles created by tectonic activity (Reading and Richards, 1994). Such is the case in the Lower and Middle Pennsylvanian of the Delaware Basin.

Might the basin-margin deposits be a lowstand sytems tract deposited during a fall in relative sea level? Correlative fluvial-deltaic strata on the shelf argue against this interpretation. A fall in relative sea level could be caused by decreased accommodation space due to an increase in sedimentation, a decrease in basin subsidence, or a drop in eustatic sea level. The Delaware Basin was subsiding and deepening at the beginning of the Pennsylvanian (Frenzel et al., 1988). Local sea level was rising during Early and Middle Pennsylvanian as the sea encroached, filling the northern Delaware Basin (Wright, 1979). Eustatic sea level was also rising during this period in the form of the large-scale Absaroka transgression (Sloss, 1988). Sedimentation rate is difficult to quantify. However, my interpretation is that the rate was not enough to fill the subsiding basin, and did not cause a significant relative fall in sea level. Morrowan deposits, for example, were deposited directly on the Barnett Shale, which consists of deep-water pelagic sediments deposited during starved basin conditions. Furthermore, the presence of sponge spicules in the lower and middle Morrow indicate marine to deep marine conditions. In addition, there are no coals in the study area indicative of a lowstand deltaic system, suggesting that these are not the deposits of a lowstand system. Interpretations of correlative deltaic deposits farther up paleoslope indicate that the Haley Field area was in deep water during deposition of the lower and middle Morrow (James, 1985; Bay and Baltensperger, 1990; Casavant and Mallon, 1999; Worthington, 1999; Walsh, 2007). This also suggests that deposits to the southeast of the upper Morrow and Atoka shelf edge were in deep water as well (Mazzullo, 1981).

Deep-water deposits constitute a considerable quantity of the world's petroleum reservoirs (Reading and Richards, 1994). Stratigraphic traps are the principal targets in the Morrowan and Atokan of the Haley Field area. In the mud- and sand-rich ramp system derived from the Northwest Shelf and the northern end of the Central Basin Uplift, stacked channels and lobate sand bodies such as fan lobes and overbank deposits form the best reservoirs. However, the sand to shale ratio varies considerably within the system, creating highly heterogeneous reservoirs (Reading and Richards, 1994). The channel-levee nature of a mud- and sand-rich ramp system is an ideal trapping mechanism, because shales deposited around and above potential channelized reservoirs act as seals.

The slope aprons along the Central Basin Uplift are a secondary objective in this area. These sediments accumulated in linear deposits along the flank of the uplift, are several kilometers long, and extend only a few kilometers into the basin. The medial and distal deposits of the coalescing sediments of the Northwest Shelf and the Central Basin Uplift also provide potential reservoirs, also in the form of stacked channels and lobate sand bodies. The many channels that fed this entire system both from the Northwestern Shelf and the Central Basin Uplift should also be considered as potential reservoirs.

Conclusions

Tectonic activity associated with the Marathon-Ouachita orogeny largely determined patterns of sediment distribution and accumulation in the Delaware Basin in the Early and Middle Pennsylvanian. The primary structural features affecting sedimentation in the study area were the Central Basin Uplift, Red Hills Arch, and Grisham Anticline. The basin fill was sourced from the Pedernal Massif to the northwest and from the Central Basin Uplift to the east.

The lower and middle Morrow represent the distal deposits of basin-margin turbidite complexes. Muddy and sandy sediment formed lobate submarine ramps off the Northwestern Shelf in the northern portion of the study area. Linear slope aprons were formed in the southern portion of the study area by sediment derived from the steep, uplifted margin of the Central Basin Uplift. The rising Red Hills Arch and Grisham

Anticline formed bathymetric obstacles on the sea floor that deflected currents to the southwest. Significant sediment accumulated at the junction of the Northwest Shelf and the rising Central Basin Uplift. The lower and middle Morrow consist largely of clastic sediment. Cuttings from this interval consist of very fine-grained sandstone and siltstone, and sponge spicules suggesting a distal marine setting. Some caution must be used, however, because cuttings were examined from only three wells. Lithologic determinations made from well logs seem to match those made from cuttings.

The makeup of the section changed from predominantly clastic in the lower and middle Morrow to mainly carbonate in the upper Morrow and Atoka. The oolitic horizon above the middle Morrow marks this transition. Upper Morrow and Atoka strata consist primarily of carbonate sediment deposited as the shelf edge prograded into the basin during a relative rise in sea level. Deep-water sediments were deposited to the southeast of the prograding shelf edge. The sediments were deposited in both fan and ramp settings off the nearby, steep margin of the Central Basin Uplift. By the Late Morrowan and Atokan, the Northwestern Shelf had prograded into the basin, covering the Red Hills Arch. The Central Basin Uplift and Grisham Anticline continued to control patterns of sediment distribution to the south. The depositional history of the Early and Middle Pennsylvanian, as interpreted here, is in accord with what is known about both eustatic and relative sea level changes at this time (Wright, 1979; Sloss, 1988).

Many potential hydrocarbon reservoirs exist in basin-margin depositional regimes; stacked turbidite channels, overbank splays, and fan lobes are potential reservoirs within both the Morrowan and Atokan fan complexes. These are likely to be well-sealed reservoirs given the channel-levee nature of a mud- and sand-rich submarine ramp system. However, reservoirs are likely to be highly heterogeneous due to a wide range of sand to shale ratios. Potential reservoirs also exist in feeder channels on the Northwestern Shelf and the Central Basin Uplift, as well as slope aprons deposited along the flank of the Central Basin Uplift. Natural gas accumulations in the Haley Field area are highly overpressured and very deep. Reservoirs within feeder channels and other deposits around the northern end of the Central Basin Uplift in the study area are likely to be shallower but still possibly overpressured. Great potential still exists in the relatively immature Haley Field as well as the surrounding region.

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APPENDIX A – Description of Cuttings

42-475-30700
Hunt Hassie University 18-39 #1
Ward County, Texas

Measured Depth (ft)	Lithology %	Sample Description
15,700	10sh 40ls 50ss	Ss:White - Light gray ss, vf-f grained, sub-rounded, moderately sorted Ls:Light gray mottled limestone - micrite Sh:Black shale with trace pyrite - Iron staining
15,710	10sh 40ls 50ss	Ss:same as above Ls:same as above Sh:same as above
15,720	10sh 40ls 50ss	Ss:same as above Ls:same as above Sh:same as above
15,730	10sh 35ls 45ss	Ss:same as above Ls:same as above Sh:same as above
15,740	10sh 35ls 45ss	Ss:same as above Ls:same as above Sh:same as above
15,750	10sh 90ss	Ss:same as above Sh:same as above
15,760	10sh 40ls 50ss	Ss:same as above Ls:same as above Sh:same as above
15,770	10sh 40ls 50ss	Ss:same as above Ls:same as above Sh:same as above
15,780	10sh 40ls 50ss	Ss:same as above Ls:same as above Sh:same as above
15,790	10sh 40ls 50ss	Ss:same as above Ls:same as above Sh:same as above
15,800	90sh 10ls	Ls:same as above Sh:same as above
15,810	90sh 10ls	Ls:same as above Sh:same as above
15,820	80sh 20ls	Ls:same as above Sh:same as above
15,830	70sh 30ls	Ss:trace ss - unconsolidated – glassy, pink color Ls:same as above Sh:same as above
15,840	60sh 40ls	Ss:trace ss - same as above Ls:same as above Sh:same as above
15,850	65sh 35ls	Ss:trace ss - same as above Ls:same as above Sh:same as above
15,860	50sh 50ss	Ss:White - light gray ss, vf-f grained, sub-rounded, moderately sorted Sh:same as above
15,870	65sh 35ss	Ss:same as above Sh:same as above
15,880	75sh 25ss	Ss:same as above Sh:Dark gray black shale - trace mica
15,890	80sh 20ss	Ss:same as above Sh:same as above
15,900	90sh 10ss	Ss:same as above Sh:same as above
15,910	90sh 10ss	Ss:same as above Sh:same as above
15,920	80sh 10ss	Ss:same as above Sh:same as above
15,930	NO SAMPLE	Sh:same as above
15,940	90sh 10ss	Ss:same as above Sh:same as above
15,950	95sh 5ss	Ss:same as above Sh:same as above
15,960	85sh 15ss	Ss:same as above Sh:same as above
15,970	NO SAMPLE	Sh:same as above
15,980	85sh 15ss	Ss:White to tan ss, abundant unconsolidated sand grains Sh:Dark gray, lithified, trace pyrite & Iron staining
15,990	98sh 2ss	Ss:White to tan ss, v-f grained, black-brown colored, sub-rounded, well-sorted Sh:same as above
16,000	95sh 5ss	Ss:same as above Sh:same as above
16,010	98sh 2ss	Ss:same as above Sh:same as above
16,020	90sh 10ss	Ss:same as above Sh:same as above
16,030	80sh 20ss	Ss:same as above Sh:same as above
16,040	50sh 50ss	Ss:same as above Sh:same as above
16,050	20sh 80ss	Ss:same as above Sh:same as above
16,060	30sh 70ss	Ss:same as above Sh:same as above
16,070	40sh 60ss	Ss:same as above Sh:same as above
16,080	30sh 70ss	Ss:same as above Sh:same as above

Measured Depth (ft)	Lithology %	Sample Description
16,090	70sh 30ss	Ss:same as above Sh:same as above
16,100	100sh	Sh:same as above
16,110	100sh	Sh:same as above
16,120	100sh	Sh:same as above
16,130	20ls 80ss	Ss:White to light gray ss, fine-grained. Abundant calcite cement Ls:Light gray micrite Sh:same as above
16,140	98sh 2ls	Ss:same as above Ls:same as above Sh:same as above
16,150	95sh 5ls	Ss:same as above Ls:same as above Sh:same as above
16,160	90sh 10ss	Ss:same as above Sh:same as above
16,170	80sh 20ss	Ss:same as above Sh:same as above
16,180	80sh 20ss	Ss:same as above Sh:same as above
16,190	80sh 20ls	Ls:same as above Sh:same as above
16,200	100sh	Sh:same as above
16,210	NO SAMPLE	
16,220	NO SAMPLE	
16,230	90sh 5ls 5ss	Ss:White to tan ss, tan brown grains with white matrix also with calcite cement Ls:Light gray, micrite - uniform color Sh:same as above
16,240	NO SAMPLE	
16,250	NO SAMPLE	
16,260	40sh 30ls 30ss	Ss:same as above Ls:same as above - fossils Sh:same as above
16,270	30sh 40ls 40ss	Ss:same as above Ls:same as above - chert fragments Sh:same as above
16,280	20sh 40ls 40ss	Ss:same as above Ls:same as above Sh:same as above
16,290	30sh 70ss	Ss:same as above Sh:same as above
16,300	NO SAMPLE	
16,310	40sh 60ss	Ss:White to gray ss, fn grained, abundant calcite cement, sub-rounded, well-sorted Sh:Dark gray shale
16,320	80sh 20ss	Ss:same as above Sh:same as above
16,330	25sh 25ls 50ss	Ss:same as above Sh:same as above
16,340	20sh 30ls 50ss	Ss:same as above Sh:same as above
16,350	20sh 30ls 50ss	Ss:same as above Sh:same as above
16,360	20sh 30ls 50ss	Ss:same as above Sh:same as above
16,370	20sh 20ls 60ss	Ss:same as above Sh:same as above
16,380	NO SAMPLE	
16,390	NO SAMPLE	
16,400	80sh 20ss	Ss:White to gray ss, fn grained, abundant calcite cement Sh:Light gray shale with abundant iron staining & pyrite
16,410	85sh 15ss	Ss:same as above Sh:same as above
16,420	NO SAMPLE	
16,430	NO SAMPLE	
16,440	100ls	Ls:Light gray to white oolitic limestone, some fossils Sh:
16,450	10sh 90ls	Ls:same as above Sh:Light gray shale
16,460	100ls	Ls:same as above Sh:
16,470	10sh 90ss	Ss:White to Light gray ss, fn grained, abundant calcite cement Sh:Light gray lithified, Iron staining
16,480	20sh 80ss	Ss:same as above Sh:same as above
16,490	50sh 20ls 30ss	Ss:same as above Ls:White to gray, oolitic ls, fossils Sh:same as above
16,500	90sh 10ss	Ss:same as above Sh:same as above
16,510	95sh 5ss	Ss:same as above Sh:same as above
16,520	20sh 80ss	Ss:same as above Sh:Light gray lithified trace pyrite, iron staining
16,530	10sh 90ss	Ss:same as above Sh:Light gray, lithified

Measured Depth (ft)	Lithology %	Sample Description
16,540	95sh 5ss	Ss:same as above Sh:same as above
16,550	85sh 15ls	Ls:Light gray with oolites Sh:same as above
16,560	80sh 20ls	Ls:same as above Sh:same as above
16,570	85sh 15ls	Ls:same as above Sh:same as above
16,580	75sh 25ls	Ls:same as above Sh:Gray shale, trace pyrite, trace calcite fracture fill
16,590	NO SAMPLE	Sh:Black shale trace pyrite
16,600	80sh 20ss	Ss:Gray-black sandstone with abundant calcite cement Sh:same as above
16,610	90sh 10ls	Ls:Xln Ls, micrite, light gray Sh:same as above
16,620	70sh 30ls	Ls:same as above Sh:same as above
16,630	80sh 20ls	Ls:same as above Sh:Dark gray shale, soft, fissile
16,640	NO SAMPLE	Sh:same as above
16,650	60sh 40ls	Ls:same as above Sh:same as above
16,660	60sh 40ls	Ls:same as above Sh:same as above
16,670	70sh 30ss	Ss:White fn grained ss, well-sorted, abundant calcite cement Sh:Gray shale - trace calcite fill, trace pyrite
16,680	60sh 40ss	Ss:same as above Sh:same as above
16,690	60sh 40ss	Ss:same as above Sh:same as above
16,700	60sh 40ss	Ss:same as above Sh:Gray shale
16,710	99sh 1ss	Ss:White, fn grained ss. Sh:same as above
16,720	99sh 1ss	Ss:same as above Sh:Gray shale, trace pyrite
16,730	95sh 5ls	Ls:light gray ls Sh:same as above
16,740	90sh 10ls	Ls:same as above Sh:same as above
16750 - 16,790	100sh	Sh:same as above
16,800	100sh	Sh:Dark gray shale, fissile, iron staining, trace pyrite
16810 - 17200	100sh	Sh:same as above

42-301-10313
Pennzoil Mrs. O.P. Anderson #1
Loving County, Texas

Measured Depth (ft)	Lithology %	Sample Description
15,900	10sh 90ls	Ls:Light gray micrite Sh:Light gray, lithified, trace mica
15910 - 15,960	10sh 90ls	Ls:same as above Sh:same as above
15,970	30sh 70ls	Ss:Trace ss – Dark gray vf ss, well-sorted, moderately rounded Ls:Light gray micrite, some chalky white ls Sh:Dark gray, lithified, trace iron staining
15,980	40sh 60ls	Ls:same as above Sh:same as above
15,990	90sh 8ls 2ss	Ss:same as above Ls:Light gray micrite, some fossils. Sh:same as above
16,000	90sh 10ls	Ls:same as above Sh:same as above
16,010	20sh 80ss	Ls:same as above Sh:same as above
16,020	20sh 20ss 60ls	Ls:same as above Sh:same as above
16,030	60sh 20ss 20ls	Ss:Dark gray vf ss, well-sorted, moderately rounded w/ some calcite cement. Ls:Light gray micrite, some visible xls Sh:Dark gray, lithified
16,040	60sh 35ls 5ss	Ss:same as above Ls:same as above Sh:same as above
16,050	70sh 30ls	Ls:same as above Sh:same as above
16,060	80sh 20ls	Ls:same as above Sh:same as above
16,070	80sh 20ls	Ls:same as above Sh:same as above
16,080	90sh 10ls	Ls:same as above Sh:same as above
16,090	90sh 10ls	Ls:same as above Sh:same as above

Measured Depth (ft)	Lithology %	Sample Description
16,100	90sh 10ls	Ls:same as above Sh:same as above
16,110	90sh 5ls 5ss	Ss:White to light gray ss, fn grained, sub-rounded, well-sorted Ls:White chalky ls with some sand grains Sh:same as above
16,120	75sh 20ls 5ss	Ss:same as above Ls:same as above Sh:same as above
16,130	70sh 20ss 10ls	Ss:same as above Ls:same as above Sh:same as above
16,140	60sh 20ls 20ss	Ss:same as above Ls:same as above Sh:same as above
16,150	85sh 10ls 5ss	Ss:same as above Ls:same as above Sh:same as above
16,160	85sh 15ls	Ls:same as above Sh:same as above
16,170	90sh 10ls	Ls:same as above Sh:same as above
16,180	85sh 14ls 1ss	Ss:same as above Ls:same as above Sh:same as above
16,190	90sh 10ls	Ls:Dark gray somewhat xln ls, grainy appearance Sh:same as above
16,200	10sh 90ss	Ss:same as above Ls:same as above Sh:Black to Dark gray shale with abundant mica and pyrite.
16,210	10sh 40ls 50ss	Ss:same as above Ls:same as above Sh:same as above
16,220	50sh 30ls 20ss	Ss:same as above Ls:same as above Sh:same as above
16,230	50sh 20ls 30ss	Ss:same as above Ls:same as above Sh:same as above
16,240	50sh 40ls 10ss	Ss:same as above Ls:same as above Sh:same as above
16,250	70sh 25ls 5ss	Ss:same as above Ls:same as above Sh:same as above
16,260	50sh 50ss	Ss:same as above Ls:same as above Sh:same as above
16,270	30sh 10ls 60ss	Ss:same as above Ls:same as above Sh:same as above
16,280	10sh 90ss	Ss:White ss fn grained, moderately sorted with some calcite cement, well rounded Ls:same as above Sh:same as above
16,290	40sh 10ls 50ss	Ss:White to tan to light gray, somewhat arkosic with chalky matrix Ls:same as above Sh:same as above
16,300	40sh 50ls 10ss	Ss:same as above Ls:same as above Sh:same as above
16,310	70sh 20ls 20ss	Ss:same as above w/ calcite cement Ls:same as above Sh:same as above
16,320	40sh 50ls 10ss	Ss:same as above Ls:same as above Sh:same as above
16,330	10sh 40ls 50ss	Ss:same as above Ls:same as above Sh:same as above
16,340	10sh 60ls 30ss	Ss:same as above Ls:same as above Sh:same as above
16,350	20sh 60ls 20ss	Ss:same as above with abundant calcite cement Ls:same as above - grainy appearance Sh:same as above
16,360	20sh 80ls	Ss:tr sandstone - same as above Ls:same as above Sh:same as above
16,370	50sh 50ls	Ls:same as above - some loose calcite xls Sh:same as above
16,380	80sh 19sh 1ss	Ss:White with calcite cement, well-rounded, well-sorted Ls:Light gray, some visible xls, round chert nodules Sh:same as above
16,390	60sh 20ls 20ss	Ss:same as above Ls:same as above Sh:same as above
16,400	70sh 28ls 2ss	Ss:same as above Ls:same as above Sh:same as above - abundant micas & pyrite
16410 - 16,430	70sh 28ls 2ss	Ss:same as above Ls:same as above Sh:same as above
16,440	80sh 20ls	Ls:same as above Sh:same as above
16,450	70sh 48ls 2ss	Ss:White to light gray ss, fn grained, sub-rounded, well-sorted with trace chert Ls:Gray ls, elongate calcite xls, some visible grains Sh:Dark gray
16,460	70sh 48ls 2ss	Ss:same as above - white ss fragment Ls:same as above Sh:same as above
16,470	10sh 80ls 10ss	Ss:same as above Ls:same as above Sh:same as above
16,480	10sh 80ls 10ss	Ss:same as above Ls:same as above Sh:same as above
16,490	60sh 30ls 10ss	Ss:White, clear, light gray ss, moderately rounded, well-sorted - calcite cement Ls:Dark gray microcrystalline ls with some light gray ls Sh:same as above
16,500	30sh 50ls 20ss	Ss:Dark gray vf ss & White to light gray ss Ls:same as above Sh:Dark gray shale, lithified
16,510	20sh 60ls 20ss	Ss:Dark gray vf ss, well-sorted, moderately rounded – calcite cement. Ls:same as above Sh:same as above
16,520	40sh 60ls	Ls:Dark gray ls with elongate calcite xls, abundant pyrite with fossils Sh:same as above
16,530	50sh 50ls	Ls:same as above Sh:same as above

Measured Depth (ft)	Lithology %	Sample Description
16,540	40sh 60ls	Ls:same as above Sh:same as above
16,550	20sh 40ls 40ss	Ss:Dark gray vf ss, well-sorted, moderately rounded with calcite cement. Ls:light gray micrite with some fossils - some elongate calcite xls Sh:same as above
16,560	90sh 10ls	Ls:Dark gray ls, trace chalky ls, some calcite fracture fill Sh:same as above
16,570	90sh 10ls	Ls:same as above Sh:same as above
16,580	80sh 15ls 5ss	Ss:White ss, with calcite cement, well sorted, sub-angular Ls:same as above Sh:same as above
16,590	60sh 20ls 20ss	Ss:Dark gray vf ss, well-sorted, moderately rounded with calcite cement. Ls:Dark gray micrite, chalky red ls, trace pyrite, trace iron staining Sh:Light gray
16,600	60sh 30ls 10ss	Ss:same as above Ls:same as above Sh:same as above
16,610	60sh 30ls 10ss	Ss:same as above Ls:same as above Sh:Dark gray shale, trace pyrite, lithified
16,620	20sh 60ls 20ss	Ss:same as above Ls:same as above Sh:same as above
16,630	10sh 40ls 50ss	Ss:same as above Ls:Dark gray micrite - no visible calcite xls Sh:same as above
16,640	60sh 40ls	Ss:trace sand grain - pink glassy appearance - possibly chert? Ls:same as above Sh:same as above
16,650	10sh 90ls	Ls:same as above Sh:same as above
16,660	10sh 50ls 40ss	Ss:Dark gray vf ss, well-sorted, moderately rounded - calcite cement. Ls:same as above Sh:same as above
16,670	10sh 90ls	Ls:same as above Sh:same as above
16,680	10sh 90ls	Ls:Light gray with visible elongate calcite xls Sh:same as above
16,690	70sh 30ls	Ss:trace sandstone w/ white with calcite cement Ls:Dark gray micrite - no fossils Sh:same as above
16,700	10sh 50ls 40ss	Ss:Dark gray vf ss, well-sorted, moderately rounded - calcite cement. Ls:same as above Sh:same as above
16,710	10sh 50ls 40ss	Ss:same as above Ls:same as above Sh:same as above
16,720	10sh 85sh 5ss	Ss:White ss, well-rounded, moderately sorted Ls:Dk gray micrite with elongate calcite xls. Sh:same as above
16,730	10sh 85sh 5ss	Ss:same as above Ls:same as above Sh:same as above
16,740	15sh 75ls 10ss	Ss:Dark gray vf ss, well-sorted, moderately rounded with calcite cement Ls:same as above Sh:same as above
16,750	15sh 75ls 10ss	Ss:same as above - white ss fragment Ls:same as above Sh:same as above
16,760	20sh 80ls	Ss:trace white ss fragment, vf grained, rounded, well-sorted, calcite cement Ls:same as above Sh:same as above
16,770	20sh 70ls 10ss	Ss:Dark gray vf ss, well-sorted, moderately rounded with calcite cement Ls:same as above - some white chalky ls with trace chert Sh:same as above
16,780	40sh 40ls 20ss	Ss:same as above Ls:Dark gray micrite with elongate calcite xls Sh:same as above
16,790	70sh 10ls 20ss	Ss:same as above Ls:same as above Sh:same as above
16,800	80sh 20ls	Ss:trace ss - same as above Ls:same as above Sh:same as above
16,810	90sh 10ls	Ss:trace ss - white, vf grained, clean, rounded, well-sorted Ls:same as above Sh:same as above
16,820	98sh 2tr frags	Ss:trace ss - same as above Ls:trace ls - same as above Sh:same as above
16,830	50sh 30ls 20ss	Ss:Dark gray vf ss, well-sorted, moderately rounded with calcite cement Ls:same as above Sh:same as above
16,840	20sh 40ls 40ss	Ss:same as above Ls:same as above Sh:same as above
16,850	20sh 40ls 40ss	Ss:same as above Ls:same as above Sh:same as above
16,860	50sh 40ls 10ss	Ss:same as above Ls:same as above Sh:same as above
16,870	50sh 40ls 10ss	Ss:same as above Ls:same as above Sh:same as above
16,880	30sh 50ls 20ss	Ss:same as above Ls:same as above Sh:same as above
16,890	50sh 30ls 20ss	Ss:same as above Ls:same as above Sh:same as above
16,900	50ls 50ss	Ss:Dark gray vf ss, white, clear, black grains, with calcite cement Ls:same as above Sh:
16,910	5sh 20ls 75ss	Ss:same as above Ls:Dark gray ls with elongate calcite xls Sh:same as above
16,920	5sh 20ls 75ss	Ss:same as above Ls:same as above Sh:same as above
16,930	80sh 20ls	Ss:trace ss Ls:same as above Sh:same as above
16,940	NO SAMPLE	

Measured Depth (ft)	Lithology %	Sample Description
16,950	60sh 40ls	Ss:trace ss Ls:same as above Sh:same as above
16,960	40sh 20ls 40ss	Ss:White to Light gray grains, vf, well-sorted, moderately rounded Ls:Dark gray crystalline ls Sh:same as above
16,970	90sh 10ls	Ss:trace red ss fragment-orthoclase Ls:same as above Sh:same as above
16,980	90sh 10ls	Ls:same as above Sh:same as above
16,990	70sh 10ls 20ss	Ss:White to clear ss, with calcite cement, fn grained Ls:Light gray with bladed calcite xls. Sh:same as above
17,000	70sh 10ls 20ss	Ss:same as above Ls:same as above Sh:same as above
17,010	5sh 15ls 80ss	Ss:same as above Ls:same as above Sh:same as above
17,020	5sh 15ls 80ss	Ss:same as above Ls:same as above Sh:same as above
17,030	100sh	Sh:Dark gray, lithified, bladed
17,040	40sh 60ls	Ls:Light gray somewhat xln limestone Sh:Light gray, lithified.
17,050	50sh 50ls	Ls:same as above Sh:same as above
17,060	50sh 50ls	Ls:same as above Sh:same as above
17,070	20sh 80ls	Ls:same as above Sh:same as above
17,080	10sh 90ls	Ls:same as above Sh:same as above
17,090	40sh 60ls	Ls:same as above Sh:same as above
17,100	40sh 60ls	Ls:same as above Sh:same as above
17,110	50sh 50ls	Ls:same as above Sh:same as above
17,120	10sh 90ls	Ls:same as above Sh:same as above
17,130	100sh	Sh:same as above
17,140	20sh 80ss	Ss:White-tan-gray ss, vf grained, with abundant calcite cement Sh:same as above
17,150	20sh 80ss	Ss:same as above Sh:same as above
17,160	50sh 50ss	Ss:same as above Sh:same as above
17,170	70sh 10ls 20ss	Ss:same as above Ls:Fine-grained gray ls. Sh:same as above
17,180	70sh 10ls 20ss	Ss:same as above Ls:Dull-gray ls, vf grained, no visible xls. Sh:same as above
17,190	70sh 30ss	Ss:same as above Sh:same as above
17,200	50sh 50ss	Ss:same as above Sh:same as above
17,210	100ls	Ls:Light gray, vf grained, micritic Sh:Gray shale - trace micas
17,220	100ls	Ls:same as above - and iron staining Sh:same as above
17,230	10sh 90ls	Ls:same as above Sh:same as above
17,240	5sh 95ls	Ls:White to Light gray ls, trace pyrite & micas as calcite xls. Sh:same as above
17,250	90sh 10ls	Ls:Light gray ls with clean calcite grains Sh:same as above
17,260	90sh 10ss	Ls:same as above Sh:same as above
17,270	95sh 5ls	Ls:same as above Sh:same as above
17,280	95sh 5ls	Ls:same as above Sh:same as above
17,290	95sh 5ls	Ls:same as above Sh:same as above
17,300	100ss	Ss:Light gray ss, with clear grains with calcite cement, vf-fn grained
17,310	70sh 30ss	Ss:same as above Sh:same as above
17,320	30sh 60ls 10ss	Ss:same as above Ls:Gray ls - micrite Sh:same as above
17,330	30sh 60ls 10ss	Ss:same as above Ls:same as above Sh:same as above
17,340	30sh 40ls 30ss	Ss:same as above Ls:same as above Sh:same as above
17,350	NO SAMPLE	Ls:same as above Sh:same as above
17,360	100sh	Sh:Gray shale, lithified, bladed
17,370	80sh 20ls	Ls:same as above Sh:same as above
17,380	75sh 25ls	Ls:same as above Sh:same as above
17,390	75sh 25ls	Ls:same as above Sh:Light gray, trace micas & pyrite
17,400	100sh	Sh:same as above

Measured Depth (ft)	Lithology %	Sample Description
17,410	100sh	Sh:same as above
17,420	90sh 10ls	Ls:White chalky ls Sh:same as above
17,430	90sh 10ls	Ls:same as above Sh:same as above
17,440	NO SAMPLE	Sh:same as above
17,450	50sh 50ls	Ls:Light gray ls - micrite Sh:Black shale, lithified, bladed
17,460	40sh 90ls	Ls:same as above Sh:same as above
17,470	10sh 90ls	Ls:same as above Sh:same as above
17480 - 17550	100sh	Sh:same as above
17,560	NO SAMPLE	Sh:same as above
17,570	NO SAMPLE	Sh:same as above
17,580	98sh 2ls	Ls:same as above Sh:same as above
17,590	99sh 1ls	Ls:same as above Sh:Light gray shale
17600 - 17,620	100sh	Sh:same as above
17,630	20sh 80ss	Ss:White, tan, black ss fn-grained, abundant calcite cement Sh:same as above
17,640	98sh 2ss	Ss:same as above Sh:same as above
17,650	90sh 10ss	Ss:same as above Sh:Light gray shale, lithified, trace micas/pyrite
17,660	98sh 2ss	Ss:same as above - also trace arkosic sand with orthoclase fragments Sh:Light gray shale, lithified, trace micas/pyrite
17,670	NO SAMPLE	
17,680	100sh	Sh:Dark black shale, lithified, some calcite cement
17,690	99sh 1ss	Ss:Arkosic sandstone fragment with orthoclase Sh:same as above
17,700	99sh 1ss	Ss:same as above Sh:same as above
17,710	99sh 1ss	Ss:White, gray grains, some tan - vf grained, well-sorted Ls:some tan chalky limestone Sh:same as above
17,720	90sh 10ss	Ss:same as above Sh:same as above
17,730	95sh 5ss	Ss:same as above Ls:trace sulphur Sh:same as above
17,740	NO SAMPLE	
17,750	90sh 5ls 5ss	Ss:Fine-grained ss, moderately sorted, with orthoclase, subangular, with calcite cement Ls:Some chalky white ls with chert fragments Sh:same as above
17,760	99sh 1ss	Ss:White-tan-gray ss, vf grained, with abundant calcite cement Sh:same as above
17,770	90sh 5ls 5ss	Ss:same as above Ls:same as above Sh:same as above
17780 - 17,800	95sh 5ss	Ss:same as above Ls:same as above Sh:same as above
17,810	100sh	Sh:same as above - trace pyrite and micas
17,820	98sh 1ls 1ss	Ss:same as above Ls:same as above Sh:same as above
17830 - 17880	100sh	Sh:same as above
17,890	99sh 1ss	Ss:same as above Ls:trace ls - same as above Sh:same as above - some calcite cement
17900 - 17,930	99sh 1ss	Ss:same as above Sh:same as above
17,940	100sh	Sh:Black shale, lithified, trace pyrite, no calcite cement
17950 - 17990	100sh	Sh:same as above

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Sun Oil Moore Hooper et al. #1
Loving County, Texas

Measured Depth (ft)	Lithology	Sample Description
15,300	100sh	Sh: Gray shale, some Light gray, lithified
15,310	100sh	Sh:same as above

Measured Depth (ft)	Lithology	Sample Description
15,320	90sh 10ss	Ss:Clear ss, poorly-sorted, angular grains, some calcite cement Sh:same as above
15,330	50sh 50ss	Ss:same as above Sh:same as above
15,340	50sh 50ss	Ss:same as above Sh:same as above
15,350	20sh 80ss	Ss:same as above Sh:Dark-black shale, somewhat fissile
15,360	99sh 1ss	Ss:same as above Sh:same as above
15,370	99sh 1ss	Ss:same as above Sh:same as above
15,380	90sh 5ls 5ss	Ss:same as above white chalky ls Sh:same as above
15,390	90sh 5ls 5ss	Ss:same as above Sh:Black shale - trace pyrite & trace mica
15,400	98sh 2ss	Ss:same as above Sh:Very black shale - abundant micas - silty nodules
15410 - 15,450	100sh	Sh:same as above
15,460	100sh	Sh:same as above - trace calc cement
15,470	98sh 2ss	Ss:Black-gray grains calcareous cement, vf grained, well-sorted Sh:same as above
15,480	98sh 2ss	Ss:same as above Sh:same as above
15,490	NO SAMPLE	
15,500	100sh	Sh:same as above - trace pyrite
15,510	98sh 1ls 1ss	Ss:same as above Ls:white chalky ls Sh:same as above
15,520	100sh	Sh:Black shale - trace pyrite & trace mica
15,530	100sh	Ss:trace ss, poorly-sorted, angular clear grains Ls:trace chalky ls Sh:same as above
15,540	100sh	Ls:trace chalky ls with some grains (volcanic?) Sh:same as above
15,550	100sh	Sh:same as above
15,560	NO SAMPLE	
15,570	100sh	Ss:trace ss, poorly-sorted, angular clear grains Ls:trace ls - same as above Sh:same as above
15,580	100sh	Ss:trace ss - same as above Ls:trace ls - same as above Sh:same as above
15,590	100sh	Sh:Gray - Dark Gray shale, some iron staining
15600 - 15,620	100sh	Sh:same as above
15,630	100sh	Ss:trace ss - dark gray - black, vf grained Sh:same as above - trace sulphur
15640 - 15,650	100sh	Sh:same as above
15,660	95sh 5ls	Ss:trace ss - pebble-sized rounded clasts - conglomerate? Ls:White, pink chalky ls with small black grains Sh:same as above
15,670	95sh 5ls	Ls:same as above Sh:same as above
15,680	95sh 5ls	Ls:same as above Sh:same as above
15,690	100sh	Sh:Gray shale, lithified
15,700	100sh	Sh:same as above
15,710	100sh	Sh:same as above
15,720	99sh 1ss	Ss:vf grained, black, white, red, blue grains, well sorted Sh:same as above
15,730	95sh 5ss	Ss:same as above Sh:same as above
15,740	95sh 5ss	Ss:same as above Sh:same as above
15,750	100sh	Sh:same as above
15,760	95sh 5ss	Ss:White-gray ss, vf grained, moderately sorted, moderately rounded - trace round pebbles Sh:same as above
15,770	100sh	Sh:same as above
15,780	98sh 2ss	Ss:Reddish colored ss - orthoclase colors Ls:trace chalky white ls with small black grains Sh:same as above
15,790	95sh 5ss	Ss:Grey-brown-black ss, fn grained, moderately sorted, moderately rounded Sh:Gray - light gray shale, trace mica, lithified
15800 - 15,810	100sh	Sh:same as above
15,820	95sh 5ss	Ss:Feldspathic grains, white, gray qtz, poorly-sorted, angular Sh:same as above

Measured Depth (ft)	Lithology	Sample Description
15830 - 15,840	100sh	Sh:same as above
15,850	80sh 20ss	Ss:same as above, very angular clasts Sh:same as above
15,860	70ss 30sh	Ss:same as above Sh:same as above
15,870	95sh 5ss	Ss:same as above - Dark gray, red, black – well-sorted, well-rounded Sh:same as above
15,880	90sh 5ls 5ss	Ss:Both white ss and Dark ss present Ls:Dark gray, xln ls Sh:same as above
15,890	90sh 10ss	Ss:same as above Sh:same as above
15,900	90sh 10ss	Ss:same as above Sh:same as above
15,910	80sh 20ss	Ss:same as above Sh:same as above
15,920	50sh 50ss	Ss:same as above Sh:same as above
15,930	80sh 20ss	Ss:same as above Sh:same as above
15,940	70sh 30ss	Ss:same as above Sh:same as above
15,950	90sh 10ss	Ss:Both reddish ss and white ss present Sh:same as above
15,960	95sh 5ss	Ss:same as above Sh:same as above
15,970	95sh 5ss	Ss:dark black-gray ss, well-sorted, subrounded, fn grained. Sh:Black shale, abundant micas
15,980	98sh 2ss	Sh:Black shale
15,990	100sh	Ss:trace ss Sh:same as above
16,000	90sh 10ss	Ss:Black and clear grains, fn grained, sub-rounded, well-sorted Sh:same as above
16,010	40sh 60ss	Ss:White - gray grains, poorly-sorted, sub-rounded Sh:Gray to light gray shale - lithified
16,020	95sh 5ss	Ss:same as above Sh:same as above
16,030	70sh 30ss	Ss:same as above Sh:same as above
16,040	90sh 10ss	Ss:same as above Sh:same as above
16,050	98sh 2ss	Ss:same as above Sh:same as above
16,060	60sh 40ss	Ss:same as above Sh:same as above
16,070	100sh	Sh:Dark gray shale - trace micas
16,080	60sh 10ls 30ss	Ss:Dark gray, white/clear, brown grains, moderately sorted, sub-rounded Ls:Grainy ls with elongate calcite xls Sh:same as above
16,090	70sh 30ss	Ss:same as above Sh:same as above
16,100	40sh 30ls 30ss	Ss:same as above Ls:Grainy texture trace pyrite Sh:same as above
16,110	30sh 40ls 30ss	Ss:same as above Ls:same as above Sh:same as above
16,120	100 ls	Ls:Gray micrite ls with sponge spicules? Sh:same as above
16,130	20sh 80ls	Ls:same as above Sh:same as above
16,140	80sh 10ls 10ss	Ss:same as above Ls:same as above Sh:same as above
16,150	90sh 10ls	Ls:same as above Sh:Gray shale, lithified, trace micas
16,160	50sh 50ss	Ss:White, clear, red (orthoclase), plus pyrite, fn grained, moderately sorted, sub-rounded Ls:trace calcite with black with elongate calcite xls. Sh:same as above
16,170	80sh 20ss	Ss:same as above Sh:same as above
16,180	98sh 2ss	Ss:same as above Sh:same as above
16,190	95sh 5ss	Ss:same as above Sh:same as above
16200 - 16,220	100sh	Ss:trace ss - same as above Sh:same as above
16,230	98sh 2ss	Ss:White, black, gray grains - same as above Sh:same as above
16,240	60sh 20ls 20ss	Ss:same as above - some calc cement Ls:Black-brn xln ls with micrite Sh:same as above
16,250	95sh 5ss	Ss:same as above Sh:same as above
16,260	70sh 15ls 15ss	Ss:same as above Ls:same as above Sh:same as above
16,270	50sh 25ls 25ss	Ss:same as above - some calcite cement Ls:same as above Sh:same as above
16,280	80sh 10ls 10ss	Ss:same as above Ls:same as above Sh:same as above
16,290	30sh 40ls 30ss	Ss:same as above - calcite cement Ls:same as above - abundant pyrite Sh:Light gray

Measured Depth (ft)	Lithology	Sample Description
		sh, lithified
16,300	70sh 30ls	Ss:trace white/clear ss Ls:black-gray micrite limestone Sh:same as above
16,310	50sh 50ls	Ls:same as above - with elongate calcite xls Sh:same as above
16,320	40sh 60ls	Ls:same as above Sh:same as above
16,330	40sh 60ls	Ls:same as above Sh:same as above
16,340	40sh 60ls	Ls:same as above Sh:same as above
16,350	30sh 70ls	Ls:same as above Sh:same as above
16,360	30sh 70ls	Ls:same as above Sh:same as above
16,370	100sh	Sh:same as above
16,380	80sh 20ls	Ss:trace ss - white, light gray, with calcite cement Ls:same as above Sh:Dark gray shale - trace micas
16,390	80sh 20ls	Ss:trace ss - same as above Ls:same as above Sh:same as above
16,400	50sh 50ls	Ss:* Looks like ss @16850 but with calc cement Ls:same as above Sh:same as above
16,410	80sh 10ls 10ss	Ss:* Looks like dark gray ss up-hole but with calc cement Ls:same as above Sh:same as above
16,420	80sh 10ls 10ss	Ss:same as above Ls:same as above Sh:Black shale
16,430	50sh 45ls 5ss	Ss:same as above Ls:same as above Sh:same as above
16,440	90sh 10ls	Ss:same as above Ls:same as above Sh:same as above
16,450	60sh 45ls 5ss	Ss:same as above Ls:same as above - with elongate calc xls Sh:same as above
16,460	60sh 45ls 5ss	Ss:same as above Ls:same as above Sh:same as above
16,470	70sh 30ss	Ss:White ss, vfn grained, well-sorted, sub-rounded with calcite cement Ls:Black-light gray xln, micrite Sh:Dark gray shale
16,480	30sh 70ss	Ss:same as above but with dark gray ss as well Ls:same as above Sh:same as above
16,490	98sh 1ls 1ss	Ss:same as above Ls:same as above Sh:same as above
16,500	100sh	Sh:same as above - trace iron staining, ss, ls
16,510	98sh 2ls	Ss:trace ss - no calcite cement Ls:same as above Sh:same as above
16,520	80sh 20ls	Ls:same as above Sh:same as above
16,530	50sh 50ls	Ss:trace ss with calcite cement Ls:same as above Sh:same as above
16,540	90sh 10ls	Ss:trace rounded pebble-sized clast Ls:same as above Sh:same as above
16,550	90sh 10ls	Ls:same as above Sh:same as above
16,560	90sh 10ss	Ss:Dark gray, black ss fn grained, well-sorted, sub-rounded Sh:same as above
16,570	90sh 10ss	Ss:same as above Sh:same as above
16,580	50sh 50ss	Ss:White ss, vfn grained, well-sorted, sub-rounded Sh:Black shale - lithified, trace pyrite/micas
16,590	80sh 20ss	Ss:same as above Sh:same as above
16,600	NO SAMPLE	Sh:same as above
16,610	100sh	Sh:same as above
16,620	80sh 20ls	Ls:Black with elongate calcite xls Sh:Black shale - looks like phyllite
16,630	60sh 30ls 10ss	Ss:White, clear, gray grains, vf grained, moderately sorted, sub-rounded Ls:Gray ls with abundant pyrite Sh:same as above
16,640	60sh 40ls	Ls:same as above Sh:same as above - abundant micas
16,650	50sh 50ls	Ls:Black with elongate calcite xls Sh:same as above
16,660	20sh 80ls	Ls:Light gray, possible oolites or microfossils? Sh:Dark gray shale - tr micas
16,670	20sh 80ls	Ls:same as above Sh:same as above
16,680	30sh 70ls	Ls:same as above Sh:same as above
16,690	80sh 20ls	Ls:same as above - abundant pyrite Sh:same as above
16,700	100sh	Sh:Black shale, lithified, abundant micas
16,710	90sh 10ss	Ss:Black, gray, brown ss, vf grained, some calcite cement, sub-rounded clasts Sh:same as above
16,720	80sh 20ls	Ls:Black, xln, micrite Sh:Black shale, trace mica, trace pyrite

Measured Depth (ft)	Lithology	Sample Description
16,730	100sh	Ss:trace ss Sh:same as above
16,740	100sh	Sh:dark gray shale - lithified - trace micas
16750 - 16,760	100sh	Sh:same as above
16,770	100sh	Sh:same as above - abundant mica, trace pyrite
16,780	90sh 10ss	Ss:Some red orthoclas (vfn grained), white fn grained angular clasts, white mtrx Ls:Trace chert, and round pebble-sized clasts Sh:same as above
16,790	95sh 5ss	Ss:same as above - including pebbles, red ss, & angular clasts. Sh:same as above
16,800	70sh 20ls 10ss	Ss:White-gray vfn ss, well-sorted, moderately rounded Ls:Black - dark gray xln ls Sh:same as above
16,810	70sh 20ls 10ss	Ss:same as above Ls:same as above Sh:same as above
16,820	70sh 20ls 10ss	Ss:same as above Ls:same as above Sh:same as above
16,830	100sh	Sh:Black - lithified, some calcite fracture fill
16,840	90sh 10ls	Ls:Dark gray, xln ls Sh:same as above
16,850	80sh 20ss	Ss:same as above Sh:same as above
16,860	95sh 5ss	Ss:same as above Sh:same as above
16,870	95sh 5ss	Ss:Gray black, vfn grained ss Sh:same as above
16,880	100sh	Sh:same as above
16,890	98sh 2ss	Ss:same as above Sh:same as above
16,900	98sh 2ss	Ss:same as above Sh:same as above
16,910	100sh	Sh:Black shale with calcite cement
16,920	100sh	Sh:same as above
16,930	100sh	Sh:same as above - trace micas
16,940	95sh 5ss	Ss:same as above Sh:same as above
16,950	100sh	Ss:trace ss with green grains. Sh:same as above
16,960	100sh	Ss:trace ss with green grains. Sh:same as above
16,970	100sh	Sh:Black shale - lithified
16,980	100sh	Sh:same as above
16,990	100sh	Ss:trace ss & chert Sh:same as above
17000 - 17060	100sh	Sh:same as above
17,070	100sh	Ss:trace ss (white with pink (orthoclase) grains - immature) Sh:same as above
17,080	100sh	Ss:trace ss - same as above Sh:same as above
17,090	100sh	Ss:trace ss - same as above Sh:same as above
17100 - 17500	100sh	Sh:same as above

Vita

Personal Background	William Everett Hasler Fort Worth, Texas Born February 8, 1982, Ely, NV Son of Richard and Julie Hasler Married to Lacey (Whiting) Hasler, April 30, 2004
Education	Bachelor of Science in Geology, 2007 Brigham Young University-Idaho, Rexburg, ID Master of Science in Geology, 2009 Texas Christian University, Fort Worth, TX
Experience	Geology Technician, 2000-2001 BHP Billiton, Tintaya, Peru Intern Geologist, 2007 Anadarko Petroleum Corporation, Woodlands, TX Teaching Assistant, 2007-2008 Texas Christian University, Fort Worth, TX Intern Geologist, 2007-2008 XTO Energy, Fort Worth, TX Associate Geologist, 2008-Present XTO Energy, Fort Worth, TX
Professional Memberships	Fort Worth Geological Society (FWGS) American Association of Petroleum Geologists (AAPG) Society for Sedimentary Geology (SEPM)

Abstract

DEPOSITIONAL SYSTEMS OF THE ATOKA AND MORROW SERIES (PENNSYLVANIAN), HALEY FIELD AREA, LOVING COUNTY, TEXAS

By William E. Hasler, M.S., 2009
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Dr. John Breyer – Professor of Geology
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Haley Field, Loving County, Texas has produced over 300 bcf of gas from Morrowan and Atokan strata in the Delaware Basin. However, only one in four wells drilled in the field is economic. These reservoirs were deposited in a deep-water setting in a basin undergoing active tectonism in response to the Marathon-Ouachita orogeny. The Central Basin Uplift, the Grisham Anticline, and the Red Hills Arch all altered sediment distribution in the basin. Lower and middle Morrow strata are multiple-source submarine ramp turbidites that flowed from the Northwest Shelf and the Central Basin Uplift. A carbonate shelf edge developed along the Northwest Shelf during the late Morrowan and prograded basinward during the Atokan. Channels cut into the high-relief shelf edge fed sand-rich turbidites deposited on the basin plain. Exploration potential exists in stacked channels, fan lobes and overbank deposits associated with turbidites both in the Morrow and the Atoka.