THE FACIES, ENVIRONMENTS OF DEPOSITION AND CYCLICITY OF THE YATES FORMATION, NORTH WARD-ESTES FIELD, WARD COUNTY, TEXAS

A Thesis

by

RONNIE DELANE JOHNSON

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 1997

Major Subject: Geology

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Approved as to style and content by:

James Mazzullo
(Chair of Commitee)

Steven Dorobek
(Member)

Ching Wu
(Member)

Phillip Rabinowitz
(Head of Department)

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ABSTRACT

The Facies, Environments of Deposition and Cyclicity of the Yates Formation,
North Ward-Estes Field, Ward County, Texas. (August 1997)
Ronnie Delane Johnson, B.S., Louisiana State University
Chair of Advisory Committee: Dr. James Mazzullo

The Yates Formation is part of the Artesia Group, a sequence of interbedded carbonates, clastics and evaporites that was deposited across the back-reef shelves of the Permian basin in Late Permian (Upper Guadalupian) time. The Artesia Group is the shelfal equivalent of the shelf-marginal Capitan and Goat Seep Reefs and deep-basinal Delaware Mountain Group. This study is based on the description of seven cores and twenty-two well logs from North Ward-Estes field along the western margin of the Central Basin Platform.

The Yates Formation consists of sub-arkosic sandstones and siltstones and dolomitic mudstones and wackestones. It has sharp contacts with the carbonates of the underlying Seven Rivers Formation and evaporite-rich beds of the underlying Tansill Formation. Five facies are distinguished in the Yates Formation and its bounding surfaces on the basis of their lithologies and stratification. Three clastic facies (Facies 1, 2, and 3) were deposited in fluvial, deltaic, eolian and sabkha environments. One carbonates facies (Facies 4) was deposited in a shallow subtidal environments and one evaporite facies (Facies 5) was deposited in a sabkha environment.

The stratigraphy of the Yates Formation was determined by the correlation of cores and well log data strike and dip profiles through the field. Two sequences and ten to twelve parasequences are recognized within the Yates Formation. Each sequence consists of basal lowstand incised valley fill (IVF), which is overlain by a Transgressive Systems Tract (TST) and Highstand Systems Tract (HST). The two sequences which have slightly wavy sheet geometries in the strike direction and thin in the landward direction, marking two long-term cycles of relative sea level fall and subsequent rise in the field area.

Reservoir properties of the Yates Formation were determined by the use of core plug data for porosity and permeability measurements. This physical data, along with measured data from well logs, was then correlated to identify the quality, lateral extent and continuity of the clastic reservoirs in this formation. Facies 1 is identified as the best reservoir rock and Facies 3 is identified as the poorest. Facies 2 has intermediate quality.

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INTRODUCTION

This study will examine the facies, environment of deposition, stratigraphy and reservoir characteristics of the Yates Formation (Late Permian/Guadalupian) in the North Ward-Estes feild (Figure 1). The Yates Formation is a part of the Artesia Group, a series of interbedded carbonates, clastics and evaporites that was deposited across the back-reef shelves of the Permian Basin in Late Permian (Upper Guadalupian) time. The group is the shelfal equivalent of the shelf-marginal Capitan and Goat Seep Reefs and deep-basinal Delaware Mountain Group. This thesis will address several problems of the Yates Formation. The major ones being facies and the environment of deposition of these sediments and their cumulative affect on the reservoir characteristics of the field.

The first purpose of this thesis is to characterize the facies and environment of deposition of the Yates Formation and to determine the effects of sea level changes and sediment supply on its accumulation. Proper interpretation of the depositional history of the Yates Formation plays an important role in delineating the facies control in the reservoir and non-reservoir sandstones. The second purpose of this thesis is to determine the stratigraphic relationships of the facies present in the Yates Formation and to determine the repercussions of cyclic deposition on clastic sediments. The third purpose of this thesis is determine some reservoir characterization using petrographic data and core descriptions.

This thesis follows the format of the American Association of Petroleum Geologists Bulletin.

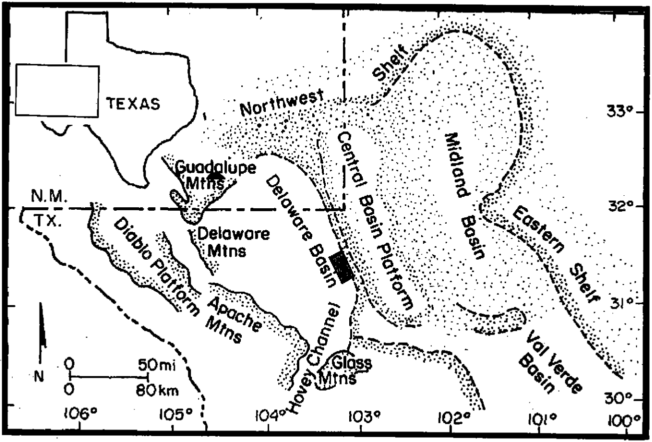


Figure 1--Map showing the location of North Ward-Estes field (shaded gray) in the Permian Basin (after Ward et al., 1986).

GEOLOGIC BACKGROUND

Geologic History and Tectonic Setting

The Permian Basin evolved from a symmetric structural depression in the Precambrian basement, the Tobosa Basin, at the southern margin of the North American plate (Ward et al., 1986). The Tobosa Basin was segmented into several smaller sub-basins as a result of the Late Paleozoic deformation of the Marathon-Ouachita orogeny (Adams et al., 1951: Hills, 1963,1972, 1984: Nicholas and Rozendal, 1975: Kluth and Coney, 1981: Wuellner et al., 1986: Frenzel et al., 1988: Denison, 1989).

The prominent physiographic features of the Permian Basin, the Midland and Delaware basins and surrounding shelves, were well developed before sedimentation began during the Permian time (Oriel et al, 1967). During the Late Pennsylvanian, the Midland and Delaware basins became two separate depocenters as a result of folding and faulting of the median sector of the Tobosa basin and development of the Central Basin platform, while at the same time, the Matador uplift arose to become the northern boundary of the basin (Hill, 1972). These uplift and folding events left mountainous areas in the northern section of the Central Basin platform, as well as in central Texas, southern Oklahoma, and central New Mexico. The sources of the Yates clastics are thought to be the Guadalupe Mountains, the Diablo platform and the Roosevelt uplift (Figure. 2).

From Early Permian to Late Permian, the shelves and platforms of the Permian Basin were sites of carbonate deposition, while the basins were sites of deposition of clastics and limestones. The pre-existing positive areas, such as the Roosevelt uplift and Diablo platform, were the suppliers of detritus for the Delaware basin since the Wolfcampian. During the Middle Wolfcampian, thrusting of the Ouachita-Marathon structural belt at the southern edge of the Permian Basin resulted in sedimentation in the Val Verde trough and increased the relief in the basins and surrounding platforms. The Central Basin platform and the Northwest shelf remained quiescent during this time, and were characterized by the deposition of thick sections of dolomite.

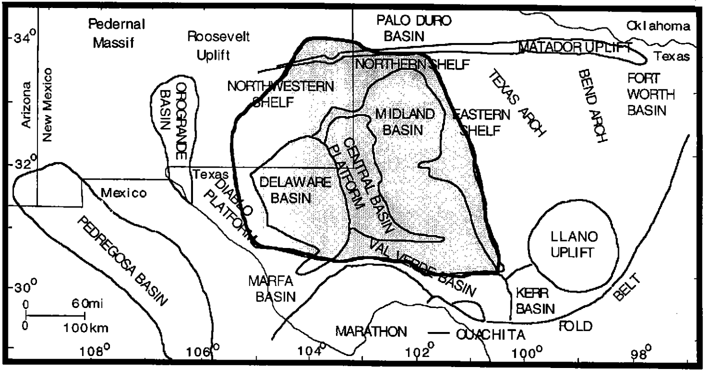


Figure 2--Geologic division of the Permian Basin with ancestral Tobosa Basin shaded (Modified from Frenzel et al., 1988).

Uniform regional subsidence of the Permian basin which began at the onset of Leonardian time, favored the proliferation of reefs at the basin margin and caused a restriction in the lagoons behind them. The shallow parts of these lagoon were hyper saline resulting in the deposition of evaporites and seaward the abundance of calcareous organisms at the shelf edge resulted in the deposition of thick sections of carbonates.

During Guadalupian time, the Midland basin became filled while the Delaware basin continued to deepen (Figure 3). Sea water oscillated in and out of the Northwest shelf and Central Basin platform for most of the Guadalupian. This cyclic fluctuation along with the hot and arid climate, promoted the deposition of clastics, evaporites, and carbonates on these shelves. The Central Basin platform remained stable until the Late Permian, with sedimentation occurring on the shelf edge margin.

Post-Permian tectonics is marked by uplift and erosion with broad regional warping in the western and northern peripheries of the Permian basin region. Throughout the Mesozoic, most of the Permian basin remained emergent, although the southernmost part experienced down warping. The result of the latter was a seaway encroachment from Mexico and the deposition of marine sediments, including the Comanche and Gulf Limestones (Cretaceous) which extend laterally throughout the region (Figure 4). Regional upheaval by the Late Cenozoic exposed Permian strata in the west Texas Permian basin to continued erosion.

Stratigraphy

The Artesia Group is a sequence of interbedded clastics, carbonate and evaporites of Late Permian (Guadalupian) age that is found in the back-shelves of the Permian Basin. The Artesia Group is composed of five formations (in ascending order), the Grayburg, Queen, Seven Rivers, Yates, and Tansill. The Artesia Group is subdivided into "carbonate" and "clastic" divisions based on the abundance of sediment type. The Grayburg, Seven Rivers and Tansill are generally composed primarily of carbonates whereas the Yates and Queen formations comprise the clastic units. The shelf-edge equivalent units, of the Yates

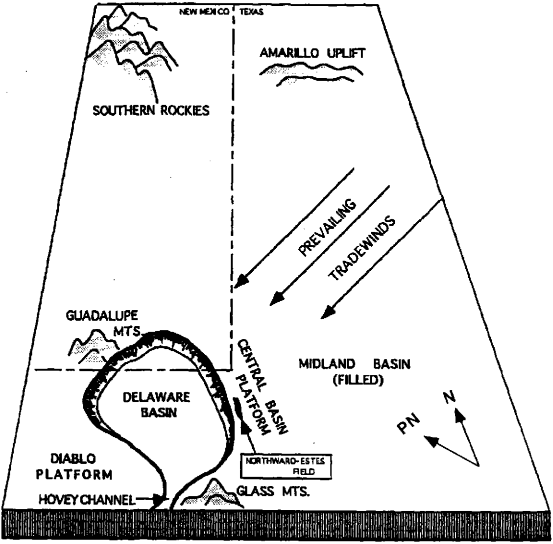


Figure 3--Paleogeographic map of the Permian Basin during Yates time, PN (Permian North); modified after Mazzullo et al., 1991).

System	Series	Unit
	Recent	Sand & Gravels
	Pleistocene	Sand & Gravels
TERTIARY	Pliocene	Ogallala Group
TERTIARY	Miocene	Absent
TERTIARY	Oligocene	Absent
TERTIARY	Eocene	Absent
CRETACEOUS	Upper	Gulf Limestone
CRETACEOUS	Lower	Comanche Limestones
JURASSIC		Absent
TRIASSIC	Upper	Dockham Group
TRIASSIC	Middle	Absent
TRIASSIC	Lower	Absent
PERMIAN	Upper	Ochoa
PERMIAN	Upper	Guadalupe
PERMIAN	Lower	Leonard
PERMIAN	Lower	Wolfcamp

Figure 4--Stratigraphy of the Permian Basin region from Permian to Recent (modified from Hills, 1970).

Formation is the Capitan Reef which in turn pass basinward into the Bell Canyon Formation of the Delaware Mountain Group (Figure 5), (Tait et al., 1962 and Meissner, 1974).

The shelf sandstones and carbonates of the Artesia Group are commonly hydrocarbon reservoirs with combined structural and stratigraphic traps, and have produced over 1.4 billion barrels of oil since 1980 (Ward et al., 1986). The group also contains bedded evaporites which provide impermeable seals for these reservoirs. There has been considerable interest in the depositional histories and petrophysical properties of these rocks, especially when they constitute stratigraphic traps for hydrocarbons. The purpose of this thesis to determine the depositional and diagenetic properties which controlled the developement of these reservoirs.

The Yates Formation of North Ward-Estes field consists of interbedded sequence of clastics, carbonates and evaporites. It varies in thickness from 300 ft (92 m) in the western part of the field (toward the shelf margin), and thins to 220 ft (67 m) to the east (towards the shelf interior). The basal contact of the Yates Formation with underlying Seven Rivers Formation is sharp and he upper contact is graded with the evaporite-rich beds of the Tansill.

The Problem of the Yates Formation

The first question to be addressed is the environments of deposition and depositional history of the Yates Formation. The carbonates and evaporites are accepted to be deposited in shallow coastal and restricted marine settings, but it is not clear whether the Yates clastics were deposited in lagoonal, deltaic, fluvial, sabkha or continental settings. In fact, three different models have been proposed to explain the origin of the Yates, and particularly its clastic members. The **wet model** calls for the deposition of the clastics in the shelf interior lagoonal and coastal settings during high stands of sea level, when the Central Basin platform was completely submenrged (Boyd, 1958; Ball et al., 1971; Sarg 1977; Wheeler, 1989). The **dry model** calls for the deposition of these clastics in sabkha and coastal deserts, when the shelf was exposed by low stands of sea level (Kendall, 1969; Silver and Todd, 1969; Jacka et al., 1969; Williams, 1969; Jacka and Franco, 1974: Meissner, 1974; Sarg, 1985; Mazzullo et

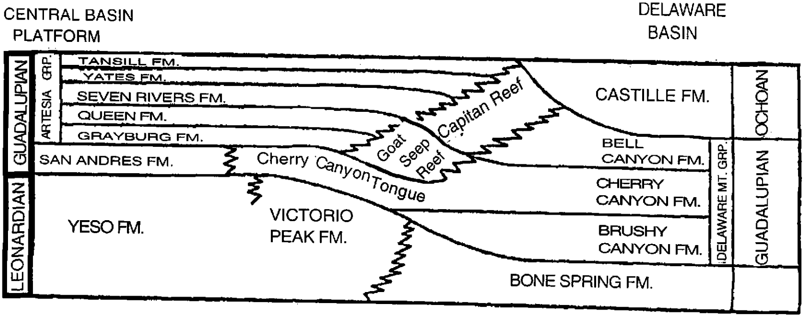


Figure 5--Cross-sectional representation of Upper Permian stratigraphic relationships in the Delaware Basin (modified after Ward et al., 1986).

al., 1985). The **hybrid model** suggests that the deposition of the Yates Formation began with a lowstand of sea level, when clastic sediments began to be supplied to the shelves of the basin, and then continued as sea level rose (Mazzullo et al., 1990). Therefore, the first objective of this study is to examine cores of the Yates Formation, describe its facies and interpret these environments of deposition.

In addition, this thesis will also examine the stratigraphy of the Yates Formation in a sequence stratigraphic framework which employs the use of tectonics, sediment supply as well as sea level changes to interpret depositional history. The stratigraphy of the Yates Formation was previously described by Borer and Harris (1991), who studied the interbedded carbonates and clastics of the formation on the shelf edge margin, to the immediate west of the Central Basin Platform.

The third objective of this thesis is to identify the factors that control the formation of reservoirs and non-reservoirs in the Yates Formation. The shelf sandstone reservoirs are primarily stratigraphic traps, but little is known about depositional and diagenetic origins of these Yates reservoirs and specifically the depositional environments of these reservoirs and the diagenetic processes which either created or preserved porosity and permeability within them. It is commonly accepted that the sandy red beds of the Yates Formation are primarily sabkha deposits and generally poor reservoirs: gray sandstones are delta plain deposits of fluvial and eolian origin and of variable reservoir quality and that the tan to brown sandstones are eolian deposits that form the best reservoirs.

METHODS

Field Area

The Yates Formation at North Ward-Estes field (Ward and Winkler Counties, Texas) is situated in the shelf edge margin of the Central Basin platform of the Permian basin and is 4-6 miles (6.4- 9.6 km) to the east of the Goat Seep reef margin. The Yates Formation in North Ward-Estes field is a part of the "river of sand", a series of strike-trending sand bodies deposited on the western margin of the Central Basin platform that was discovered in 1929 (Figure 6, Ward et al., 1986). This field which has 1424 producing wells and 1255 non-producing wells is approximately 35 square miles in area and has produced over 373 million barrels of oil through 1992 from the clastic members of the Queen and Yates formations (Andreason, 1992).

Cores

A total of seven slabbed cores recovered by Chevron in the 1950's thru 1980's were examined in this study. They are 1) G.W. O'Brien 1514, 2) G.W. O'Brien 1491, 3) E.W. Estes 262, 4) W.A. Estes 128, 5) Hutching Joint Stock Association (HSA) 1391, 6) HSA 1255, 7) HSA 1169 (Figure 7). The slabbed cores were examined for lithologies, sedimentary structures and diagenetic features.

Thin Sections

From the cores, 37 oriented thin sections were made in selected clastic intervals. These thin sections were impregnated with blue dyed epoxy for porosity enhancement. The thin sections were point counted with the Glagolev- Chayes method with a total of 100 monocrystalline quartz grains per slide, in order to determine detrital and authigenic composition (Glagolev, 1934; Chayes, 1949). The 100 quartz grains were measured for grain size analysis for the purpose of making cumulative frequency curves and for statistical analysis for mean grain size, and standard deviation for computational sorting measures. With the sampling technique that was used, only larger grains were measured and clay to silt size grains were not measured.

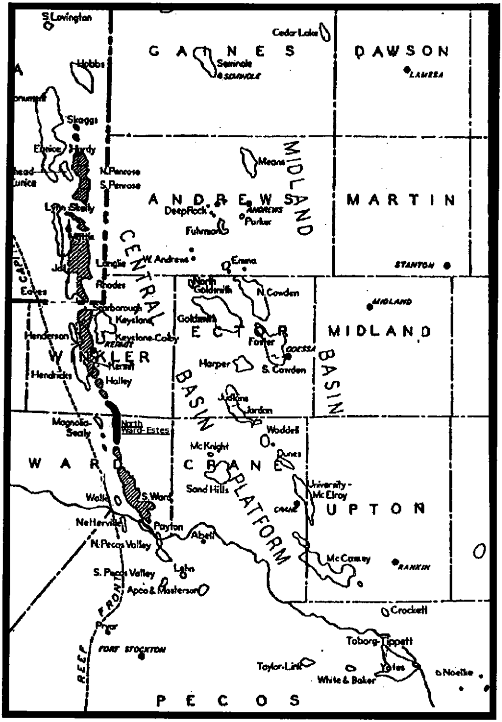
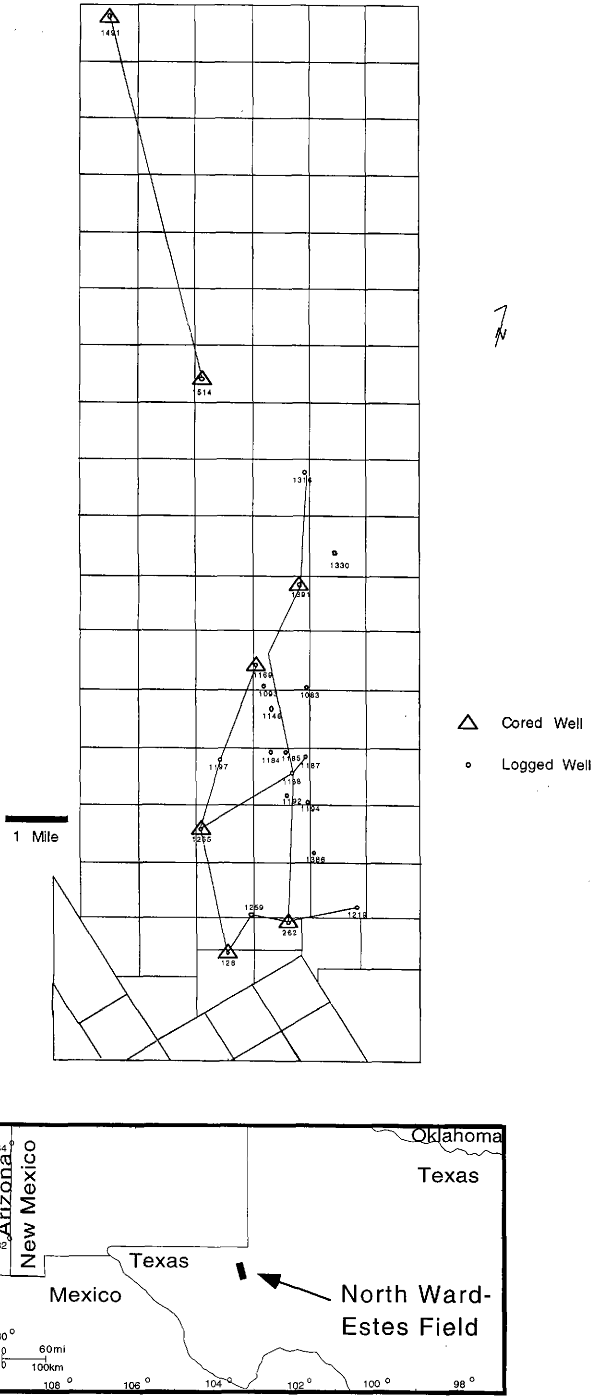


Figure 6 --Map showing the location of the "River of Sand" (striped with North Ward-Estes field in black) Hydocarbon fields producing from Guadalupian age clastics(after Denham and Dougherty,1941).

Figure 7--North Ward-Estes field showing cored and logged wells. The G.W. O'Brien 1491 and 1514 cores are in sections 16 and 30 respectively, of Block F. The E.W. Estes 262 and W.A. Estes 128 are in Block B-19, sections 27 and 28. Hutchings Stock Association (HSA) 1391 is in Block F, section 1 while HSA 1255 and HSA 1169 are in Block O sections 9 and 5.


Cored Well
Logged Well
1 Mile
Oklahoma
Texas
Arizona
New Mexico
Texas
Mexico
North Ward-
Estes Field
60mi
100km
34°
32°
30°
108°
106°
104°
102°
100°
98°

Well Logs

In addition to the cores, a total of 22 well logs from North Ward-Estes field were examined to determine structural configuration and sediment isopach thicknesses. Gamma-ray logs were used for these determinations, since they are common geophysical logs available in all the wells. The natural radioactivity of the lithologies is the basis of the log response. For example, the carbonates and evaporites have a low gamma-ray log response due to the absence of radioactive components, on the other hand sandstones and siltstones are sub-arkosic and so give higher gamma-ray response that are most conspicuous when situated between carbonates or evaporites (Figure 8). The lower contact of the Yates Formation can be traced in the subsurface by a rapid increase in gamma-ray counts as well as a decrease in density of the formation. The uppermost contact is marked by a rapid increase in bulk density as well as a decrease in gamma-ray counts, due to the transition to the overlying anhydrite of the Tansill formation.

Sequence Stratigraphy

The sequence stratigraphy of the Yates Formation is determined by the stacking patterns of the clastic and carbonate rocks forming shoaling upward parasequences. The correlation of continuous carbonate strata is employed to create the regional sequence stratigraphic framework and then the cyclicity of the clastic and carbonate is compared to previous works by Borer and Harris (1991) and Ross and Ross (1988). Each of these sets of authors gave a different interpretation of the stratigraphy of the Yates Formation by using different assumptions. Borer and Harris assumed that a simple stacking pattern of an interval of carbonate rocks overlain by an interval of clastic rocks represented a 100,000 year cycle of sea level change. Ross and Ross however based their work on pre-existing sea level curves by Vail, Mitchum et al. (1977), thus producing an alternate absolute age of the formation.

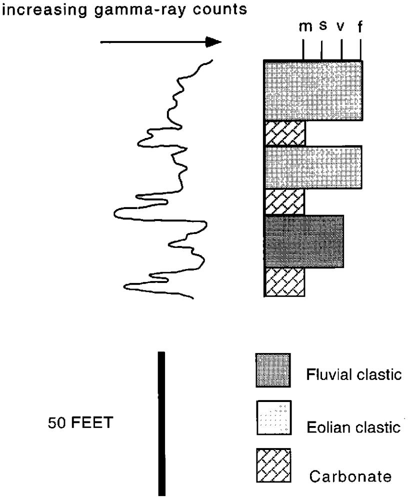


Figure 8--Log signature of clastic versus carbonate rocks.
(HSA 1169, 2520-2600 feet)

RESULTS

Facies of the Yates Formation

The Yates Formation in North Ward-Estes field consists of very thin to very thickly interbedded clastic and carbonate rocks and minor amounts of evaporites. It is underlain by carbonates of the Seven Rivers Formation and overlain by evaporite-rich beds of the Tansill Formation.

The clastic rocks of the Yates Formation comprise approximately 55% of the formation. They range from less than 0.1 to 5m (.3 to 18 ft) in thickness, and consist of very thin to very thick beds of very fine to fine grained sandstones and siltstones. The bulk of the clastics are moderately to well sorted very fine sandstones and siltstones with sub-angular to sub-rounded grains that are sub-arkosic in composition and cemented by dolomite.

The carbonate rocks comprise 40% of the formation and range in thickness from less than 0.1 to 3.5 m (.3 to 13 ft). They are comprised of dolomitic mudstones and lesser amounts of dolomitic wackestones but they usually contain some siliciclastic mud and sand.

Evaporites comprise less than 5% of the rocks of the Yates Formation, and are usually found only in the upper part of the formation, near the graded contact with the Tansill Formation. They occur in two forms: beds of nodular mosaic anhydrite and displacive anhydrite nodules. The intervals range from less than 0.1 to 2.5 m (.3 to 8 ft) thick, and are typically very thin to thick. The anhydrite nodules are found within the carbonate and clastic beds.

Yates Clastic Facies and Environments of Deposition

Three distinct facies can be distinguished in the clastic rocks in the Yates Formation in the North Ward-Estes field on the basis of sediment lithology, color and structures. These facies indicate deposition in a hot, semi-arid, and poorly-vegetated desert coastal plain. The lack of vegetation led to erosion by eolian processes during prolonged dry spells, as well as fluvial processes during brief torrential rainfalls and their ensuing floods in these deserts

(Glennie, 1970). In addition, low-lying sabkhas wherein sediments were deposited by eolian and fluvial processes and were subsequently deformed by haloturbation.

Three clastic desert facies are interpreted in the Yates Formation: eolian sandsheets (Facies 1), fluvial sandflats (Facies 2) and clastic-dominated sabkhas (Facies 3).

Facies 1 consists of tan- to brown-colored fine sandstones and siltstones. The sandstone beds are typically thick to very thick and massive, but they also contain thin planar laminae. They are generally well sorted and highly friable, and the coarser sand grains are well rounded. The siltstones beds are thin and form planar to wavy laminations within the sandstones (Figure 9).

The massive sandstone beds of facies 1 are thick to very thick bedded and often have graded contacts with the laminated sandstone and siltstone beds. They are tan to brown and consist of fine, well sorted and sub-rounded sand. The massive beds near the top of the formation also contain nodules of anhydrite which were apparently formed after deposition, because they appear to displace the primary stratification in them. Laminated sandstone beds are rarely seen, and when present the laminae are straight, parallel and continuous. The massive sandstones are generally consolidated to highly friable, and missing sections of cored intervals appear to correspond to the most friable intervals.

The laminated beds of facies 1 consist of thin bedded well sorted sub-rounded tan to greenish grey sandstones and siltstones. The laminae vary from straight, parallel and continuous to wavy, non-parallel, and discontinuous (or "wispy"). These beds also display syndepositional faults, paleosols and possible bioturbation traces.

The color of Facies 1 of which varies from dark brown to tan to greenish gray is due to varying degrees of hydrocarbon staining. The darker brown is a result of residual oil present in the pores, and the tan to greenish gray color is a result of less hydrocarbon..

The depositional environment of Facies 1 is interpreted as the deposits of dry eolian sand sheets. Eolian sandsheets are variable scale regional deposits found in deserts. They range from isolated patches found in fluvial sandflats and sabkhas to broad plains or ergs that

Figure 9--Facies 1 (Erg) of the Yates Formation.

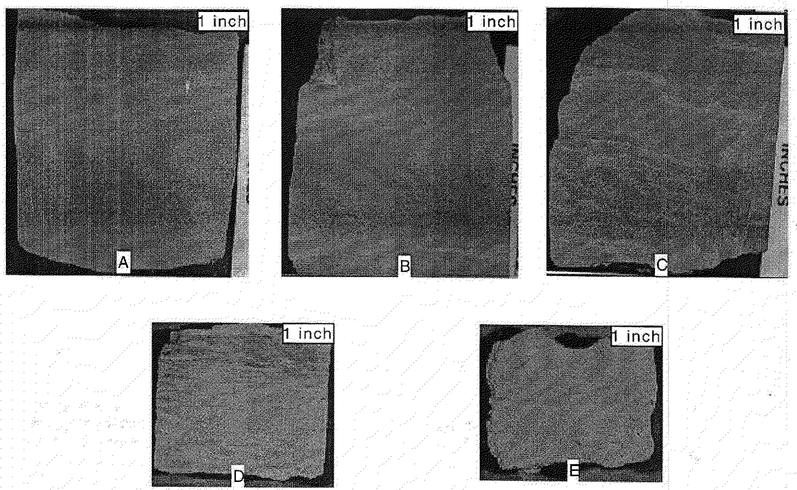
9A Massive sandstone (HSA 1255; 2737- 2737.4 ft).

9B Massive sandstone with anhydrite (HSA 1255; 2701.8- 2702.4 ft).

9C Massive sandstone with syndepositional faults (HSA 1255; 2747.5- 2748 ft).

9D Siltstone with lamiantions (HSA 1391; 2537.8- 2538.2 ft).

9E Friable sandstone (HSA 1391; 2502.3-2502.6).


1 inch
A
1 inch
B
1 inch
INCHES
C
1 inch
D
1 inch
E

form downwind from alluvial plains, sabkhas, sandy shorelines and other sources of sediment (Kocurek and Neilson, 1986). The surfaces of erg sandstones generally have low relief and are poorly vegetated, so that they are dominated by wind erosion and deposition. Grainfall and upper low regime plane-bed laminae, and rarely deflation lags, are also present in eolian sandsheets. These sandstone deposits are further distinguished by the high degree of sorting and the lack of clays and silts which are winnowed by the wind (Hunter, 1977; Kocurek, 1981; Fryberger et al., 1983; and Kocurek and Neilson, 1986).

Facies 2 consists of two subfacies. **Subfacies 2a** consists of interbedded gray fine sandstones and dark gray siltstones. The sandstone beds are thin to medium in thickness and are sometimes separated by very thin beds of shale. They are typically wavy and planar laminated, but they also contain mud drapes, ripples, load structures, fluid escape structures and bioturbation traces. The siltstones beds of are gray to dark gray thinly bedded and separated by very thin beds of shale. The siltstones are generally bioturbated but they also contain load structures, mud drapes and fluid escape structures (Figure 10).

Subfacies 2b consists of gray, fine to medium, and sometimes gravelly, sandstones. The beds are medium to thick, always overlie scour surfaces, and commonly grade from pebbly sandstones with subrounded dolomicritic clasts at their bases upward into very fine sandstones (Figure 10).

Facies 2 is interpreted to have been deposited in the channels and distributaries of fluvial sandflats and fan deltas. **The environment of deposition** of Facies 2a is interpreted to be of desert braided streams (fluvial sandflats) and their fan deltas. **The environment of deposition** of facies 2b is interpreted as to be channels and distributaries of the fluvial sandflats and fan deltas of facies 2a. Fluvial sandflats are poorly vegetated sheetflood plains that are dissected by a few channels. The sheetflood surfaces are generally low relief, poorly vegetated and are dominated by deposition during flash floods. Due to the nature of deposition of these sediments, the major deposits are thin planar laminated fine to very fine grained sandstones and siltstones that are straight crested laminated bedforms that migrate

Figure 10--Facies 2 (Delta plain and Channel) of the Yates Formation.

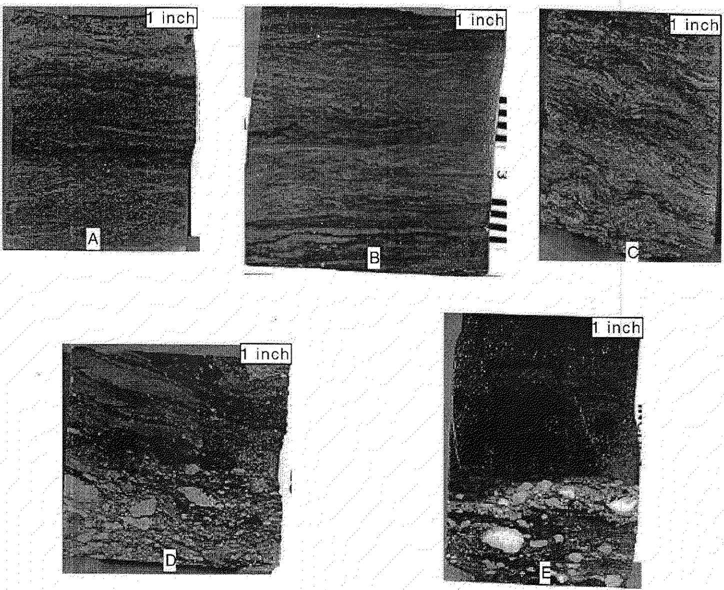
10 A Sandstone and siltstone (EWE 262; 2519.7-2520).

10 B Sandstone and siltsone with wavy laminations (EWE 262; 2445-2445.3).

10 C Sanstone and siltstone with bioturbation and fluid escape structures (WAE 128; 2497-2497.4).

10 D Channel scour (WAE 128; 2505.4-2505.7).

10 E Channel (EWE 262; 2448-2448.4).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across the surface of deposition. The channels of fluvial sandflats which are represented by subfacies 2b, are typically wide and shallow, and lack cohesive banks due to the lack of vegetation. Deposition in these channels occur after torrential rainfalls when scour surfaces eroded by high flow velocities at their base and grade to siltstones at the tops (Schumm, 1968; Glennie, 1970; Hardie and Eugster, 1970; and Hardie et al. 1978). Fan deltas are simply a seaward extension of fluvial sandflats.

Facies 3 consists of red to reddish brown fine sandstones and siltstones. The beds are very thin to thin bedded and contain abundant discontinuous laminae as well as evaporite nodules, fluid escape structures, ripples, scour surfaces, haloturbation structures, and possible bioturbation traces (Figure 11).

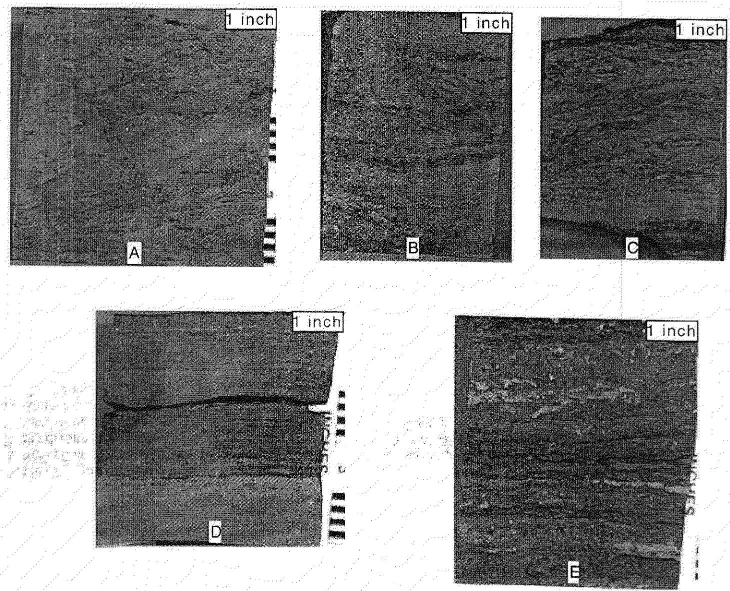
The environment of deposition Facies 3 is interpreted as the deposits of fluvial-dominated coastal sabkhas. Clastic-dominated sabkhas are low-lying poorly vegetated continental and coastal plains that are adjacent to eolian sandsheets and fluvial sandflats. The clastic component of them are interpreted to have been deposits in eolian sandsheets and fluvial sandsheets, but they were subsequently deformed by the alternating periods of evaporite formation and subsequent dissolution (Butler, 1969; Kinsman, 1969; Smith, 1971; Handford, 1981,1988; Sonnenfeld, 1984; and Kendall and Warren, 1987).

Yates Carbonate and Evaporite Facies and Environment of Deposition

One carbonate and one evaporites facies can be distinguished in the Yates formation in the North Ward-Estes field on the basis of sediment lithology, color and structures.

Figure 11--Facies 3 (Sabkha) of the Yates Formation.

11 A Sandstone and siltstone with haloturbation and fluid escape structures (HSA 1169; 2671.2-2671.6).
11 B Sandstone and siltsone with wavy laminations and anhydrite (WAE 128; 2548-2548.6).
11 C Sandstone and siltstone with bioturbation and fluid escape structures (WAE 128; 2497-2497.4).
11 D Siltstone with anhydrite layer (HSA 1255; 2687.4-2687.8).
11 E Sandstone with non-iron stained sections (HSA 1255; 2686.5-2687).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Facies 4 consists of gray to pink dolomudstones with minor amounts of dolowackestones. The beds are thin to medium bedded, and contain fecal pellets, peloids, fusulinids and rare crinoidal fragments. They are generally structureless, but also contain some crinkly laminae, erosion surfaces, pressure seams (stylolites) and collapse breccia (Figure 12).

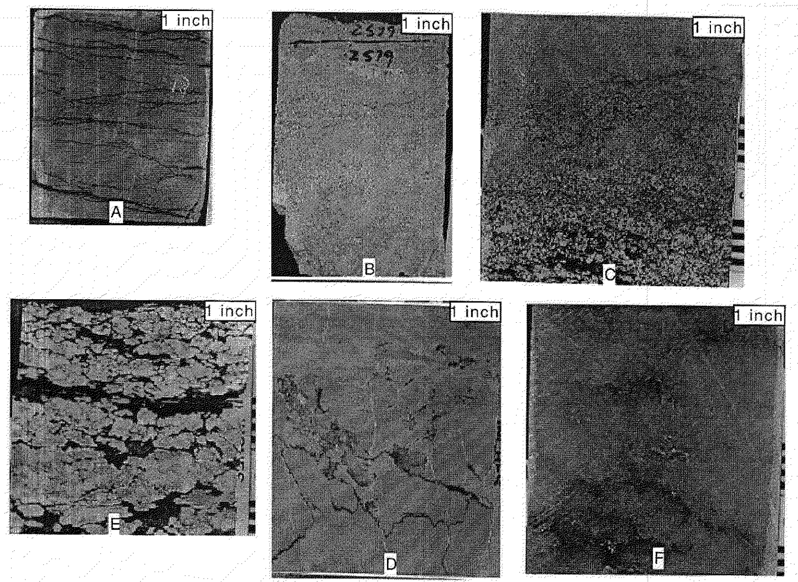
The environment of deposition of Facies 4 is interpreted as deposits in a shallow subtidal setting of an inner shelf lagoon.. Dolomudstones and dolowackestones form from the recrystallization of calcareous mud from various biota which are either locally produced or eroded from nearby reefs. The desiccation features and erosional surfaces are a result of exposure, dissolution and desiccation in lagoonal deposits (Hardie and Eugster, 1970;Shearman, 1971; Wilson, 1975; Sarg, 1977, 1981; Schreiber et al., 1982; Longacre, 1983; Sonnenfeld, 1984; Chuber and Pusey, 1985; Mazzullo and Hedrick, 1985; Ward et al. 1986; Fischer and Sarnthein, 1988).

Facies 5 consists of light gray nodular-mosaic beds and some anhydrite rich siltstone beds. The anhydrite beds are thick and very thick, and they have nodular- mosaic fabrics which displace and deform the surrounding siltstone laminae (Figure 11).

The environment of deposition of Facies 5 is interpreted as deposits of an evaporite-rich coastal sabkha. Evaporite-rich sabkhas are coastal deposits that form along the landward edge of shelf-interior lagoons. The clastic component was similar to that of fluvial sandsheets that are infiltrated by clay rich floodwaters and displaced by growth of massive anhydrite nodules. The anhydrite was precipitated from hyper-saline lagoonal waters that typically underlies the surfaces of coastal sabkhas (Butler, 1969; Kendall, 1969; Kinsman, 1969; and Schreiber et al., 1982).

Figure 12--Facies 4 (Carbonate) and Facies 5 (Anhydrtite) of the Yates Formation.

12 A Dololmudstone with pressure seams (WAE 128; 2553.4-2553.8).
12 B Dolomudstone-Dolowackestone with crinkly laminations (HSA 1391; 2579-2579.4).
12 C Dolowackestone with moldic porosity (HSA 1169; 2562.5-2563).
12 D Anhydrite with chicken wire texture displacing siltstone (HSA 1169; 2434-2434.5).
12 E Anhydrties displacing dolomudstone (HSA 1255; 2682.2-2683).
12 F Anhydrite bed with some siltstone (HSA 1255; 2479.1-2479.5).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Stratigraphy

The Yates Formation of North Ward-Estes field consists of subarkosic sandstones and siltstones and dolomitic mudstones and wackestones. It reaches a maximum thickness of 300 feet (92m) in the western part of the field (towards the basin) and thins to 220 feet (67m) to the east towards the shelf margin. The surface type section is found in lower Dark Canyon, Guadalupe Mountains, New Mexico (Sec. 27, T23S, R25E) according to Lanphere (1972) and the subsurface type section is found on the Northwest shelf (Tait et al., 1962).

The stratigraphy of the Yates Formation was determined by the correlation of core and well log data along strike and dip profiles through the field (Appendix B). The lower contact of the formation is abrupt, wavy and presumably unconformable with a relief of 125 feet. (38m) in the southern part of the study area along the HSA 1255- HSA 1187 profile. In the northern part of the study areaalong the HSA 1491-HSA 1514 profile, the relief is 460 feet (140m). In both cases, however, the contact is presumably unconformable. It is marked in well logs by a sudden increase in gamma ray counts, and in cores by the brecciated carbonates at the top of the Seven Rivers Formation. The upper contact of the Yates Formation is usually gradational and is marked in logs by transitions from clastics into evaporite-rich beds of the lower Tansill Formation (Figure 13).

Previous works by Borer and Harris (1991, 1992) and Ross and Ross (1988) give varying interpretations of the absolute age of the Yates formation. This study will not address that question, but rather attempt to give an explanation for the cyclicity of the clastics and carbonates of the formation. The approach to fit the formation into a sequence stratigraphic framework employs using both sequence stratigraphic techniques as well as lithostratigraphy (stacking patterns) of facies, with special attention to specific facies and their relative locations.

Two High Frequency Sequences (HFS) and 10 to 12 stacked "upward drying cycles" or parasequences are recognized in the Yates formation. Each sequence consists presumable of a low relief basal lowstand incised valley fill (IVF), which is overlain by a transgressive

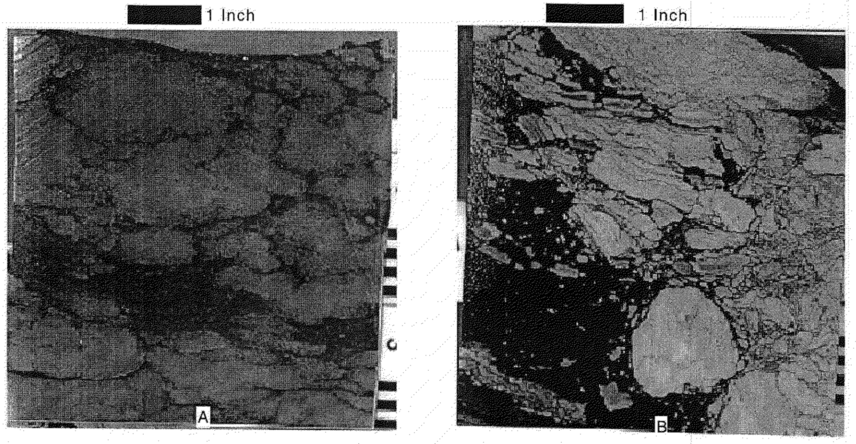

Figure 13-- Contacts of Yates Formation. Gradational contact with the overlying Tansill Formation (13 A) and brecciated basal contact with underlying Seven Rivers Formation (13 B).

systems tract (TST) and a highstand systems tract (HST). The base of the lower sequence is the unconformable contact between the Yates and Seven Rivers carbonates, and is overlain by eolian and fluvial clastics that filled the incised valleys on the shelf during a relative lowstand of sea level. This contact is noted on cross-sections as sequence boundary 1 (SB1).

The base of the upper sequence is marked by the truncation of the upper parasequence of the underlying highstand systems tract, and it is also directly overlain by eolian and fluvial lowstand valley fill deposits. This boundary is marked as sequence boundary two (SB2) on the cross-sections.

Highstand system tracts (HST) of both sequences consist of two to four stacked "drying upward" cycles or parasequences that generally become thicker and more clastic-rich towards the tops of these HSTs. Generally, each parasequence consists of basal beds of subtidal carbonates that are truncated at their top by weathering or erosional surfaces and then overlain by upward coarsening eolian, fluvial and deltaic clastics (Figure 14). The base of these highstand system tracts is chosen in the sections either where the clastics begin to become thicker or where the carbonates are laterally continuous across the field.

Transgressive systems tracts (TST) of both sequences consist of two to three parasequences which become thinner and more carbonate rich towards the tops of these TSTs. The parasequence of the lower TST consist of basal beds of subtidal carbonates, again truncated at their top, and upward coarsening sequence of sabkha, eolian, fluvial and deltaic clastics. The subtidal carbonates are different in that they are not always laterally continuous across the field from east to west. The parasequences of the upper TST differ slightly in that they contain far fewer sabkha deposits (Figure 14). The notable exception to this generalization is in the northern part of the study area, on the strike section from G.W. O'Brien 1491 to G.W. O'Brien 1514, where sabkha deposits are present as the majority of the clastics regardless of systems tract or sequence.

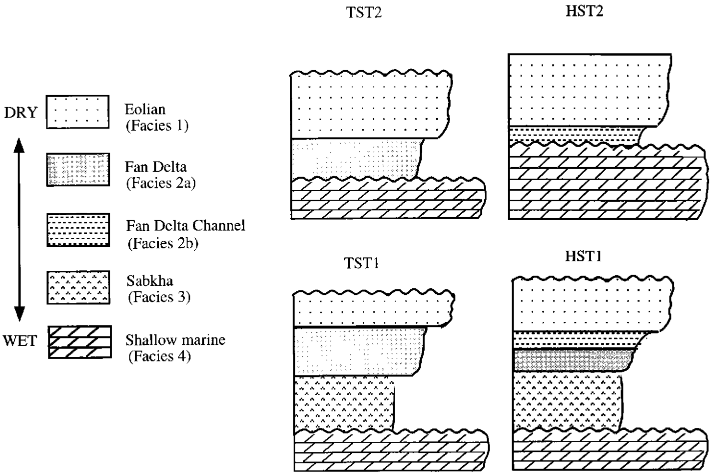

Figure 14--Idealized cycles (parasequences) in upper and lower HFS in Yates the formation (modified after Mazzullo et al. 1996).

Interpretations

The two High Frequency Sequences (HFS), which have slightly wavy sheet geometries in the strike direction and thin in the landward (eastern) direction, mark two long-term cycles of relative sea level fall and subsequent rise in the field area. A third order (1.5-2 million year) change with higher fourth order cycles is reasonable in this study area (Figure 15). It is difficult if not impossible to determine absolute ages of these changes without either detailed paleontology or radiometric age dating. In an environment such as the Permian Basin, lateral changes of clastic facies are difficlut to impossible to delineate for several reasons. Due to clastic depositon that occurs in some cases localized depocenters, regional stratigraphic interpretations are tenuous at best without extensive core control. The first reason being that the log signatures of the clastic facies are very similar and lack a characteristic shape except in the case of channel deposits (Figure 8). All the remaining clastic facies have similar log responses and properties according to the data that can be derived from the logs. Also the northernmost strike section presents an interesting problem as well, in that sabkha facies are found in a system tract in one core and not in any others in the field. As a matter of fact sabkha deposits are not found in this system tract in the field directly south either (Mazzullo et al., 1996). This could be attributed to being in closer proximity to the Northwest shelf and the fluvial source area The Incised Valley Fills (IVF ?) are implied but are not definitively present due to the low relief, sheet like geometry of the High Frequency Systems (HFS) present and no evidence of deep incision.

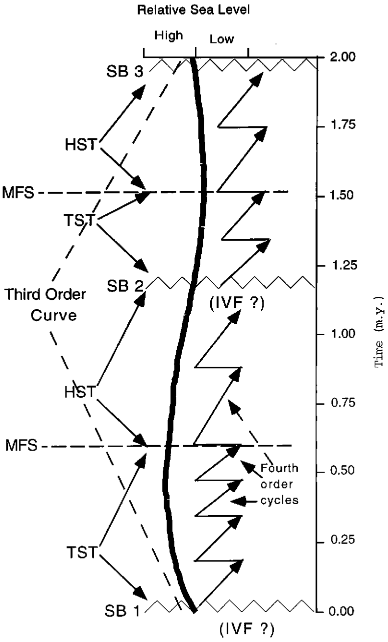

Figure 15--Third order sea level curve. Fourth order cycles on the right of the third order curve displayed from HSA 1255 well which is most basinward in the study area. Transgressive Systems Tracts (TST), Highstand Systems Tracts (HST), Sequence Boundaries (SB 1-3), Incised Valley Fills (IVF ?) and Maximum Flooding Surfaces (MFS) noted (modified after Borer and Harris, 1991).

Petrography

Composition

1. Major detrital grains

The Yates Formation clastics are sub-arkosic in composition with monocrystalline quartz constituting 70 to 86% of the grains. These grains exhibit both undulose and non-undulose extinction and Boehm lamellae. Feldspar grains, predominately potash feldspar, constitute 9 to 17% of grains. Most of these grains are altered and show some replacement by authigenic clays. Accessory minerals make up a small portion (0 to 17%) of detrital content. The most common accessory minerals are mica, polycrystalline quartz and opaques minerals, the latter of which are composed of pyrite in the eolian facies (Facies 1) and delta plain facies (Facies 2) and hematite in sabkha facies (Facies 3). Rock fragments are an even smaller part of the detrital content, with some samples containing a maximum of 5% (Figure 16-A). There is not a great deal of compositional variation between clastic facies.

2. Major Cements

The principal cementing minerals in the Yates Formation clastics are dolomite, clay minerals, hematite and anhydrite. The anhydrite cement is the least of four and dominant near the top of the formation. The dolomite cement is dominant in the remaining clastics of all facies. Hematite cements and grain-coating clays constitute cements in the sabkha facies (facies 3) only.

3. Facies Petrography

Facies 1 (Figure 16-C) displays a composition that is sub-arkosic. The monocrystalline quartz constitutes 80- 86% of the grains, and polycrystalline quartz constitutes 0-3%. Feldspars constitute 9-15% of the grains, with the majority of these grains being potash feldspars that have undergone alteration. The common accessory minerals are mica and occasionally pyrite that formed nodules and reaction rims. The major cement is dolomite, with the only notable exception near the top of the section where anhydrite cement becomes dominant.

Facies 2 (Figure 16-D) has a composition that is subarkosic. The monocrystalline quartz content ranges from 80-86% and polycrystalline quartz constitutes another 0 - 5% of the grains. Feldspars constitute 9- 17% of the grains, with most of these being potash feldspars which have undergone alteration and replacement by authigenic clays. The common accessory minerals are micas, but the amount of clays is greatly increased and is most notable at the core scale. The major cement is the authigenic clays in most cases, and dolomite in lesser amounts.

Facies 3 (Figure 16-E) has a subarkosic composition in the samples observed. Monocrystalline quartz constitutes 76- 88% of the grains, polycrystalline quartz constitutes 1-8% of the grains, and feldspars constitute 10-18% of the grains. The majority of the latter are potash feldspars which have undergone both alteration and replacement by authigenic clays. The accessory minerals are micas and more commonly opaques which are hematitic. The major cements are dolomite, anhydrite and hematite. The hematite coats most of the grains and even fills pores to destroy porosity.

<u>Texture</u>

The Yates clastics of North Ward-Estes field are generally composed of moderately to well sorted sandstones and siltstones. They have mean grain sizes that range from 0.199 mm to 0.059 mm, with an overall average of 0.094 mm. The standard deviation ranges from 0.035 mm to 0.025 mm with an overall average of 0.028 mm.

Facies 1 is composed of well sorted and very well sorted sandstones and siltstones. The grains ranged from a maximum of 0.194 mm to a minimum of 0.039 mm in size the mean grain size ranging from 0.133 mm to 0.103 mm (average of 0.119 mm) and the standard deviation ranges from 0.035 mm to 0.025 mm (average of 0.030mm). The grains measured as fine and medium sand are between 92 to 100% (Figure 17). The medium sand constituted up to 60% and at least 23% of the grains.

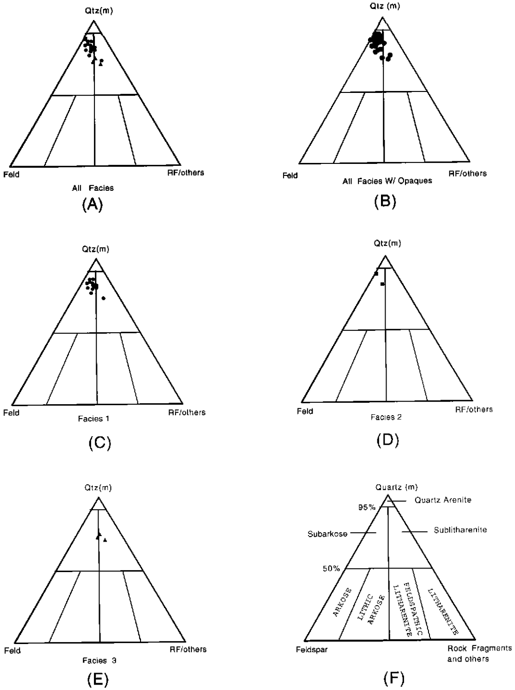

Figure 16--Ternary diagrams of detrital composition of clastic facies.

Facies 3 is composed of well sorted sandstones and siltstones. The grains that were measured ranged from 0.194 mm to 0.019 mm with a mean grain size ranges form 0.088 mm to 0.059 mm (average of 0.071 mm) and a standard deviation ranges from 0.032 mm to 0.025 mm (average to 0.025 mm). The grains measured as fine and medium sand were 78% to 35% (Figure 18). The medium sand constituted as much as 15% of the grains and as little as 0%.

Facies 2 is composed of moderately sorted and well sorted sandstones and siltstones. The grains that were measured ranged from 0.194 mm to 0.029 mm, the mean grain size ranges from 0.090 mm to 0.073 mm (average of 0.082 mm) and a standard deviation ranges from 0.035mm to 0.026 mm (average of 0.029 mm). The grains measured as fine and medium sand were 80% to 60% (Figure 19). The medium sand constituted a maximum of 23% and a minimum of 9% of the grains.

Interpretations

The key for identification Facies 1 petrographically is the mean grain size. This facies has such a coarse grain size due to its eolian origin. The high degree of sorting is due to winnowing of the wind removing silt and clay as well as very fine sand. Facies 3 has the finest grain size due the effects of both eolian and fluvial weathering. The hematite that is present is also very diagnostic of this facies. Facies 2 has an intermediate mean grain size due to its fluvial origin as both channel and overbank deposits. The sorting is moderate due to the sediment transport being dominantly fluvial during flash flooding events that mixes grains of various sizes. This facies is also the dominant location for the presence of pyrite.

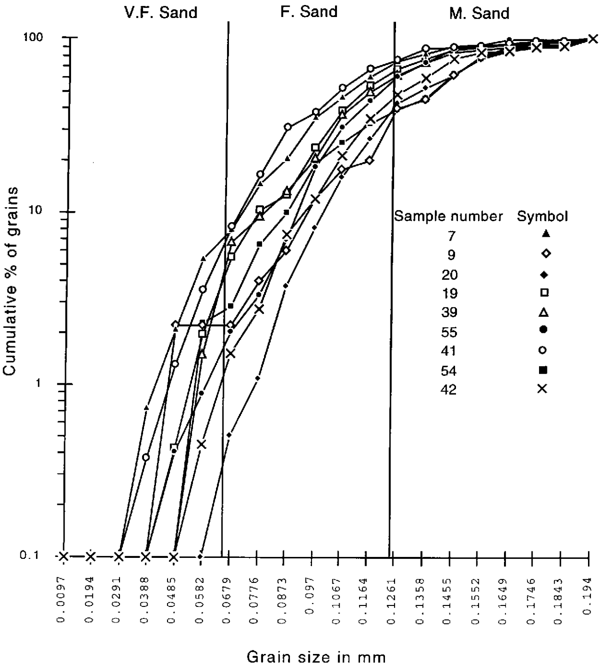

Figure 17--Facies 1 Cumulative Frequency Curve (CFC).

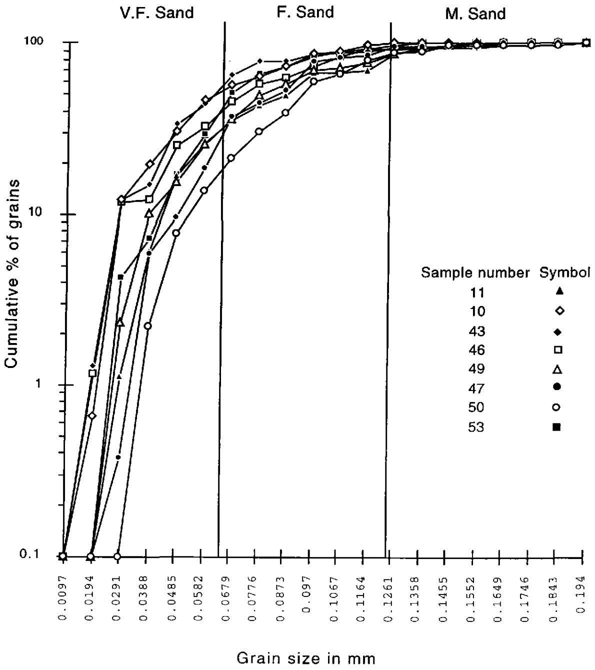

Figure 18--Facies 3 Cumulative Frequency Curve(CFC).

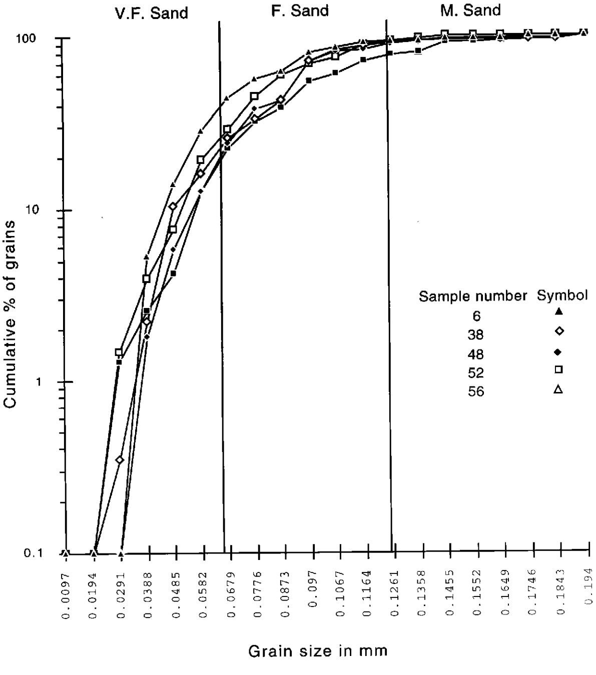

Figure 19--Facies 2 Cumulative Frequency Curve (CFC).

Reservoir Characterization

The Yates Formation of North Ward-Estes field is a prolific hydrocarbon reservoir, with nearly all production from the clastic facies. The quality of each of these facies varies to some degree, with the eolian sandsheet deposits (Facies 1) being the best reservoirs, and the fluvial-dominated sabkha deposits (Facies 3) being the poorest. The two subfacies of the fluvial sandflats (Facies 2) are intermediate quality reservoirs, and the carbonate (Facies 4) and evaporite (Facies 5) facies are non-reservoir quality, but they do provide good, nearly impermeable seals that form the traps for the reservoirs.

The formation was sampled with 1-inch and 1.5-inch core plugs in the seven cored wells used in this study. From these cores, 566 samples were taken and analyzed for various properties, including bulk density, porosity, permeability, water saturation, and oil saturation. The properties that will be examined in this study are the porosity and permeability data. A series of porosity - permeability cross plots were made for each of the facies of the formation.

Facies 1, with 264 core plugs, is the most sampled due to its tendency to be the best reservoir rock in this setting and others that are similar in the Permian Basin (Mazzullo et al. 1985; Borer and Harris, 1991, 1992). The average porosity of this facies is 17.45% with a maximum of 31.8% and a minimum of 1.4%. The average permeability average of this facies is 217.87 md, with a high of 958 md and a low of 0.05 md (Figure 20).

Facies 2, with 188 core plugs, was the second most analyzed. The average porosity of this facies is 11.98% with a high of 20% and a low of 2.4%. The average permeability of this facies is 3.63 md, with a high of 61.32 md and a low of 0.01 md (Figure 21).

Facies 3, with 33 core plugs, is the least studied of the clastic facies. The average porosity of this facies is 11.89%, with a high of 20.2% and a low of 2.13%. The average permeability of this facies is 2.13 md, with a high of 25.06 md and a low of 0.11 md (Figure 22).

Facies 4 has 62 core plugs of the carbonate facies. The average porosity is 7.49%, with a high of 18.8% and a low of 2%. The average permeability of this facies is 1.04 md, with a high of 1.7 md and a low of 0.01. The variability in this facies can be attributed to a variety of sources including the influence of anhydrite as a pore-plugging agent as well as exposure to form breccias which have enhanced porosity and permeability diagenetically. This facies usually provides a good seal when it bounds a reservoir-quality clastic facies (Figure 23).

Facies 5 has 19 core plugs of evaporite dominated intervals. The average porosity is 4.36%, with a high of 11.4% and a low of 2%. The average permeability is 0.39 md, with a high of 1.84 md and a low of 0.01 md. This facies is found only at the top of the section near the contact with the overlying Tansill, and provides an excellent seal to prevent migration of hydrocarbons into overlying formations (Figure 24).

<u>Interpretations</u>

Facies 1 is the best reservoir rock of the Yates formation due to high porosity and permeability as well as an absence of clays and silts. The exception to this generalization is that in erg margin deposits, in which the anhydrite significantly reduces the quality of reservoir by reduced both porosity and permeability. Facies 2 is an intermediate reservoir rock due to variability in result of sorting. The amounts of clay and silt reduces the quality of the reservoir which has the most effect in the overbank delta plain facies and much less in the scours of the channels. Facies 3 is the poorest reservoir quality rock. It has porosity and permeability which has been reduced by evaporites, which distorts bedding as well as iron staining and coating of grains by clay minerals and hematite.

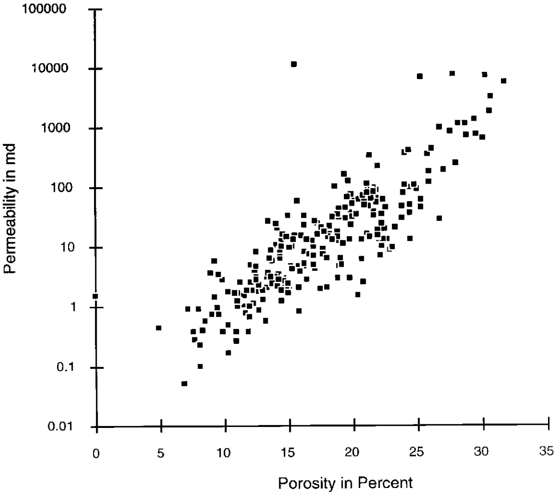

Figure 20--Facies 1 porosity-permeability crossplot.

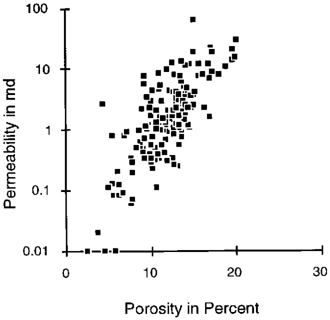

Figure 21--Facies 2 porosity-permeability crossplot.

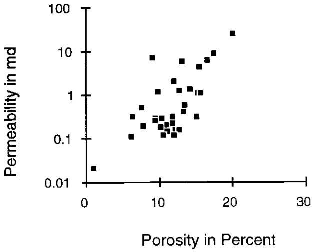

Figure 22--Facies 3 porosity-permeability crossplot.

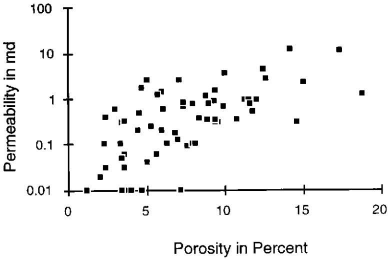

Figure 23--Facies 4 porosity-permeability crossplot.

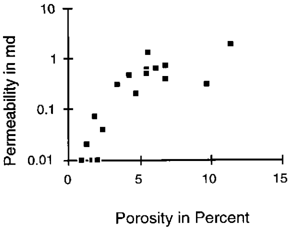

Figure 24--Facies 5 porosity-permeability crossplot.

CONCLUSIONS

The purpose of this thesis has been to determine the facies, environments of deposition and stratigraphy of the Yates formation in North Ward-Estes field.

The results indicate the Yates clastics were deposited in coastal settings that are dominated by both fluvial and eolian processes. These environments vary from eolian sandsheets to fluvial channels and overbanks to fluvial dominated sabkhas. The carbonates were deposited in shallow subtidal settings and the evaporites were deposited in coastal regions that have become restricted from the sea. Cyclic sedimentation of clastic and carbonate sediments began during a period of rapid sea level fall where subtidal carbonates are exposed and clastic sediments begin to erode and eventually overlie them. These cycles are truncated by the deposition of carbonate sediments as sea level rises again and the clastic depocenter has shifted. There truly is no pattern to which of the clastic facies is deposited in any of the sequences that is present but generalities about sabkha deposits can be made. The only other generality that can be drawn is that the channel deposit facies is only found in Highstand Systms Tracts (HST's). The continuity of each of the clastic facies in sheet like deposits is highly variable as well due in part to the nature of channels that erode through very limited regions but whose overbank deposits can provide nearly impermeable flow boundaries for hydrocarbons.

The petrographic portion of this work revealed some distinctive results. The key being an analytical method for identifying facies on the basis of grain size and grain sorting. The type of cement whether carbonate or evaporite or both and the amount of grain alteration due to diagenesis are also diagnostic for various facies.

The basal contact is a result of sudden exposure and brecciation of the underlying carbonates of the Seven Rivers Formation. The upper sequence is a result of high sea level and a restricted marine setting forming. The assumption of a third order (1.5-2.0 million years) sea level cycle is reasonable in that it explains the level of cyclicity in the formation when higher cyclicity fourth order cycles are superimposed on the sea level curves. The cyclicity that is most apparent is the presence two sequences that start with a basal incised valley fill that is subsequently filled with a Transgressive Systems Tract which is overlain by a Highstand Systems Tract. The reservoir quality in the field is variable as well due to the lack on continuity of the facies. The carbonate and evaporite facies provide good seals and are conspicuous on logs but there is no log character that is present for the clastic facies to determine reservoir from non-reservoir clastic facies.

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APPENDIX A

CORE DESCRIPTIONS

FIELD SUMMARY

NORTH WARD-ESTES FIELD

INTRODUCTION

Location:	Ward and Winkler Counties Texas Western Central Basin Platform, Permian Basin
Tectonic/Regional Paleosetting:	Continental interior restricted basin
Operator:	Chevron USA

FIELD DATA

Discovery:	1929
Areal Dimensions:	18 miles by 4 miles
Productive Area	Approximately 36 sq. miles
Hydrocarbons:	Oil and Gas
Trapping Mechanism:	Combination structural anticline/stratigraphic pinchout
Total Wells (1991):	2679
Producing Wells (1991):	1424
Well Spacing:	1320 feet
Depth:	2500 to 3200 feet
Annual Oil Production (1991):	4,333,443 BBLS
Cumulative Oil Production:	373,887,757 BBLS through 1/92
Typical Well Production:	Average Daily: 2 to 5 BBLS Cumulative: 14,000 BBLS/day
Original Reservoir Pressure:	1500 psi @ 3000 feet

RESERVOIR PETROPHYSICS

Porosity:	Range: 10% to 30% Average: 18% Cutoff: 15%
Permeability	Range 0.01 to 900 md Average 40 md
Residual Water Saturation:	Range: 30% to 100% Average: 65%
API Gravity:	29.4^0

RESERVOIR ROCKS

Age:	Late Permian (Guadalupian)
Stratigraphic Units:	Yates, Seven Rivers, and Queen Formations
Lithology:	Very fine to fine grained subarkosic sandstones
Number of Pay Zones:	Multiple
Gross Pay Thickness:	Variable

CORE DESCRIPTION
E.W. Estes 262
Ward County, Texas
Sec. 27, Blk j B-19, PSL
Core: 2497-2557 Feet

Depth	Thickness Feet	(Meters)	Description
2415	14	(4.27)	SANDSTONE friable(2419-2422) green, grey, tan fine sandstone/siltstone with some bioturbation with majority of section consolidated.
2429	4	(1.22)	SANDSTONE fine tan, golden brown sandstone with soft-sediment deformation.
2433	4	(1.22)	SANDSTONE fine green sandstone with no bedding structures visible.
2437	4	(1.22)	SANDSTONE fine sandstone, tan, golden brown and green with friable section and "fault" surfaces.
2441	9.2	(2.80)	SANDSTONE/CONGLOMERATE fine sandstone that is grey, green, and brown with bioturbation. Brecciated dolomitic layers with nodules in dolomitic section and evaporites.
2450.2	9.8	(2.99)	SANDSTONE bioturbated fine sandstone/ siltstone that is green and tan with prominent splayed bedding surface.
2460	16	(4.88)	LOST CORE
2476	7.5	(2.29)	MUDSTONE lt. grey dolomite with clay layers and nodules of anhydrite and oil staining.
2483.5	9.5	(2.90)	SANDSTONE green, tan, and grey sandstone interfingered with dolomitic layers. Coarsen downwards with base very friable.
2492	17	(5.18)	LOST CORE
2509	3.5	(1.07)	SANDSTONE dk. grey oil stained fine sandstone, with "fault" surfaces and anhydrite interbedded at the base.

2512.5	6.5	(1.98)	BRECCIATED sandstone/siltstone with dolomud layers with slumping and faulting surfaces visible.
2519	5.5	(1.68)	SANDSTONE with clay seams and bioturbation present that are green, tan, and dk. brown.
2524.5	3	(0.90)	MUDSTONE lt. grey dolomite with clay seams.
2527.5	17	(5.18)	SANDSTONE green, tan, dk. brown with some friable layers and varying other sedimentary structures and bioturbation.
2544.5	2.5	(0.76)	MUDSTONE iron stained dolomite with some siltstone interfingered.

CORE DESCRIPTION
G.W. O'Brien 1491
Winkler County, Texas
Sec. 30, Blk F, G&MMB&A
Core: 2802-3132 Feet

Depth	Thickness Feet	(Meters)	Description
2802	4.8	(1.46)	ANHYDRITE, transparent with tan clay layers an some oil staining.
2806.8	7.2	(2.20)	SANDSTONE, fine sandstone/siltstone with some oil staining and soft sediment deformation and channel like erosional surface at base.
2814	1	(0.30)	MUDSTONE, dolomud with pressure solution layer within.
2815	15.4	(4.70)	SANDSTONE, fine sandstone/siltstone with coarsening upward sequences with some layers. contortion of beds in coarser layers and oil staining with some interbedded dolomud layers.
2830.4	1.1	(0.34)	MUDSTONE, dolomud with some erosional surfaces within.
2831.5	13.2	(4.02)	SANDSTONE, fine sandstone/siltstone with coarsening upward sequences with oil staining.
2844.7	2.3	(0.70)	MUDSTONE, dolomud with seams and erosional contact atop.
2847	66	(20.12)	LOST CORE
2913	6.9	(2.10)	SANDSTONE, fine sandstone with iron staining within most of section, non-stained sections grey, some friable layers with sharp basal contact.
2919.9	2.1	(0.64)	MUDSTONE, grey bioturbated dolomud with stylolites at base.
2922	4	(1.22)	SANDSTONE, fine sandstone/siltstone with iron staining with a non stained dolomitic layer and sharp basal contact.

2926	7.6	(2.32)	MUDSTONE, grey bioturbated dolomud with iron staining in top 2/3 of section. stylolites more prominent at base with sharp basal contact.
2933.6	4.4	(1.34)	SANDSTONE, lt. grey, grey-green and iron stained pink fine sandstone/siltstone with some oil staining and sharp basal contact.
2938	2	(0.61)	MUDSTONE, lt. grey dolomite mudstone with stylolites at base.
2940	6	(1.83)	SANDSTONE, lt. grey, grey and green bed interbedded with iron stained red beds that have undergone soft sediment deformation with sharp basal contact.
2946	1	(0.30)	MUDSTONE, lt. grey dolomud with bioturbation and stylolites.
2947			

CORE DESCRIPTION
G.W. O'Brien 1514
Winkler County, Texas
Sec. 16, Blk F
Core: 2580-2878 Feet

Depth	Thickness Feet	(Meters)	Description
2580	12	(3.66)	ANHYDRITE with siltstones that are dk, grey with displacive nodules.
2592	2.5	(0.76)	SANDSTONE with scour surfaces representing channels.
2594.5	1	(0.30)	MUDSTONE lt. grey, bioturbated with sharp basal contact.
2595.5	20.5	(6.25)	SANDSTONE/ SILTSTONE that is interchanging layers of tan oil stained and non-stained grey with some layers too friable to handle or see structures.
2616	26	(7.93)	LOST CORE
2642	19	(5.79)	SANDSTONE with siltstones that are tan (oil stained), grey, and maroon-purple, with micro-faults, minimal bioturbation, and soft sediment deformation.
2661	17	(5.18)	LOST CORE
2688	2	(0.61)	MUDSTONE lt. grey, oil stained with vertically oriented stylolites and fractures.
2690	12	(3.66)	SANDSTONE with some interbedded dolomud in reddish brown, green, grey oil stained sandstones/ siltstones with some sulfide reaction rims.
2702	4	(1.22)	MUDSTONE lt. grey and iron stained pink with stylolites and erosional channel like surfaces.
2706	27	(8.23)	LOST CORE
2733	1.7	(0.52)	MUDSTONE lt. grey with oil staining and stylolites.
2734.7	1.3	(0.40)	SANDSTONE tan and grey with oil staining.

2736	1.5	(0.46)	MUDSTONE lt. grey with vuggy porosity.
2737.5	8.5	(2.59)	SANDSTONE tan, lt. grey, green sandstone/ siltstone with oil staining that is interfingered with non-stained sections.
2746	4.5	(1.37)	MUDSTONE lt. grey with vuggy porosity and oil staining and erosional seam contacts.
2750.5	0.5	(0.15)	SANDSTONE grey
2751	27	(8.23)	LOST CORE
2778	2	(0.61)	SANDSTONE with oil stained lavender and lt. grey layers with soft sed. deformation.
2780	8	(2.44)	MUDSTONE lt. grey with vuggy porosity and oil staining and seams present.
2788	4	(1.22)	SANDSTONE fine sandstone/siltstone that is grey with some layers of dolomud with vuggy porosity.
2792	4	(1.22)	MUDSTONE with stylolites and some oil staining.
2796	27	(8.23)	LOST CORE
2823	4	(1.22)	SANDSTONE friable sandstone with oil streaks that are lavender, green and grey.
2827	5	(1.52)	MUDSTONE with stylolites and seam and fractures with lower most part iron stained pink.
2832	36	(10.98)	LOST CORE
2868	8	(2.44)	SANDSTONE and siltstone that are oil stained with soft sediment deformation and some friable sections.

CORE DESCRIPTION
Hutchings Stock Association 1169
Ward County, Texas
Sec. 5, Blk O
Core: 2408-2704 Feet

Depth	Thickness Feet	(Meters)	Description
2408	15	(4.57)	MUDSTONE grey dolomitic with displacive anhydrite nodules, stylolites common is non-disturbed sections and oil staining in lower section.(2411-2413 missing).
2423	7	(2.13)	SANDSTONE fine sandstone/siltstone that is dark gray to brown with some anhydrite nodules disrupting bedding structures.
2430	4	(1.22)	MUDSTONE gray dolomitic with displacive anhydrite nodules.
2434	12	(3.66)	SANDSTONE dark grey, brown and tan with displacive anhydrite nodules.(2438-2439.5, 244-2445.2, 2446-2447, 2449-2453 missing)
2456	13.5	(4.12)	SANDSTONE friable fine sandstone/siltstone that is light brown to dark. gray with oil staining with base having anhydrite nodules (2453-2466 missing).
2469.5	14.3	(4.36)	SANDSTONE fine sandstone and siltstone that is light brown, green and gray
2483.8	29.2	(8.90)	SANDSTONE friable fine sandstone that is tan with anhydrite nodules at the base. Some laminations and microfaults present in lower portions of section.
2513	20.5	(6.25)	SANDSTONE friable fine sandstone with basal laminations.
2533.5	7.5	(2.29)	MUDSTONE gray dolomitc with interbedded siliciclastics.
2541	15	(4.57)	SANDSTONE friable fine sandstone with some contorted bedding planes.
2556	9	(2.74)	MUDSTONE gray dolomitic with oil staining with interbedded silt.

2565	18	(5.49)	SANDSTONE friable fine sandstone with interbedded dolomudstone and some microfaults (2570-2570.8, 2571.5-2572, 2572.5-2572.8, and 2577.6- 2578 missing).
2583	12	(3.66)	MUDSTONE gray dolomitic with moldic porosity of fusulinids? at base.
2595	10	(3.05)	SANDSTONE friable, fine sandstone and siltstone with dolomud thinly interbedded at base.
2605	7.5	(2.29)	SANDSTONE tan, greenish gray fine sandstone and siltstone with bioturbation and dolomud at base.
2612.5	27	(8.23)	SANDSTONE friable, fine sandstone and siltstone at top with bioturbated darker gray section at base.
2639.5	3.5	(1.07)	MUDSTONE gray dolomitic with stylolites.
2643	4	(1.22)	SANDSTONE fine sandstone and siltstone that is gray with bioturbation.
2647	44	(13.41)	SANDSTONE fine sandstone and siltstone that is iron stained red with bioturbation and haloturbation.
2691	7	(2.13)	MISSING SECTION
2698	6	(1.83)	BRECCIATED DOLOMUDSTONE BASE

CORE DESCRIPTION
Hutchings Stock Association 1255
Ward County, Texas
Sec. 9, Blk O
Core: 2440-2763 Feet

Depth	Thickness Feet	(Meters)	Description
2440	29	(8.84)	ANHYDRITE grey displacing both siltstone and dolomudstone.
2469	8	(2.44)	SANDSTONE fine sandstone/siltstone that is dark gray to brown with some anhydrite nodules disrupting bedding structures.
2477	16	(4.88)	ANHYDRITE displacing grey-tan sandstone and siltstone.
2493	9	(2.74)	MUDSTONE dolomitic with interbedded siltstones with pyrite reaction rims.
2504	22.5	(6.86)	SANDSTONE fine sandstone/siltstone that is light brown to dark. gray with oil staining with base having pyrite nodules.
2526.5	20.5	(6.25)	SANDSTONE friable fine sandstone that is light brown with laminations at base.
2547	9	(2.74)	MUDSTONE oil stained dolomitic with some dark gray siltstone interbedded.
2556	11.5	(3.51)	SANDSTONE green-gray fine sandstone with basal wavy laminations.
2567.5	11.5	(3.51)	MUDSTONE gray dolomitic with interbedded siliciclastics.
2579	35	(10.67)	SANDSTONE fine iron stained red sandstone and siltstone with thin beds of dolomud interbedded.
2614	29.5	(8.99)	SANDSTONE fine iron stained red sandstone and siltstone with thin beds of dolomud interbedded.
2643.5	12.5	(3.81)	SANDSTONE green-gray brown sandstone and siltstone with dolomud clasts interbedded.
2656	2	(0.61)	MUDSTONE gray dolomitic with stylolites.

2658	4	(1.22)	SANDSTONE fine sandstone and siltstone that is iron stained at top and green-gray at base.
2662	7	(2.13)	MUDSTONE light gray dolomitic with stylolites.
2669	6	(1.83)	SANDSTONE fine iron stained red sandstone and siltstone at top with bioturbated darker gray section at base.
2675	8	(2.44)	MUDSTONE gray dolomitic with stylolites and interbedded siltstone.
2683	20	(6.10)	SANDSTONE fine sandstone and siltstone that is iron stained red with bioturbation and haloturbation.
2703	5	(1.52)	MUDSTONE light gray dolomitic with stylolites and oil staining.
2708	6	(1.83)	SANDSTONE fine sandstone and siltstone that is gray with bioturbation.
2714	14	(4.26)	MISSING SECTION
2728	6.4	(1.95)	MUDSTONE light gray dolomitic with interbedded sandstones and siltstones.
2734.4	19.1	(5.82)	SANDSTONE friable dark brown sandstone with gray siltstone and microfaults.
2753.5	9.5	(2.90)	MUDSTONE light gray dolomitic at top with iron stained pink below with interbedded fine sandstones and siltstones (2761.3-62.3 missing).

CORE DESCRIPTION
Hutchings Stock Association 1391
Ward County, Texas
Sec. 1, Blk F, G&MMB&A
Core: 2475-2654 Feet

Depth	Thickness Feet	(Meters)	Description
2475	8	(2.44)	ANHYDRITE with clay layers that are transparent to light blue with tan clay layers with some iron-staining and erosional contact at base.
2483	38.5	(11.74)	SANDSTONE fine sandstone/ siltstone with iron staining. some nodules of halite in massive beds with some few laminations and some flaser beds. Erosional contact at base.
2521.5	6.5	(1.98)	ANHYDRITE with some fine sandstone beds at the base of section.
2528	7	(2.13)	LOST CORE
2535	15	(4.57)	SANDSTONE fine sandstone with black claystone layers with flaser beds. oil staining at base of section and MISSING CORE (2540 -2541 & 2542-2549).
2550	10	(3.05)	SANDSTONE fine sandstone and dolomitic sandstones interbedded with bioturbation, some iron staining and erosional contact at base.
2560	4.5	(1.37)	SANDSTONE fine sandstone/siltstone tan-grey with fold structures.
2564.5	15.5	(4.73)	MUDSTONE dolomitic mudstone with some interbedded fine sandstone/siltstone with seams increasing bioturbation in lower sections with anhydrite nodules and stylolites at base.
2580	14	(4.27)	LOST CORE
2594	34	(10.37)	SANDSTONE fine sandstone/siltstone with layers a pair of thin bed of dolomud. clastics are tan, grey, and green with some oil staining and erosional surfaces with clasts and some very coarse layers(2618.5-2622). some MISSING CORE in 1 foot sections and oil staining at base.

CORE DESCRIPTION
W.A. Estes 128
Ward County, Texas
Sec. 28, BLK B-19
Core: 2497-2557

Depth	Thickness Feet	(Meters)	Description
2497	9	(2.74)	SANDSTONE-SILTSTONE interbedded lt. grey and grey dolomitic siltstone with nodules of dolomite. lower portions are fluvial channels with pebbly bases of clasts.
2506	10	(3.05)	SANDSTONE friable fine sandstone/siltstone that is tan to brown with some bioturbation disrupting bedding structures.
2516	9	(2.74)	SANDSTONE friable fine sandstone/siltstone that is tan, brown, grey with bioturbation throughout.
2525	4.5	(1.37)	MUDSTONE Dolomitic with oil staining and faults and nodules of clay.
2529.5	3.5	(1.07)	SANDSTONE friable fine sandstone/siltstone that is lt. brown to dk. grey with oil staining and bioturbation.
2533	20	(6.10)	SANDSTONE iron stained sandstone/ siltstone that is red to grey in non stained areas. well stratified in some sections (2533-2540) quicksand like sediments.
2553	3	(0.92)	MUDSTONE Dolomitic with interfingering of iron-stained and non stained grey sediments.

APPENDIX B

CROSS SECTIONS

FACIES 1

FACIES 2a

FACIES 2b

MISSING SECTION

FACIES 3

FACIES 4

FACIES 5

COLLAPSE BRECCIA

□ Perf Zones

A,B,C,... Field Correlation Markers

TST Transgressive Systems Tract
HST Highstand Systems Tract
SB Sequence Boundary

Legend to cross-sections of Appendix B

Authors Note:

The following cross sections are delineated on the field map (Figure 7) of this volume. The markers that are correlated are based primarily on the log signatures of the various field markers that are employed by Chevron USA. The well log traces that are displayed are from Gamma-ray traces which are reliable indiactors of formation in mixed clastic and carbonate sequences. No scales or actual API units are displayed on the traces due to the various ages (1960's to 1980's) and advancements of the tools that recorded traces. Core data is used when possible but is not completely available for all wells in the study area. The sequence stratigraphy framework is thus tenuous and based on the sea level constraints from the HSA 1255 well. No seismic stratigraphy has been done by this author in this volume due the priority nature of the data set(s). Maximum Flooding Surfaces (MFS's) and Incised Valley Fills (IVF's) are not diplayed on the cross sections either, due to the nature of how the sections were constructed.

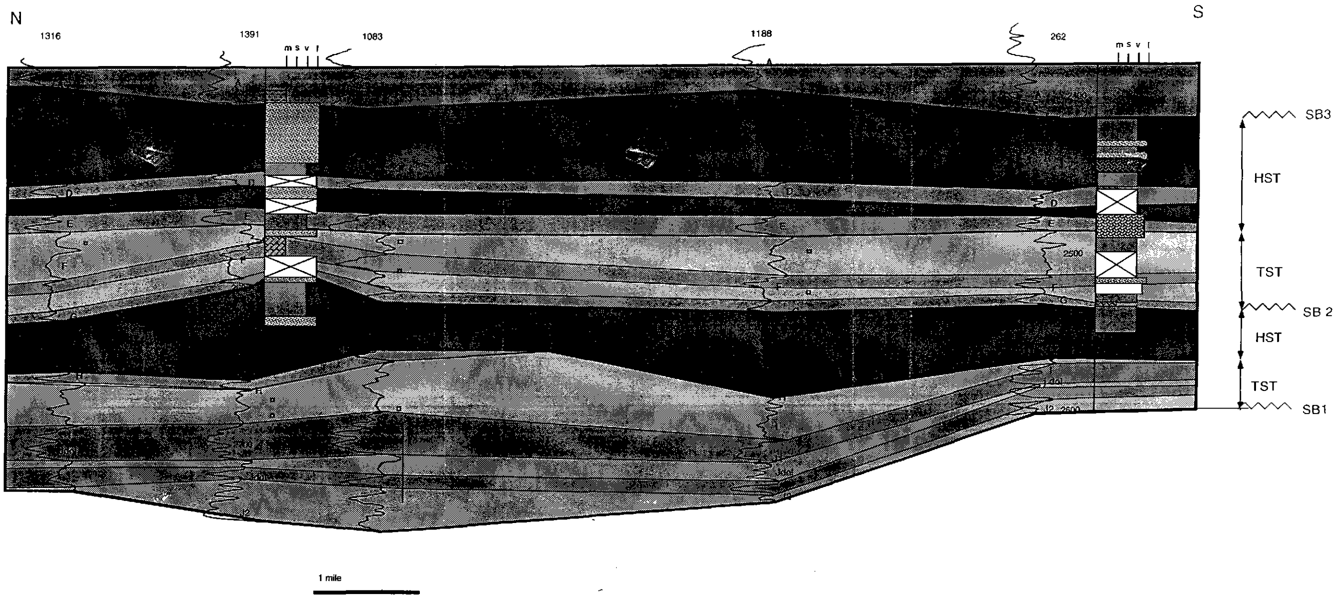

Figure 25-- Strike Section 1. North-South HSA 1316 to EWE 262.

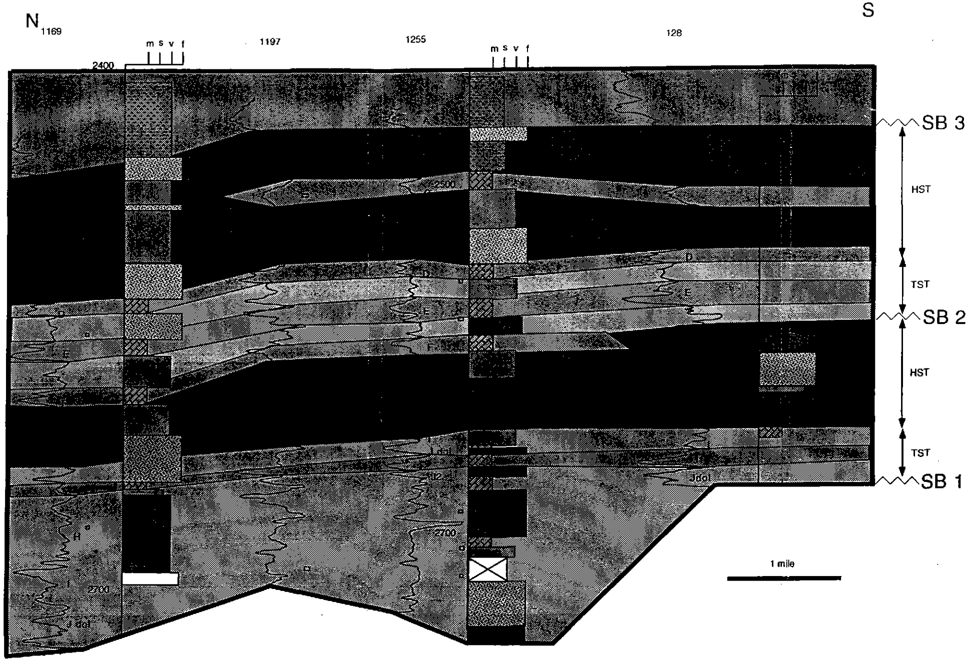

Figure 26-- Strike Section 2. North-South HSA 1169 to WAE 128.

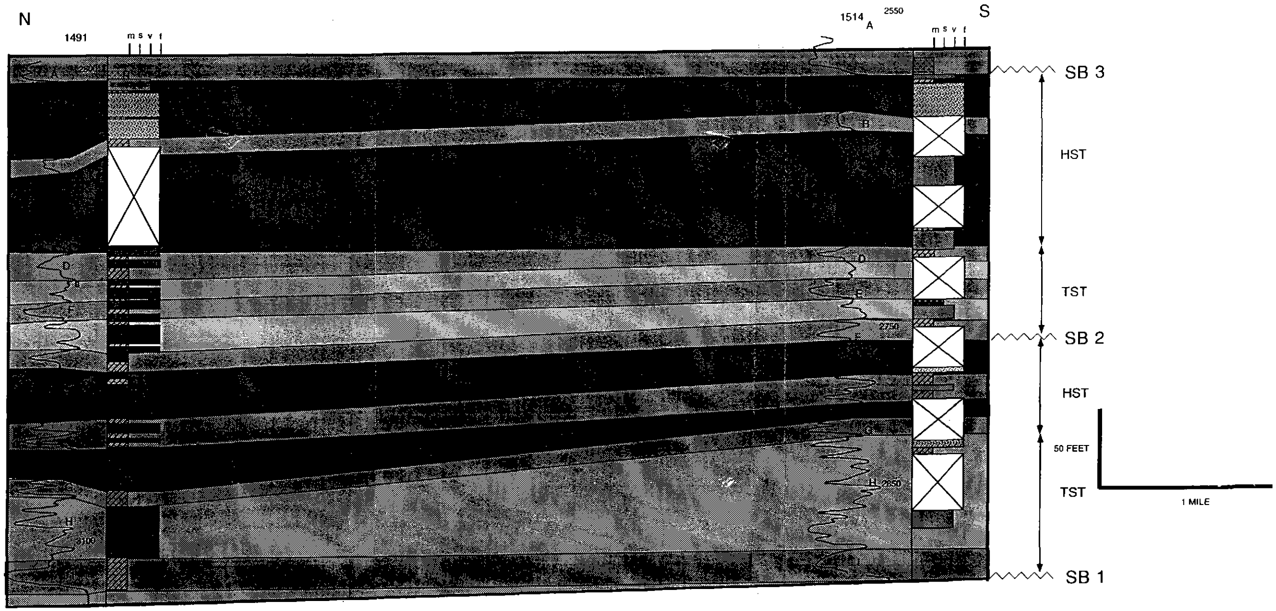

Figure 27-- Strike Section 3. North-South HSA 1491 to HSA 1514.

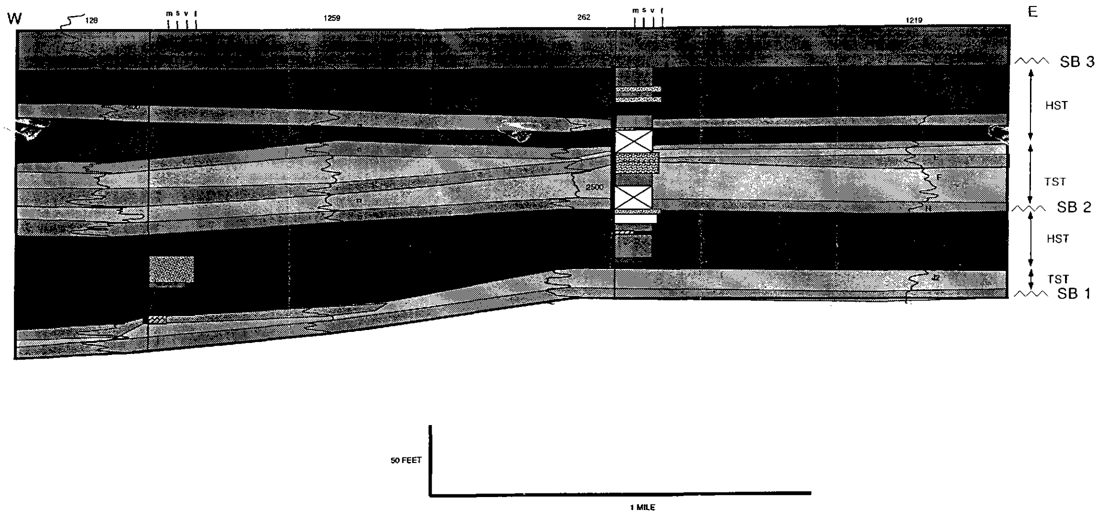

Figure 28-- Dip Section 1. West-East WAE 128 to HSA 1219.

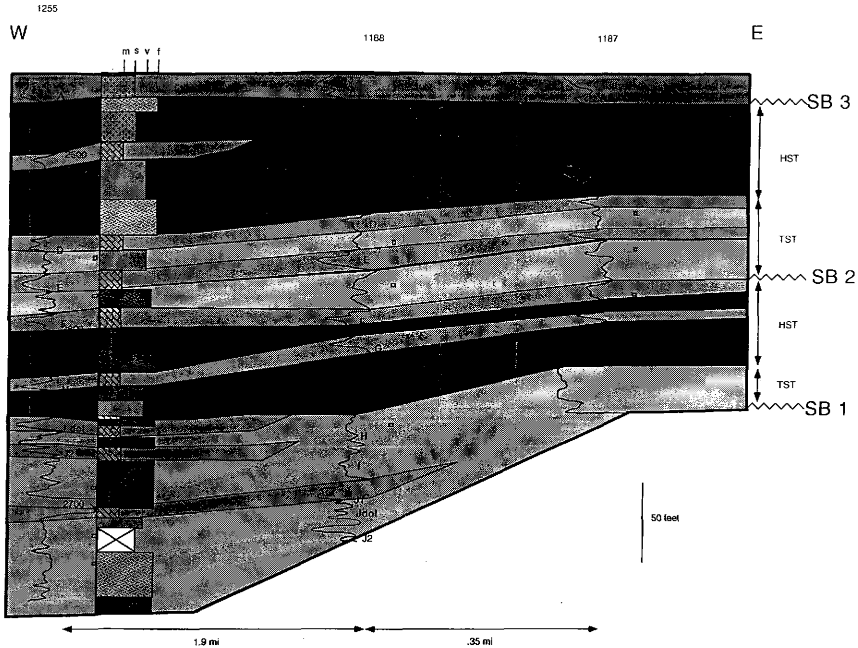

Figure 29--Dip Section 2. West-East HSA 1255 to HSA 1187.

VITA

NAME: Ronnie Delane Johnson

EDUCATION: Master of Science, Geology
Texas A&M University, College Station, TX 77840
August 1997

Bachelor of Science, Geology,
Louisiana State University, Baton Rouge, LA 70893
August 1994

PUBLICATIONS:

Johnson, R. and Mazzullo, J., 1996, Stratigraphy, facies and environments of depostition of the Yates Formation, North Ward-Estes Field, Ward County, Texas (abs.); *in* American Assciation of Petroleum Geologists Gulf Coast Association of Geological Societies meeting, A.A.P.G. Bulletin, V. 80, p. 1505.

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PROFESSIONAL AFFILIATIONS: American Association of Petroleum Geologists

PERMANENT ADDRESS: c/o Willie Mae Carter
2232 Valley Street
Baton Rouge, LA 70808