# DEPOSITIONAL ENVIRONMENT ANALYSIS OF THE PENNSLYVANIAN, MID-CONTINENT TONKAWA SANDSTONE

by

AMANDA L. CASHMAN

B.S., Kansas State University, 2008

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Geology
College of Arts and Sciences

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2011

Approved by:

Major Professor
Dr. Allen Archer

# Abstract

Hydrocarbon production throughout the continental United States has declined in past decades. New interpretations together with advanced recovery techniques can increase production in older fields. Re-examining these types of underdeveloped resources is a simple and cost effective tool that can be readily used to increase hydrocarbon production throughout the mid-continent.

Pennsylvanian sandstones throughout Oklahoma and Kansas are known for their excellent reservoir qualities. The focus of this study is the upper Pennsylvanian Tonkawa Formation, a sandstone dominated unit. The Tonkawa has been informally correlated to both the Stalnaker and Tonganoxie sandstones in Kansas. Previous publications do not present a unified understanding of the depositional environments that are seen across state borders. The interpretations vary from fluvio-deltaic to marine environments. A cohesive interpretation is necessary to understand paleo-processes and efficiently exploit the reservoir for hydrocarbons.

The study presents a regional analysis covering an eleven county area in northwest Oklahoma. Analysis of core and well log data is used to determine the range of depositional environments of the Tonkawa sandstone. Sedimentary structures, mineral assemblages, and lithologies of selected cores are described and correlated with well log data. With this data, structural isopach maps are constructed using Petra software. Earlier interpretations have relied primarily on well log data, focusing on core data rather than geophysical logs, allowing for a more detailed and accurate interpretation. Analysis of transitional sedimentary sequences, such as the Tonkawa, can be applied to sandstones deposited in similar environments throughout the mid-continent.

# Table of Contents

# List of Figures

# List of Tables

# Acknowledgements

I would like to thank the Kansas State University Geology Department for support and guidance while completing my undergraduate and graduate degree. I would like to especially thank my thesis committee, Dr. Allen Archer, Dr. Charles Oviatt and Dr. Saugata Datta. They have offered advice and instruction throughout my education.

I am greatly indebted to several people and organizations for the data and resources I utilized to complete my research. First, I would like to thank the Oklahoma Geological Survey Core Library, particularly Gene Cullman and Vyetta Jordan. They were always able to find the cores I needed and space to lay them out, even on short notice. I would also like to thank Bill Brock of MJ Logs, based in Calgary, Alberta. Mr. Brock and MJ Logs were able to donate the Log Sleuth software and any wireline data I needed. I would not have been able to make the regional correlations without the data he supplied. Tom Voght of the Kansas State Geography Department created the initial maps of core locations in the GIS Lab. These maps were incredibly helpful in selecting the first cores to examine. Lastly, Petra, the software used to complete cross sections and create maps, is available to students through an academic license from IHS incorporation headquartered in Denver, CO.

I would also like to thank Chris and Sally Flenthrope for their generous hospitality. They provided a home away from home as I stayed in Oklahoma.

# CHAPTER 1 - INTRODUCTION

Petroleum production within the US and more recently, abroad has greatly impacted the American way over the last century, shaping and reshaping our economy, politics and national security. Mid-Continent oil and gas production has played a dynamic role after World War II in propelling the United States into an era of prosperity and innovation. Dependence on energy resources has shifted our energy consumption from centrally located domestic supplies to increasingly unstable and violent areas. As the search for reliable hydrocarbons becomes increasingly crucial ever more sophisticated and complex technologies are employed. Technologies are enabling older wells to be re-explored with a fresh view of potential.

More precise technologies allow for better subsurface visualization leading to modifications ranging from slight changes to completely revamping older depositional models. The Pennsylvanian age Tonkawa sandstone is an example of how more information has led to several varying interpretations. Proposed environments for the Tonkawa have ranged from a submarine fan sequence (Kumar and Slatt, 1984) to fluvial dominated deltaic systems (Andrews, 1997; Campbell, 1997). Detailed subsurface analysis of the Tonkawa Sandstone and other sandstones within the midcontinent will lead to a better understanding or reservoir heterogeneities and led to increased recovery of overlooked production in older reservoirs.

The Tonkawa Sandstone is a Pennsylvanian age sandstone of the Douglas Group within the Virgilian Series of Oklahoma. Pennsylvanian age reservoirs have yielded the majority of Oklahoma’s oil production, and have generally been heavily explored in throughout the major basin in Oklahoma.

The principle objectives of the study are to 1) analyze sedimentary structures within Tonkawa cores; 2) provide an interpretation of micro facies seen in cored intervals; 3) correlate cored intervals with electrical logs; 4) provide a depositional environment analysis based on both core and log data.

The data collected and synthesized in this report will focus on looking at the distribution and trends in sedimentary structures of the Tonkawa Sandstone to provide a regional depositional environment interpretation. The petroleum history of the sands will also be discussed.

## Study Area

The study area encompasses eleven counties in north-central Oklahoma, including; Alfalfa, Blaine, Custer, Dewey, Garfield, Grant, Kay, Kingfisher, Major, Woods and Woodward. Several factors were considered when choosing the study area. This large area was chosen because it traverses depositional environments from the Anadarko Shelf and Basin. Due to prolific oil and gas reservoirs in the area numerous wireline logs and several cores within the Tonkawa interval are available for study.

The study area covers 11,239 sq. mi. of that approximately 40% of the subsurface contains an oil or gas reservoir that is economically viable.

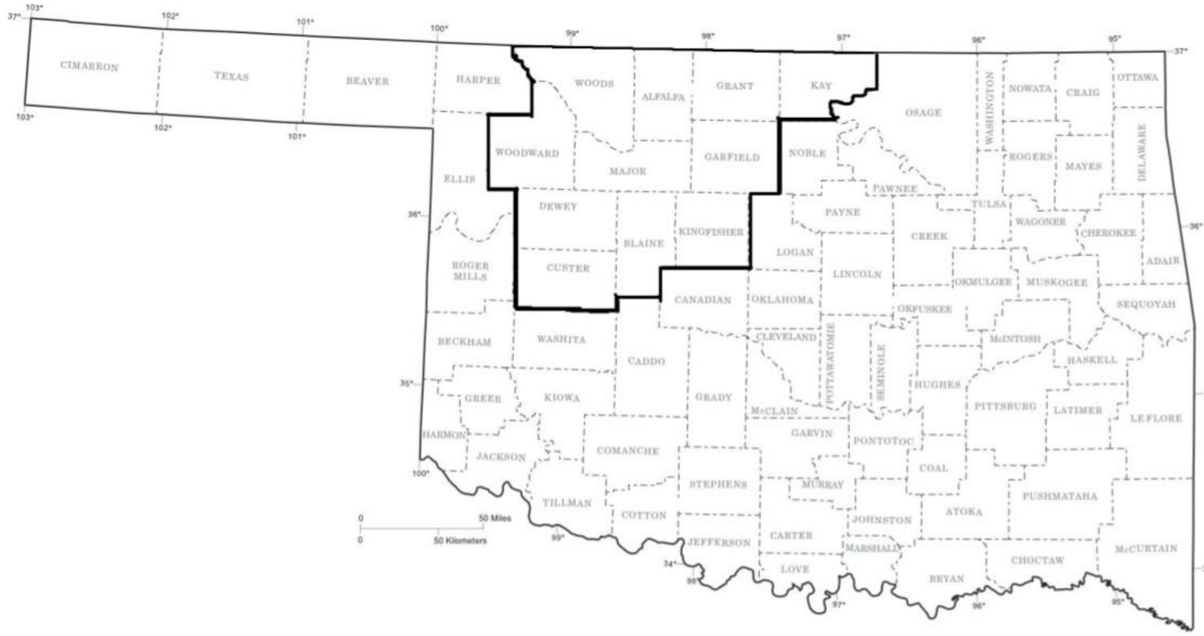


**Figure 1.1. Map of Oklahoma. Study area includes the eleven counties within the bolded outline.**

## Regional Geologic History

The study area encompasses and/or is bordered by several major structural features. Principal structures bordering the study area include Amarillo-Wichita Uplift to the south and southwest, and the Nemaha Uplift to the east. The large relatively stable Anadarko shelf lies in the north and northwest vicinity of the study area that is bound by the Oklahoma-Kansas state line.

Sediments transported into the area were first from the Ozark Mountain Uplift. This was a relatively high mountain range during the Desmoinesian Epoch. By the time the Tonkawa sands were being deposited, the range had been reduced to a low-lying topographic feature. Sediment supply began to come from the cratonic area to the north of Oklahoma. During the Missourian Epoch, the Ouachita Mountain Range in southeast Oklahoma began to supply copious terrigenous clastic material.

The Ozark Mountains had been diminished to a relatively low-lying topographic feature by the beginning of the Virgilian. As the Ouachita Mountains became a less visible feature by the early to middle Virgilian, the sediment supply slowly lessened. From the middle Pennsylvanian to the Permian, the Wichita Mountain Uplift became a major supplier of sediment to the basin (Fies, 1988).

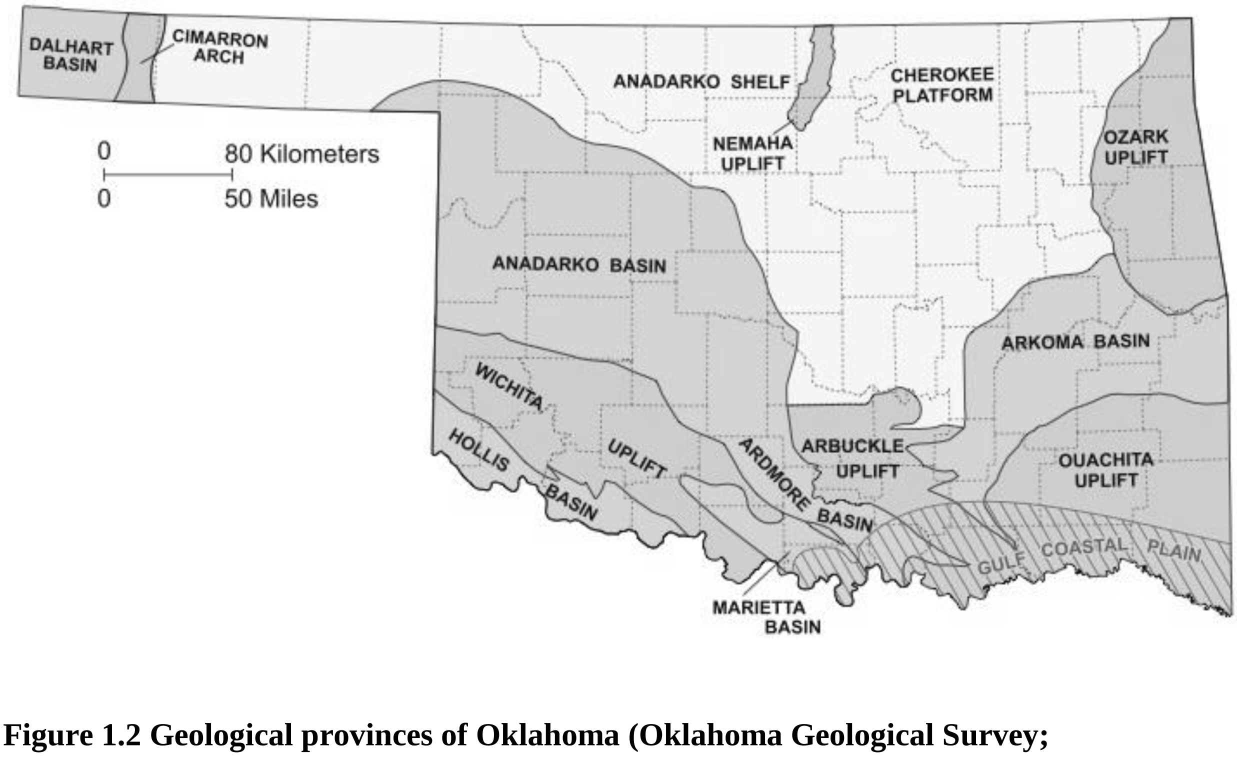
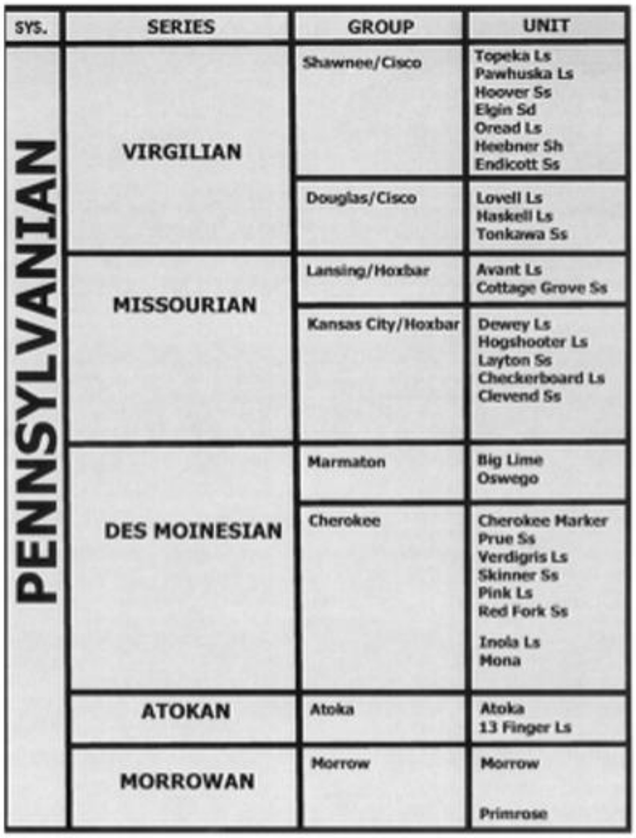


**Figure 1.2 Geological provinces of Oklahoma (Oklahoma Geological Survey; www.ogs.ou.edu/MapsBasic/Provinces)**

Sedimentary thickness increases substantially to the south-southwest of the study area. Stratigraphic layers across the shelf reach 4,300 ft and extend to a thickness of 37,000 ft in the deep basin.  The distinction between shelf deposition and deep basin deposition has been made based on drilling density and is usually placed at the -15,000ft contour on a basement map (Adler, 1971).  All geological units are represented from the Cambrian through the Leonardian (Permian), with the exception of the Middle Devonian in the basin.  Many of the older sediments (Pre-Pennsylvanian) are carbonates.  Interbedded limestone, sandstone and shale are found throughout the Pennsylvanian and Permian sequence (Adler, 1971).

The deep Anadarko Basin is structurally complex, due to uplift and movement during the Pennsylvanian and early Permian (Fies, 1988).   The basin is the largest component of several west north-west trending basins and uplifts from the Ouchita Mountains to the Sierra Grande Uplift.   The central Oklahoma area creates a gentle arch between the Anadarko and Arkoma basins (Fies, 1988).  Oil and gas reservoirs are most affected by numerous north-south faults in the Seminole area, developing structural traps.



| SYS. | SERIES | GROUP | UNIT |
|---|---|---|---|
| PENNSYLVANIAN | VIRGILIAN | Shawnee/Cisco | Topeka Ls<br>Pawhuska Ls<br>Hoover Ss<br>Elgin Sd<br>Oread Ls<br>Heebner Sh<br>Endicott Ss |
| | | Douglas/Cisco | Lovell Ls<br>Haskell Ls<br>Tonkawa Ss |
| | MISSOURIAN | Lansing/Hoxbar | Avant Ls<br>Cottage Grove Ss |
| | | Kansas City/Hoxbar | Dewey Ls<br>Hogshooter Ls<br>Layton Ss<br>Checkerboard Ls<br>Clevend Ss |
| | DES MOINESIAN | Marmaton | Big Lime<br>Oswego |
| | | Cherokee | Cherokee Marker<br>Prue Ss<br>Verdigris Ls<br>Skinner Ss<br>Pink Ls<br>Red Fork Ss<br>Inola Ls<br>Mona |
| | ATOKAN | Atoka | Atoka<br>13 Finger Ls |
| | MORROWAN | Morrow | Morrow<br>Primrose |

**Figure 1.3 Stratigraphic column for sedimentary units within the study area (Wiggins, 2004).**

The Tonkawa Sandstone falls within the Douglas Group and is the lowermost lithostratigraphic unit of the Virgilian Series of the Pennsylvanian. Douglas Group units include strata from the base of the Tonkawa sandstone to the top of the Toronto Limestone (Chenoweth, 1979). The interval is bound by the Avant and Haskell limestones, which act as good marker beds throughout northwest Oklahoma (Rascoe and Adler, 1983). Although the Haskell limestone is not present in most of the western portion of the study area, the Haskell marker, or hot shale, is easily identified. The hot shale, indicated on a wireline log with a kick to the right, is generally seen within two feet of the base of the Haskell limestone (Padgett, 1988).

The Haskell limestone, which is commonly fossiliferous and locally oolitic, is present across nearly all of the Anadarko Basin has been mapped extensively (Gibbons, 1962). Structure maps shows a gentle dip of approximately 30 feet per mile increasing to 50 feet per mile across the basin. Several anticlinal highs and synclinal troughs interrupt the regional dip (Padgett, 1988).

Going northeast the Tonkawa sandstone becomes the Stalnaker or Tonganoxie sandstone of Kansas (Lukert, 1949).

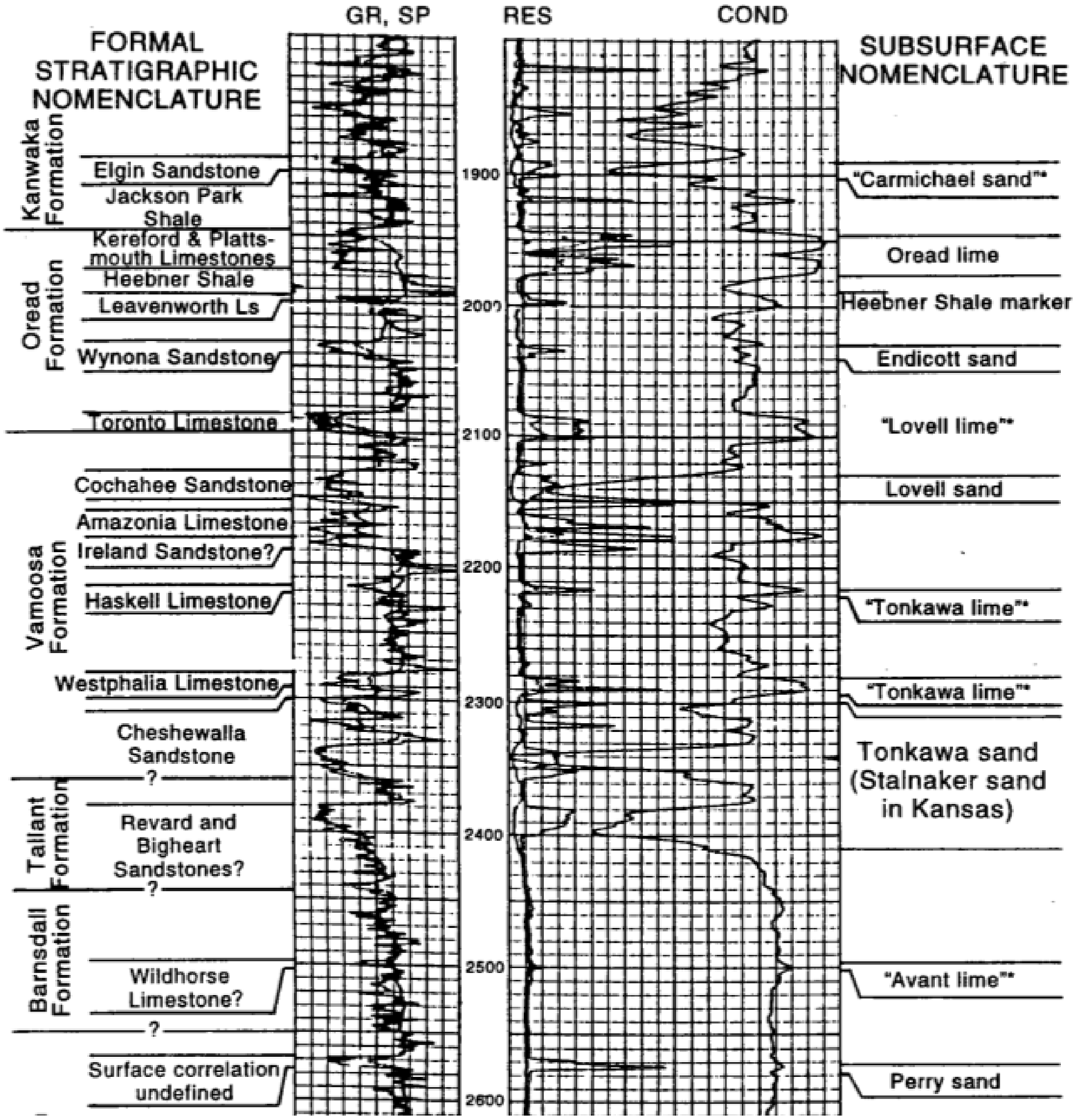


**Figure 1.4 Type log including formal and informal stratigraphic nomenclature for the Tonkawa Sandstone and surrounding units. Electrical log responses are typical of the more shallow units found in the northeastern section of the study area. GR refers to gamma ray response, SP is for sonic potential. Resistivity (RES) and conductivity (COND) are profiled on the right. Electrical log is from Wicklund Petroleum Corp. No. 1 Lyons in Kay, County, Oklahoma (Andrews, 1997).**

## Tonkawa Sandstone Age Debate

There have been two schools of thought debating the age of the Tonkawa Sandstone. These include, that the Tonkawa Sandstone is Virgilian in age representing the lowermost part of the Douglas Group (Lukert, 1949; Winchell, 1957; Lane, 1978; Padgett, 1988; Fies; 1988, Andrews, 1997) and that the Tonkawa is Missourian in age and is the equivalent of the upper part of the Lansing Group (Pate, 1959; Gibbons, 1962).

In this paper the Tonkawa will be considered Virgilian in age because of the following reasons:

The overlying Haskell Limestone has been dated as Virgilian.

Exposures in Kansas show the out cropping Tonganoxie, a stratigraphic Tonkawa equivalent, to be unconformably overlying the top of the Lansing Group on a non-erosional contact. This surface exposure has been traced into the subsurface of south central Kansas by Winchell (1957) and into northern Oklahoma by Lukert (1949).

## Petroleum Exploration and Production

Early oil and gas exploration in Oklahoma propelled the territory to statehood in 1907. Although the region has had a varied history long before the state joined the union. Native Americans mined surface seeps for asphalt and initial subsurface production was usually accidental and sold for use in lamps. The first economically valuable well was drilled in 1896 near Bartlesville in northeast Oklahoma. The rush had begun and major discoveries were creating excitement and establishing the midcontinent as a dominant force in the petroleum industry. Oklahoma was the largest oil-producing entity in the world form 1896 to 1907 and remained the lead producing state until 1923 (Boyd, 2002).

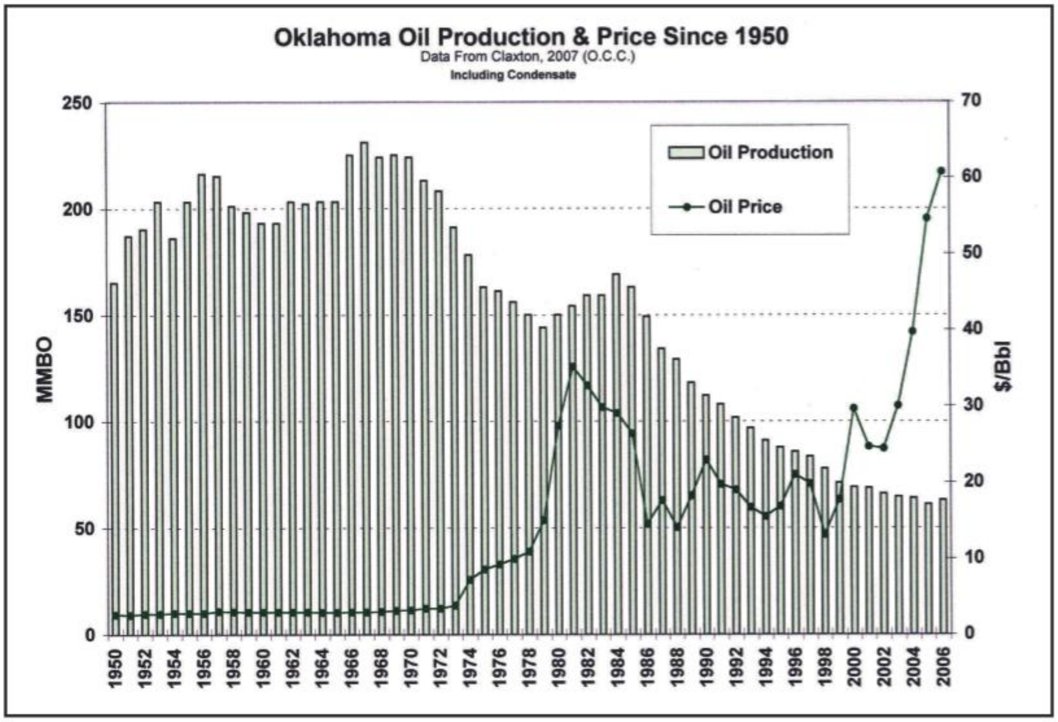


**Figure 1.5 Oil production plotted against the average unadjusted crude oil price through 2006 (Boyd, 2008).**

As major producers exit reservoirs after initial production slows, under utilized resources are left in the ground. Based on calculations of original oil in place and long-term decline projections show an approximate 19% aggregate recovery factor for the state. This is due to the innate complexities and geometries of subsurface geological formations. Combining new technologies and additional data may uncover commercial opportunities by simply revaluating older abandoned fields.

Early development began in the Tonkawa field in 1921. Five Pennsylvanian sandstones produced in the field with the Tonkawa being the most significant and giving the field its name. Rapid development of Tonkawa formations occurred again through the 1960’s to 1970’s.

In the southern extent of the study area the Tonkawa began producing in the late 1950’s. These first wells produced oil shows with some minor production as well as significantly more gas production. The Putnam Field or Trend in Dewey County has generated the most production form Tonkawa sands (Swanson, 1967). The trapping mechanism in this area appears to be controlled by the updip limit of sandstones truncated by overlying shales. The most prolific hydrocarbon production is from the main sandstone interval occurring approximately 70 to 150 feet below the Haskell marker (Padgett, 1988).

The Nemaha uplift and fault zone act as trapping structures for accumulations of Tonkawa oil and gas in the northern part of the study area. In this area anticlines and basement-rooted faults provide the main trapping mechanism (Campbell, 1997)

The Tonkawa field played a central role in the development a shallow coring method. The new method allowed the structural dip to be determined through the use of coring. The previous method of mapping anticlines was over used and not yielding any new discoveries. Determining the structural dip allowed for the great success at the Tonkawa field (Campbell, 1997).

## Previous Work

Although sandstones throughout the Anadarko Basin have been studied extensively for economic applications, studies focusing primarily on the depositional environments of individual sandstone sequences are sparse. There are few published or publically available documents describing various aspects of the Tonkawa in north-central Oklahoma. Of these papers only three look at the depositional environments.

The Tonkawa Sandstone was officially named by Clark and Aurin (1924) and Hosterman (1924) after it was seen that the sandstone was producing from anticlinal traps in the Tonkawa Field in Kay County, OK.

Pate (1959) was one of the first to look at the Tonkawa and its production trends. His study determined the primary hydrocarbon production occurs along stratigraphic traps in the Laverne field in northwest Oklahoma. Pate later (1963) produced additional maps differentiating the Tonkawa Sandstone into three members.

Khaiwaka in a master’s thesis from the University of Kansas in 1968 was the first to suggest the Tonkawa was deposited in a deltaic environment. Structures and sequences observed were described as comparable to the modern Mississippi Delta (Fies, 1988).

Biostratigraphic analysis was completed by Lane (1978). The relationship between the Tonkawa Sandstone and the Missourian Lansing Group carbonates in Beaver County, Oklahoma where seen as not representing a facies change of the Lansing, as originally suggested by Pate

(1959). Lane suggested a marine slope sand affected by a tidal pass, basing his conclusions solely on the morphologies of the limestones of the Lansing Group (Fies, 1988).

Kumar and Slatt (1984) suggested a shelf to basin slope depositional model for the Tonkawa sandstone after examining two cores in Dewey and Custer Counties, OK. There work focused on the lowest sand unit within the Tonkawa interval.

Padgett (1988) working in Dewey County has also interpreted the Tonkawa as a deltaic sandstone. He defined the Tonkawa sandstone as the sequence of clastics between the base of the Haskell marker and the base of the lowermost sandstone body marked on a wireline log by a greater than -45 API units of deflection from an averaged shale base line. This generally occurred at 175 feet below the Haskell marker in his study area. The sandstone described was placed in what Kumar and Slatt (1984) consider being the Middle Tonkawa Sandstone.

Several Tonkawa cores were described by Fies (1988) in Woods and Woodward Counties, Oklahoma. Detailed sedimentary petrology and diagenic analysis determined the sandstone to be deltaic in origin.

Other papers looking at the paleogeography and depositional environments of the Tonkawa interval include Rascoe (1962), Busch (1974) and Rascoe and Adler (1983). Much of there work is based on previous studies completed by Pate (1959) and Khaiwka (1968).

Several papers have looked at the correlation between the Tonkawa Sandstone, the Stalnaker sands and the Tonganoxie Sandstone in Kansas. The name Tonganoxie was originally given to outcrops in eastern and northeastern Kansas, and later was used to formally describe the subsurface units. Stalnaker is most commonly applied to the correlative subsurface sands in south central and southeast Kansas. A review of previous studies is below.

Bennett, Hall and Haworth (in Lins, 1950) each published papers in 1896 described the outcropping Tonganoxie units. The first subsurface study was conducted on the Stalnaker in 1929, looking at possible hydrocarbon potential of the sand (Lins, 1950). A regional study looking at the stratigraphic relationships of the Paleozoic rocks in central Kansas and north central Oklahoma was completed by Lukert in 1949. This study briefly mentions the Tonkawa and possible Stalnaker relationship.

Lins (1950) completed the first subsurface map showing sand distribution within the Tonkawa interval. From this a fluvial depositional environment was suggested for the deposition of the Tonganoxie in northeastern Kansas.

In 1957 Winchell mapped the distribution of the Stalnaker sands in several counties in south central Kansas.  Several cross sections mapped the relationship between the Tonganoxie to the northeast and the Stalnaker sand to the south.

An extensive study of the Douglas Group in the eastern midcontinent using out crops, subsurface data and cross sections was undertaken by Ball (1964).  This study agrees with Winchell’s earlier stratigraphic interpretation, stating that the Tonganoxie and Stalnaker are equivalent.

Griffith (1981) completed mapping around the areas previously mapped by Lins and Winchell.  This provided an exhaustive map of the distibution of the Tonganoxie in Kansas.

# CHAPTER 2 - DEPOSITIONAL MODELS

Climate, shelf geometry, and glacially forced sea level changes all influence the sediment supply, depositional patterns, accommodation and stabilization of both the marine and continental sediments in the study area (Moore, 1964; Heckel, 1994).

Three main depositional models have been suggested for the Tonkawa sandstone; fluvial dominated deltaic, estuarine, and deep sea clastic. Each will be reviewed in this section. The differences in sedimentation during regression and transgression will be briefly discussed.

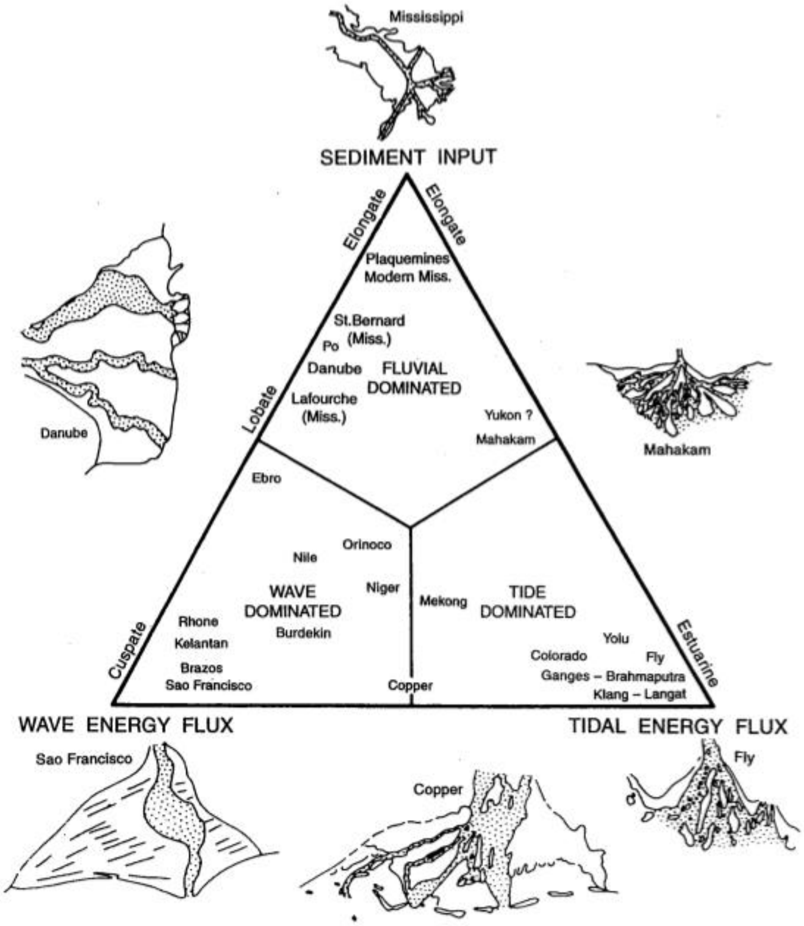


**Figure 2.1 Schematic diagram showing influences on major river systems throughout the world (Andrews et al., 1997).**

## Fluvial Dominated Deltaic Environment

Fluvial dominated deltaic (FDD) reservoir environments have been examined throughout the mid-continent area. These reservoirs have been defined as sandstones deposited in a deltaic or solely fluvial environment (Andrews et al., 1997). Fluvial-dominated deltaic systems are found at the convergence of a continental landmass and a marine setting. Significant morphological features, including point bars, distributary channels and bay fill will be discussed below.

The major components of a delta include the delta plain, delta front and prodelta. These environments are formed when a river flows to a larger water body with a generous sediment load, causing the shoreline to push seaward. The delta plain is the subaerial, lowland where active and abandoned channels and emergent surfaces. The upper delta plain deposits generally form migratory distributary channels. Lacustrine delta fill and interdistributary flood plain are also seen. The high-energy area where sediments are reworked by tidal and wave process is known as the delta front. This extends to a depth of 10m. Common deposits include sheet sands and distributary mouth bar. These sequences are the result of delta progradation. The transitional environment between the delta front and normal marine shelf deposits is known as the prodelta. This area slopes gently down to the basin floor and is unaffected by wave erosion (Serra, 1985). Due to the long transport distance of sediments deposited in the prodelta a fine-grained clay dominated sequence is generated. In an idealized sequence through delta facies the fluvial point bars and distributary channels found in the coastal plane and upper delta will overlie the delta front sands and prodelta shales. This progradation produces an overall coarsening upwards profile.

Many factors influence the characteristics and distribution of depositional products with a delta. Delta type is dependant upon the size and relief of the drainage basin, source lithologies, climate, wave action, tidal influence, and shape of the preexisting coastline and continental shelf (Andrews et al., 2002 and Reineck and Singh, 1975).

The most landward system within a delta is the coastal plain. Fluvial forces generally forming flood plains, incised valley-fill systems, and swamp or marsh areas dominate coastal plains. Channel deposits create the best reservoirs in this upper system. Common reservoirs include point bars and braided or anastomosing river deposits, with point bars being by far the most prolific (Andrews, 1997).

Point bars are accumulations of sand silt and mud deposited on the depositional bank of a meandering river. Point bars are not specific to any environment and may even be found in estuarine channels where tidal influences are more pronounced than fluvial forces. Midcontinent Pennsylvanian point bars usually range from 20-50 ft in thickness canvassing meander belts up to two miles wide. Characteristics include fining upwards or blocky textural profile. Basal point bars are commonly medium to coarse grained, containing pebble size rip-up clasts and can be conglomeratic.

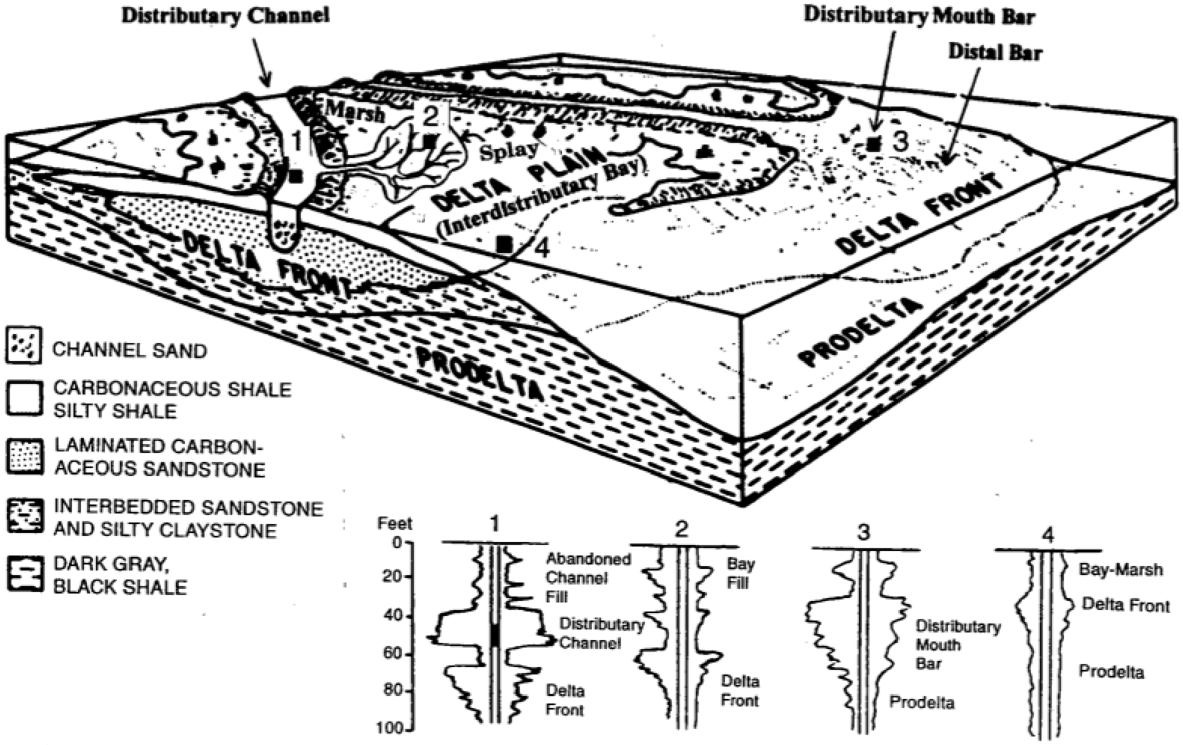


**Figure 2.2 Idealized model of the three major components of a fluvial-dominated deltaic system. Typical electrical log responses and interpreted facies for four locations within the model are given. (Andrews et al. 1997).**

The delta front is commonly segregated into an upper and lower depositional regime. Although, throughout the delta front a coarsening upwards sequence can be found, due to the steepened slope as well as increased fluvial and marine energy.

The upper delta plain extends from the coastal plain to the landward reach of marine processes. Distributary channels as well as point bars are the most common features and best reservoirs within this upper system. Meandering rivers, lacustrine delta-fill, swamps and marshes are also seen. Electrical log signatures allow for recognition of some of these environments. Bell-shaped curves are associated with fluvial point bars, while more block profiles indicate distributary channels. Point bars, coal and migrating distributary channels usually dominate the landscape of an upper delta plain (Coleman and Prior, 1982).

Marine influences may heavily influence sedimentation in the intertidal lower delta plain. Wave action is often negligible due to barrier shorelines or wide delta fronts and rarely affects deposition. Bay-fill deposits, occurring adjacent to or between major distributary channels, and ancillary distributary channels are most common (Andrews, 1997). Distributary mouth bars and bar fingers are deposited subaerially. Crevasse splays, created during flooding events, are the major source of bay-fill sands. Splays, driven by fluvial processes, carry sediment through an outlet in a distributary levee dispersing coarsening upward sand and mud into shallow bays through a preexisting complex of secondary channels. The detrital clay reduces porosity and permeability in splay environments significantly reducing reservoir quality (Coleman and Prior, 1981).

Distributary channels have transported the vast majority of sediment in the delta plain, yet these channels represent a minor amount of sediment deposition. Where deposition occurs channel sands are consistently fine-grained and well sorted. Sedimentary structures include tabular to trough cross-bedding, clay clasts and contorted beds. Shell fragments, fossils and glauconite can also be seen due to marine influences (Andrews, 1997).

Where flow is confined and directed transport of sediments into an open subaqueous prodelta occurs distributary mouth bars and bar fingers are formed. These are generally most dynamic features of a delta system due to copious sedimentation rate (Reineck and Singh, 1975). Bar sands tend to be non-branching, in marine influenced environments, and display similar lithologies to the lower delta plain. Differences occur morphological features of the bars. Wave and storm currents rework the sands to produce some of the most laterally extensive reservoirs found in deltaic environments (Andrews, 1997). Rapid deposition creates intriguing sedimentary structures including contorted beds, mud diapers and soft sediment deformation. High angle and trough cross-bedding are common. On electrical log distributary mouth bars display a serrated profile caused by coarsening upward sediments and the input of continentally sources carbonaceous material.

## Estuarine Environments

Estuarine environments have not been widely recognized in ancient depositional environments but are common in modern transgressive coastlines (Dalrymple et al., 1992). Estuaries are defined as the seaward expanse of a subaerial valley system affected by tidal, wave and fluvial processes. Figure 2.3 displays how differing degrees of influence from fluvial or marine process create distinctions between an estuarine and a deltaic environment.

Estuaries are anomalous within coastal systems due to their more transient nature. If sediment supply is abundant and fills the valley the as sea level is slow or unchanging the environment will transition to deltaic.

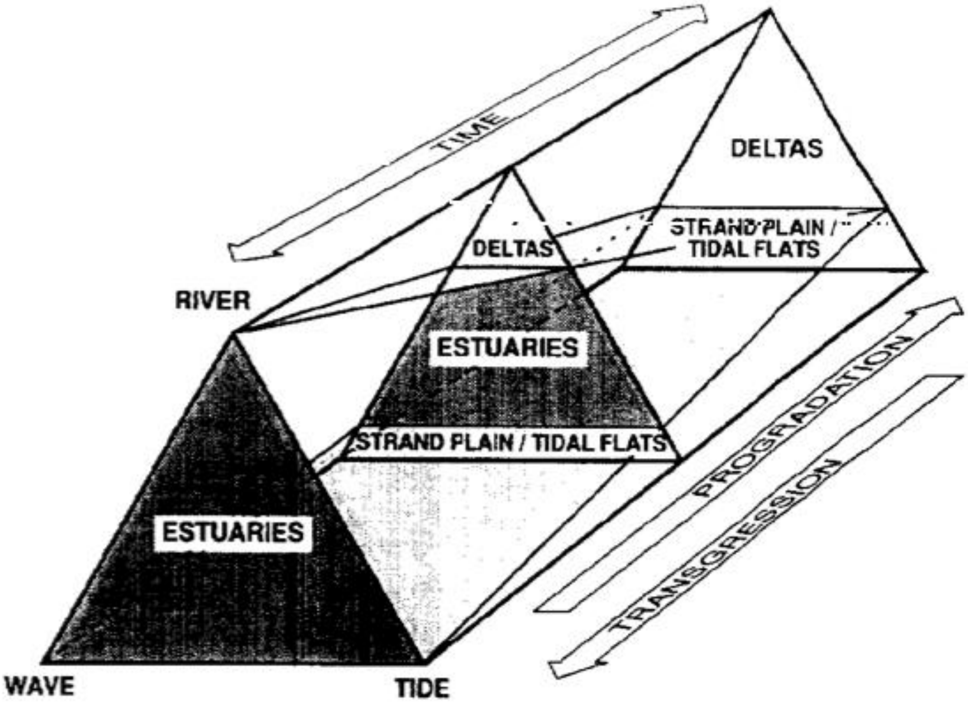


**Figure 2.3. Evolutionary classification of fluvial and marine processes (Dalrymple et al., 1992).**

Estuaries have three zones based on energy influence. The first, the outer zone is dominated by both tidal and wave action. The middle zone has a distinctly lower energy level due to the balance of marine, usually tidal forces, and fluvial currents. The most landward zone has minimal tidal influence therefore, having a net seaward transport of sediment. Estuaries are segregated once more based on their dependence of wave or tidal energies.

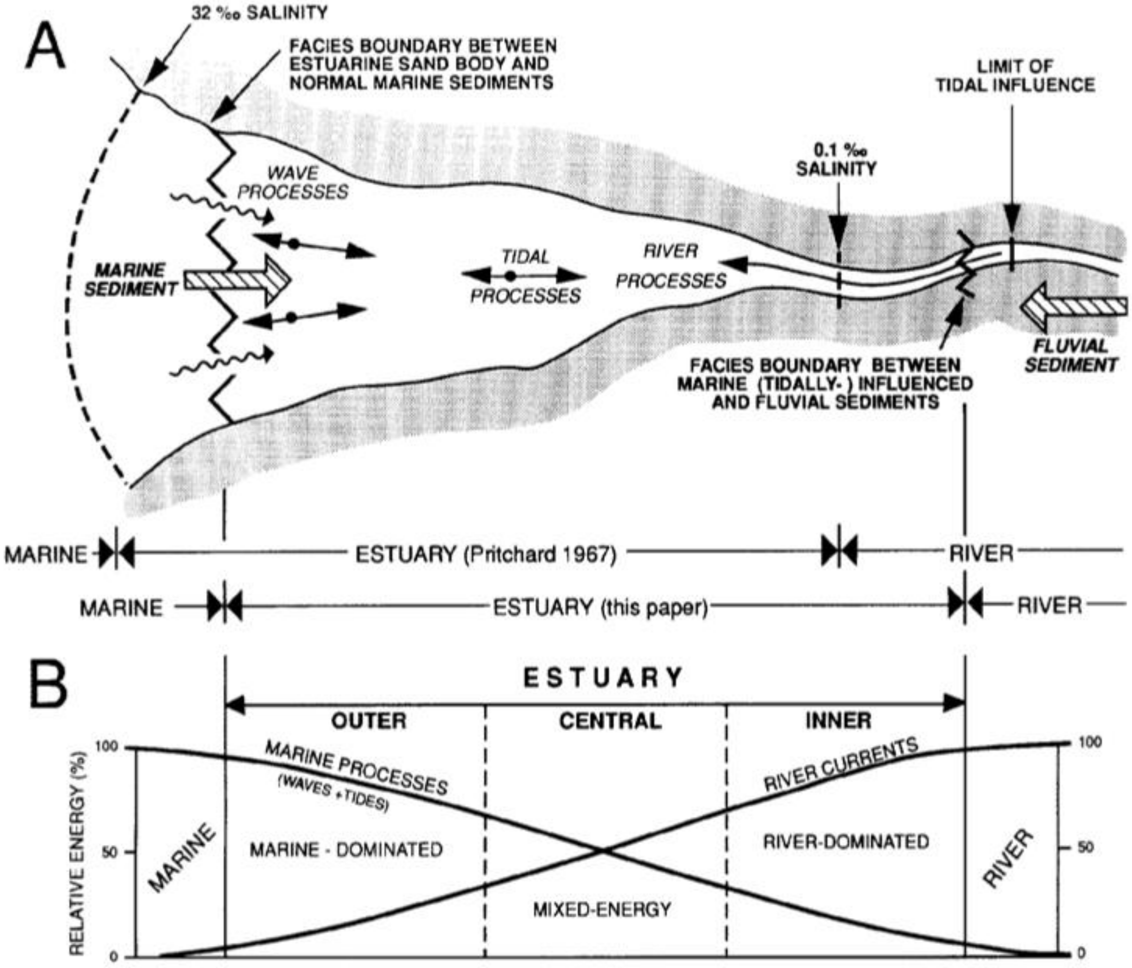


**Figure 2.4 The tripartite divisions within an estuary are created from differing energy inputs and levels. (Dalrymple et al., 1992).**

Wave dominated estuaries have minimal tidal influence and generally move sediment alongshore and onshore of an estuary. A submerged barrier bar develops further preventing wave energy to affect sedimentation within the estuary. The tripartite energy distribution created by bimodal fluvial and wave forces, is clearly seen in the lithofacies deposited. Marine sands accumulate within the zone of high wave energy at the estuary mouth. Commonly transgressive subtidal shoals are identified in electrical logs. Fine-grained organic rich muds are deposited in the low energy open water lagoon. This zone is similar to a prodelta in a deltaic system. As energy levels dissipate at the head of the estuary coarser sediments are deposited. This creates a bay head delta. Where the estuary is unrestricted straight leveed morphologies develop along with prominent inter-distributary bays. A more confined environment does not allow for many depositional features (Dalrymple et al., 1992).

Macrotidal estuaries have been more thoroughly studied (Dalrymple et al., 1990; Woodroffe et al, 1989) because of there extremely dynamic and intriguing nature. Yet, tidally dominated estuaries may develop where wave action is impeded. Elongate sand bars commonly develop at the mouth of tide-dominated estuaries further dissipating the wave energy. Consequently, as tidal energy moves farther into a narrowing funnel shaped estuary the energy is magnified, until fluvial forces negate it. The facies distinctions are not as obvious in a tidal regime because tidal energies are able to travel much farther inland than wave action. Although distinctions are not are readily made the sediment distributions are relatively similar. Estuary mouths tend to feature elongate tidal sand bars that consist of cross bedded medium to coarse sands. Sand flats with braided steam characteristics narrowing to a confined single channel inland can be found at the tidal energy maximum. Parallel fine sand laminations are common here. The middle zone typically develops tight meanders between two straighter reaches on either end. This low energy facies are generally fine-grained sediments.

## Deep-Sea Clastic Environment

Deep-sea environments are those characterized by submerged sediments deposited in a below wave action. Primary depositional controls are sediment supply, tectonics and changes in sea level (Reading, 1986).

Submarine fans are distinctive progradational features commonly found at the base of a basin shelf. Three distinctive fan types have been characterized. Radial fans are shaped by an influx of sediment coming from single feeder canyon. These deposits are often significantly sand-rich. Elongate fans form perpendicular to the basin slope and commonly receive the greatest sediment input from a deltaic system. Deltaic systems are able to move finer sediments into suspension giving rise to very distant deposition. Lastly, fan-deltas are gravel rich and are generated in high-relief alluvial fan-fed settings. A coarse sediment load give fan-deltas a pear shape with a small radius.

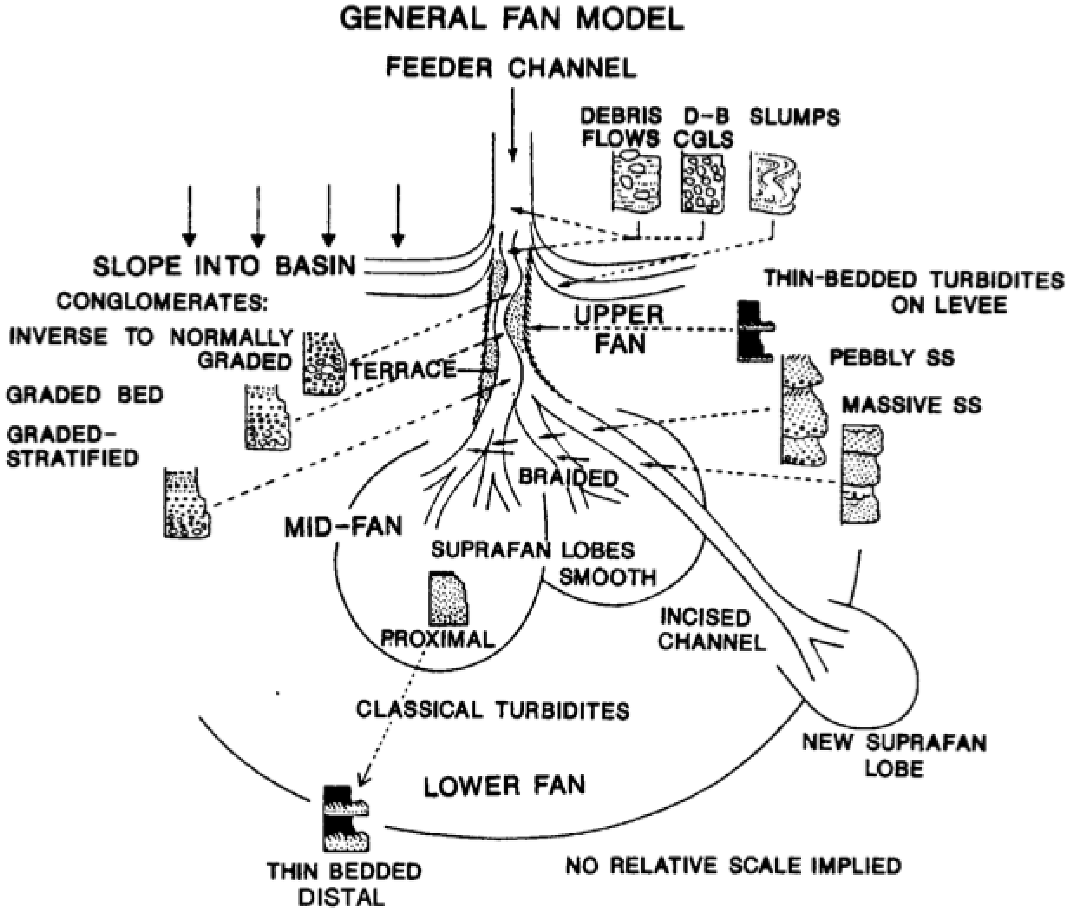


**Figure 2.5 Schematic depositional model of a subaqueous fan environment showing sediment sorting and deposition from source area (Walker, 1975).**

Grain size within a deep sea clastic environment can be highly variable and ranges from gravel to clay with fair to poor sorting. Decreasing grain size form the proximal to the distal end of a turbidite deposit is common. Common compositions include quartz, potassium feldspars, plagioclases and micas (Serra, 1985). Depending on the source area rock fragments are also present. Clays are commonly the principle matrix and cement.

Sandstone beds are graded and rhythmically interbedded with shale. Large scale cross bedding is not commonly seen. Asymmetrical ripple marks, laminated and convoluted beds may indicate deep-sea environments. Boundaries at the base contact are generally sharp and sometimes erosional. Upper sequence boundary tends to be gradational upwards and to the outer fan.

## Regression or Transgression

Stratigraphic boundaries are based on changes in depositional trends. Common changes in trend include the change from a deepening-upwards (transgressive) sequence to a shallowing-upwards (regressive) sequence. These changes are recognized in surfaces, usually referred to as a maximum flooding surface or a maximum regressive surface (Figure 2.6). The cause of change is due to shifts in base level. Base level as defined by Emery (2002, p. 153) is “an abstract surface that represents a surface of equilibrium between erosion and deposition.” As base level is continually changing so are the depositional trends within a sedimentary succession.

Two major types of change in depositional trend are defined by Emery, 2002. They are (1) the movement from sedimentation to erosion and vise versa and (2) the movement from a transgression to regression and vise versa. There are significant changes in depositional trends that help define the changes from a base level rise to a base level fall. These changes produce distinctive, observable horizons within the sedimentary record. The four surfaces generated during a base level rise include shoreface ravinement-unconformable, shoreface ravinement-normal, maximum regressive surface and the maximum flooding surface. There are two surfaces associated with base level fall, a subaerial unconformity and the regressive surface of marine erosion. A brief review of the characteristics of each horizon as described by Emery, 2002, is below.

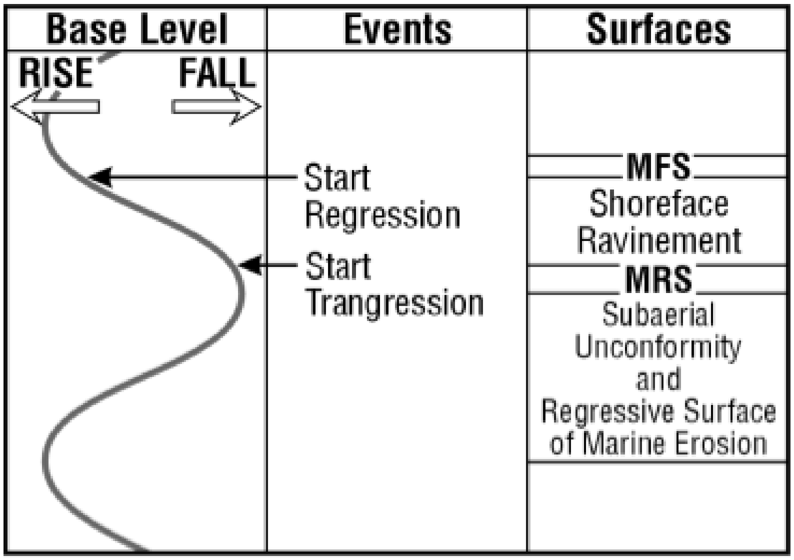


**Figure 2.6 The rise and fall of base level defines periods of transgression from regression. During a base level fall a subaerial unconformity is seen and a regressive surface of marine erosion will migrate basinward. A maximum regressive surface is formed during the transformation from base level rise to fall. During the transgression a shoreface ravinement migrates landward (Emery, 2002, p. 155).**

<u>Shoreface Ravinement-Unconformable (SR-U):</u> A shoreface ravinement-unconformable surface forms during a transgression, as base level is rising. An erosive surface, moving landward, is created as wave action removes sediment that is then transported seaward. This horizon is characterized by a sharp erosive contact overlain by a transgressive sequence of marine strata displaying a deeping-upward trend.

<u>Shoreface Ravinement-Normal (SR-N):</u> The main difference between the shoreface ravinement-unconformable and the shoreface ravinement-normal involves the underlying subaerial unconformity. In the shoreface ravinement-normal the underlying sediments, deposited landward of the shoreline, must overlie a subaerial unconformity.

<u>Maximum Regressive Surface (MRS):</u> The point where the rate of base level rise exceeds the rate of sedimentation to the shoreline, causing a landward movement of the shoreline is known as the maximum regressive surface. Recognition of this horizon requires facies analysis to determine approximate water depths. The surface may be gradational or may be abrupt with minor scouring.

<u>Maximum Flooding Surface (MFS):</u> As a shallowing-upward trend replaces a deeping-upward movement a maximum flooding surface is formed. The shoreline begins to advance as marine areas are affected by an increased sediment load. Observed boundaries range from gradational to scoured surfaces showing varying degrees of erosion. Where the maximum flooding surface is not associated with an unconformity it can be seen within a 'condensed' section, representing very low sedimentation rates. Generally, this horizon is placed at the base of the first obviously coarser interval overlying or associated with the condensed section.

<u>Subaerial Unconformity (SU):</u> This occurs during a time of base level fall. Subaerial erosion processes such as fluvial and wind action creates a surface characterized by a sharp erosive contact. A defining attribute of a subaerial unconformity is the overlying nonmarine strata that are deposited as during base level rise.

Regressive Surface of Marine Erosion (RMSE): This horizon is also an erosional surface developed during base level fall. The inner shelf becomes unstable as base level falls and currents begin to remove sediment creating an area of net erosion. Regressive surface of marine erosion are distinctive in that they are almost always overlain by shallowing-upward shoreface strata and underlain by shallowing-upward marine shelf strata.

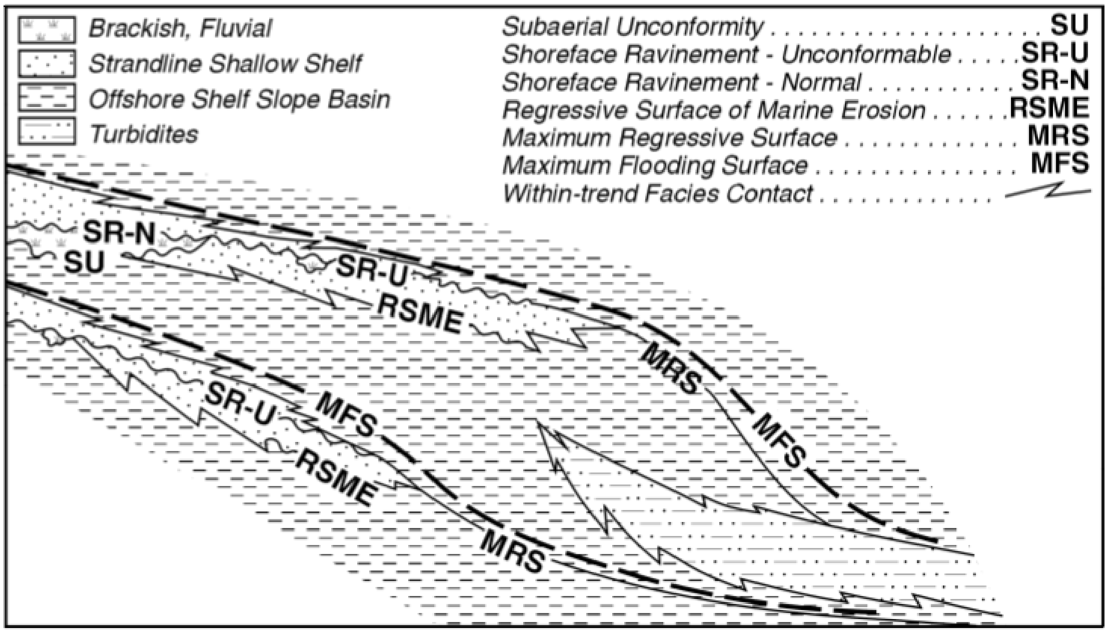


**Figure 2. A schematic cross section showing the relationship of the six surfaces created during a regressive-transgressive cycle. (Emery, 2002, p. 157).**

The surfaces generated during the base level cycle can be used to correlate sequences. This helps to gain a better understanding of the depositional environment and possible hydrocarbon potential of an area.

# CHAPTER 3 - METHODS

Three main analytical methods were used to complete this study of the Tonkawa. The first was examination of core to describe small-scale details not easily seen by the resolution available with wireline logging. Wireline logs where then examined for patterns and signals indicating depositional environments. Petra, a common geological software program used within the oil and gas industry, was used to create cross-sections and maps from the correlated wireline logs.

Interpretations for the Tonkawa sandtone were made based on information gathered from literature, core and well log analysis including: (1) texture- grain size and sorting; (2) bedding thickness; (3) sedimentary structures- soft sediment deformation and bedding types; (4) unit contacts- gradational or abrupt; (5) notice of any fossils or trace fossils; (6) electrical log signatures- mainly gamma ray, density-neutron and resistivity logs; (7) overall geometry of the sand body; and (8) overall lateral and vertical lithologic realationships.

## Core Analysis

Utilizing core data in this study is key to understanding the small-scale features not visible in wireline logs. Cores offer a unique opportunity to directly study the subsurface. Coring a well allows for calibration of the petrophysical model and gain additional information about the reservoir that is not seen by logging.

Cores from four counties within the study area were examined for sedimentary structures, mineral assemblages, and other properties. The Oklahoma Geological Survey Core Library was instrumental in viewing the core in an easily accessible location. Initial core from Custer and Dewey county was brought to the Thompson Hall for analysis. Two additional trips where made to the Core Library in Norman, OK to study the remaining available Tonkawa core.

A Microsoft Excel spreadsheet was created to organize core notes and features (see Tables 1-7 in Appendix A). The spreadsheet included general columns for percent sand and percent shale. The first two columns were just to give a very rough estimate of the core features. Two more columns were created for percent mica and percent organic material seen. There measurements were often were taken from the end-caps of the core, where the core had separated along the weaker mud draped facies. Therefore the percent mica and organics are not representative of the core as a whole, just the area of examination. The last column was for notes about the core. Notes taken generally included information about the grain size, sedimentary structure, thickness of laminations, lithology, and any accessories, such as fossils or trace fossils (Ethridge, 1992). Cores were then photographed with a centimeter scale and finalized in Adobe Photoshop. Photoshop was used to straighten the scale. All illustrations created from core descriptions were created using Adobe Illustrator and Photoshop.

Advantages of core analysis are numerous, but are often set aside because of the lack of ability to offer a three-dimensional view and observe lateral facies and large-scale sedimentary features.

## Wireline Logging

Wireline logging is the process of using tools to record characteristics, usually by electrical responses, of rocks in the subsurface. Well logs are primarily used to map the subsurface and evaluate the hydrocarbon potential of a reservoir.

Logs used in the study of the Tonkawa sandstone were donated by Bill Brock of MJ Logs, out of Calgary, Canada. The logs were viewed using the Log Sleuth software also donated by MJ Logs. More than 500 logs were donated and used in creating cross-sections and various maps with Petra. Of the logs available some were more useful than others because of the depths of the data or the type of information they yielded.

All logging tools were run in an openhole logging while drilling environment. Logs that proved the most useful for this study were: gamma ray, spontaneous potential, neutron porosity and resistivity (Darling, 2005). An example of the typical responses of the Tonkawa sandstone are shown in Fig. 3.1.

Each tool focuses on a specific measurement within the well.

Gamma Ray: Measures the strength of natural radioactivity present in the formation. This tool is most helpful when distinguishing between shales and siliciclastic environments. An increase in shale content will cause a gamma ray signal to kick to the right on a wireline log.

Spontaneous Potential: The natural difference in electrical potential is most commonly used to differentiate between the salinities of the drilling mud and formation water. The extent that a formation has been damaged or invaded by the drilling muds can be measured using the spontaneous potential tool.  The reading will increase as the amount of shale in a formation increases.

Density:  Density logs will respond to the average density between the source and detector giving a measurement of bulk density of the formation.  Measured by the reduction in gamma ray radioactivity due to Compton scattering.   Density logs are an excellent measurement of porosity. The tool shows that as density increases the formation porosity will decrease.

Neutron Porosity:  Another good measurement of formation porosity, the neutron porosity, measures the decreasing speed of neutrons by thermal neutron detectors.  The slowing process is dominated by hydrogen until they undergo neutron capture.   As the porosity increases within a formation so will the neutron measurement.

Resistivity:  There are two main resistivity logs, laterolog and induction.  Laterlog measurements are made using an electrode device.  This low frequency measurement requires water-based mud.  This log is one of the first used in subsurface exploration because of its simple ability to distinguish between formations containing hydrocarbon and those with water. Shallower readings of both resistivity logs generally give better measurements.

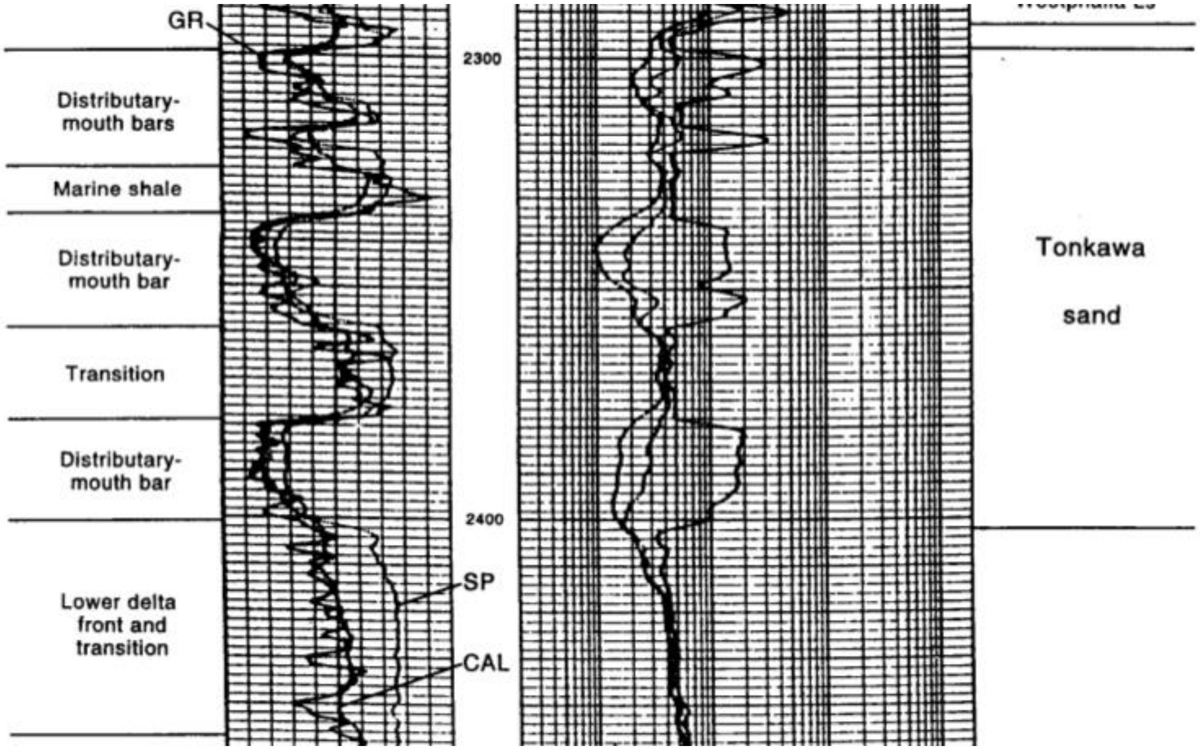


**Figure 3.1 Example of electrical log and corresponding possible interpretations. Kay County, Oklahoma (Andrews, 1997).**

## Petra

A database was created in the geological software program Petra using raster image data supplied by MJ Logs of Calgary, Alberta. Petra, a geological mapping software produced by IHS Corporation is available through an academic license in the computer lab in Thompson Hall. The raster images used were selected by determining several conditions; 1) if the well was in the study area; 2) if there was a core associated with the well; 3) if the well had valuable raster data associated with it. Raster log images where first imported using the Log Sleuth software, also supplied by MJ Logs. Each raster image is associated with an API number and latitude/longitude location for identification.

Electrical logs were looked at for overall features but were not useful in delineating small scale sedimentary structures.

# RESULTS

Previous studies have produced a variety of paleo-environment interpretations within the Tonkawa interval. Earlier works did not employ sufficient subsurface data in interpretations or were very regional, skipping important details. Subsurface maps have been created from wireline log interpretations without the benefit of core data or vise versa. This study works to present data collected from both detailed core analysis and wireline logs.

## Core Descriptions

The core descriptions provide a summary of major features seen within individual cores. Cores were described at the Oklahoma Geological Core Library in Norman, OK as well as Thompson Hall. Descriptions were based on the visual characteristics of the core. Sedimentary structures were the focus of interpretation.

The core features were then collected and if possible analyzed along with wireline log interpretations and maps to create a unified depositional environment model. Cores were three inched in diameter, with most were cut vertically to reveal a flat surface for easier interpretation. All scales seen in core images represent a cm scale. Photographs of the cored intervals follow each written description.

### *Texas Saylor 'A' #1*

Texas Saylor 'A' #1 was drilled in southwestern Dewey County and cored from depths 7895' to 7953'. The core was not fully split, so several descriptions were taken from the rounded surface. Descriptions were made in August 2009 at Thompson Hall.

From the top to approximately 7920' the core displays a sequence of interstratified sandstones and shales. The sandstone is generally fine to very fine and both slightly fining and coarsening upwards intervals are seen. Ripples and small-scale cross bedding dominate the sedimentary fabric.

The middle interval of the core from 7920' to 7940' contains fine to very fine sands that are moderately sorted. The well has produced from this interval (Padgett, 1988). Massive bedding and some small scale cross bedding are seen. Sedimentary structures include various soft-sediment deformation features and few horizontal laminations. The cement is likely quartz and some dolomite with traces of glauconite and minor shell fragments.

From 7940’ to depth the core generally increases in shale content and becomes an interstratified sequence of sandstone and shale. The sandstone is slightly fining upwards. Ripples, horizontal and some wavy laminations, small scale cross bedding are prevalent throughout the zone. Flame structures, small rip up clasts and minor load casting are seen. A two-foot interval from 7952’ to 7954’ contains abundant sideritized pebbles and clasts. This smaller interval is porous and productive (Padgett, 1988).

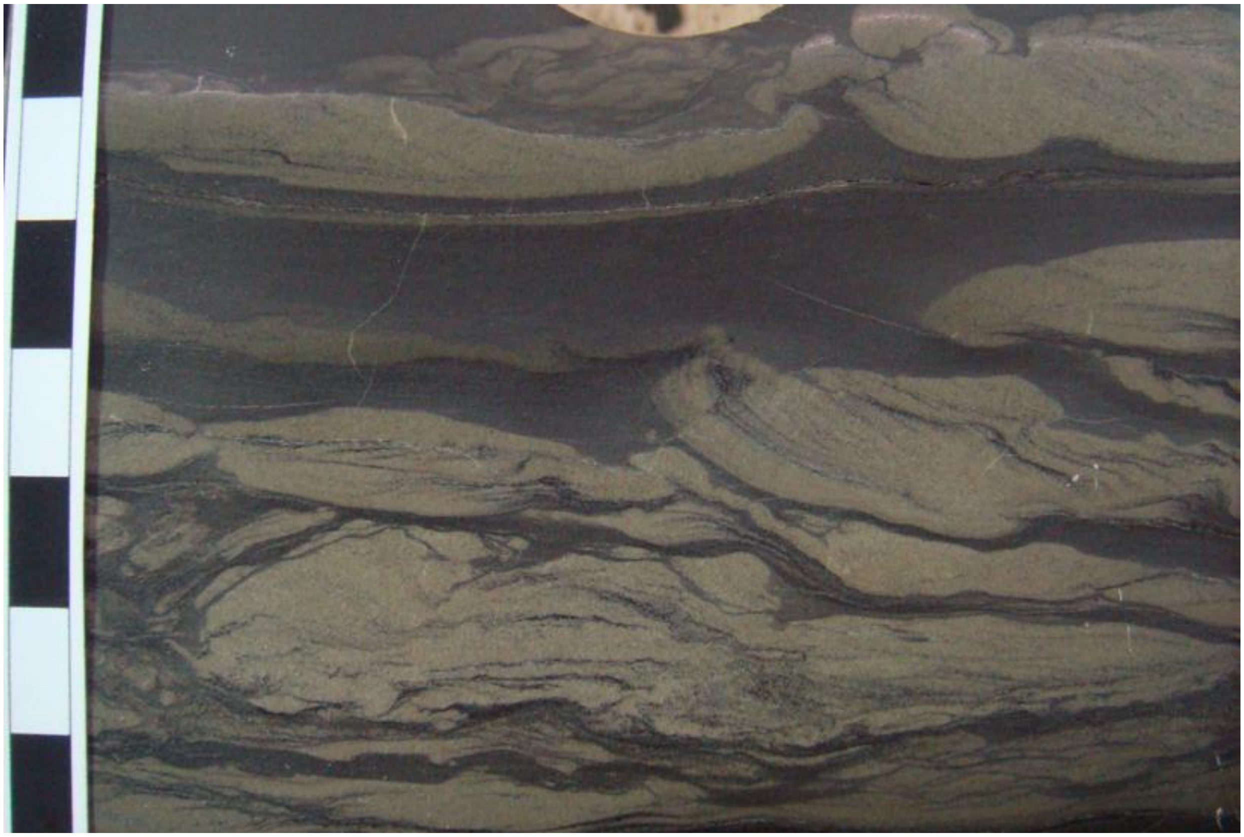


**Figure 4.1 Showing soft sediment deformation and some minor flame structures at a depth of approximately 7904’. The scale throughout core description photographs is in cm.**

**Figure 4.2. Climbing ripples at approximately 7907'.**

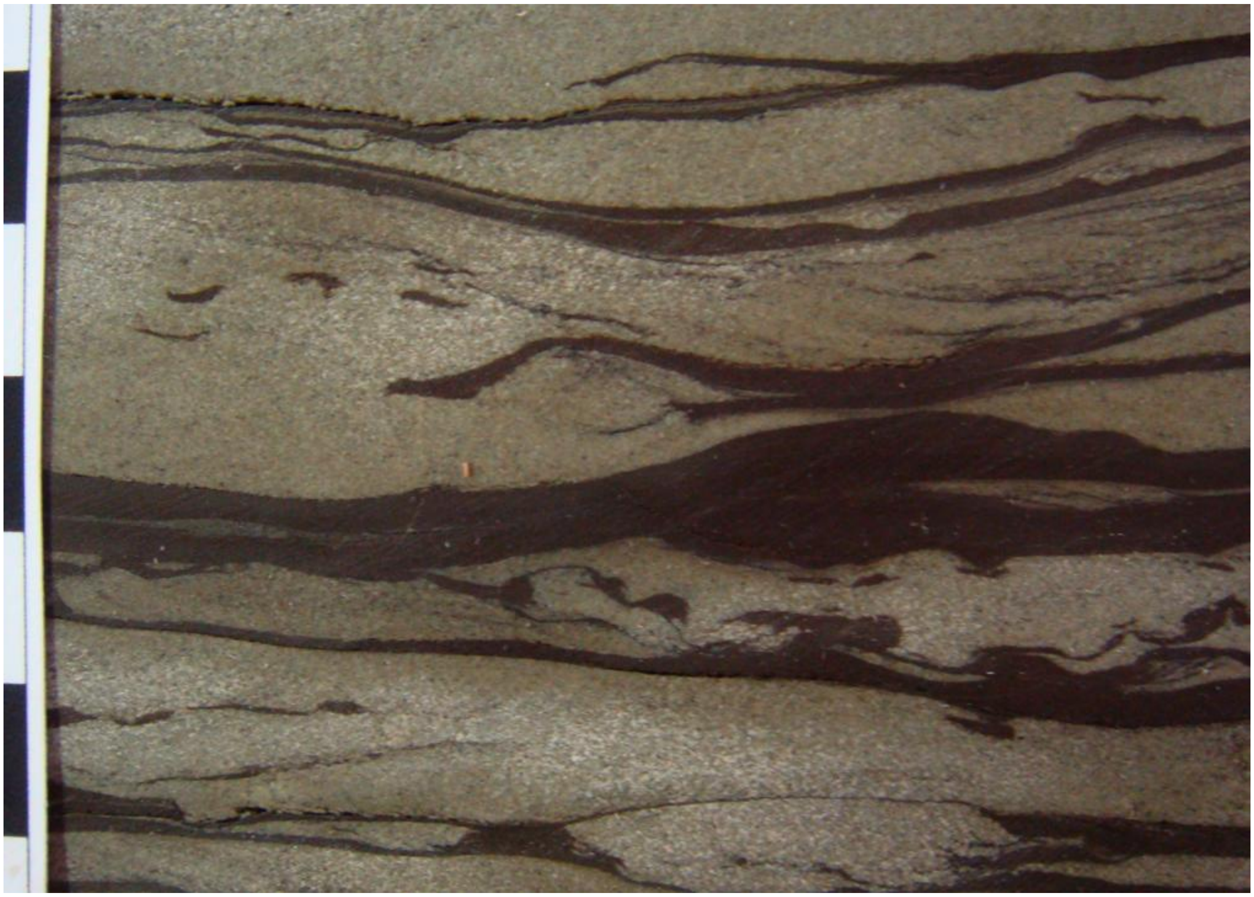


**Figure 4.3. Rip-up clasts at a depth of 7942.5'. Wavy laminations and slight load casting are also seen.**

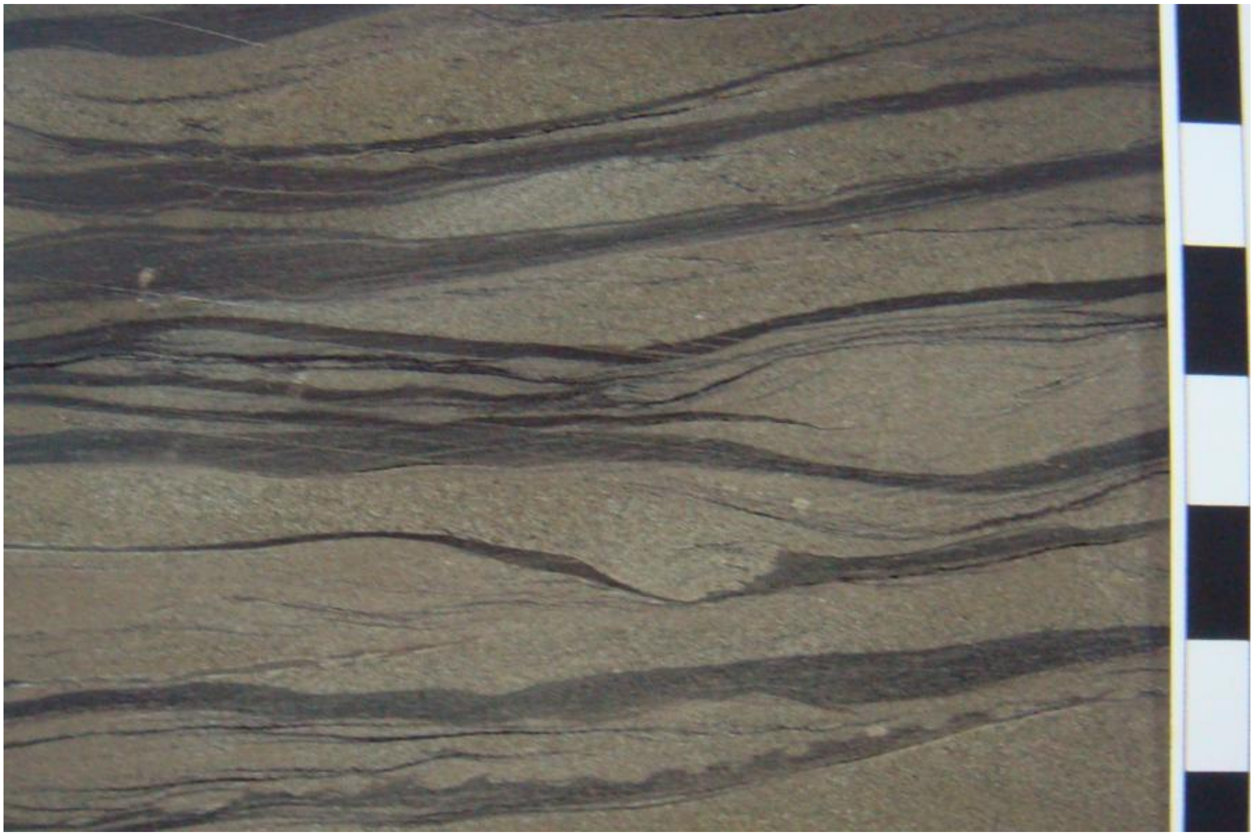


**Figure 4.4 Wavy bedding and ball and pillow structures are seen at a depth of 7941'.**

### *Sarkey's Inc. Fancher #1-17*

The Fancher core had been previously examined and then treated, rendering the core difficult to fully interpret. In some areas the covering had been cut open and the core was examined. This core was examined in August 2009 at the OGS Core Library. The electrical log, a portion of which is seen in Figure 4.5, was helpful in interpretation.

The well was cored from a depth of 7796' to 7863'. Throughout the cored interval very fine sand is dominant. Common sedimentary structures include wavy to nearly parallel laminations along with some soft sediment deformation. Load casting and possible burrows are seen in horizons throughout the core, becoming more sparse from 7820' to 7835'. The upper approximately ten feet of the core is mainly shale with interstratified sandstones. Ripples and wavy laminations are common in sections with increasing shale content.

From 7864’ to 7805’ the core is massively bedded sandstone. The sandstone is a very light gray color and may have a slight coarsening upwards profile. The sandstone was heavily micaceous in some sections.

The majority of the core is a sequence of interstratified sandstones and shales displaying ripples and possibly some small scale cross bedding. Soft sediment deformation is also seen. This section is consistent to depth.

**Figure 4.5 Example of Sarkey’s core, and the preserving methods that inhibited core examination. The core is three inches in diameter.**

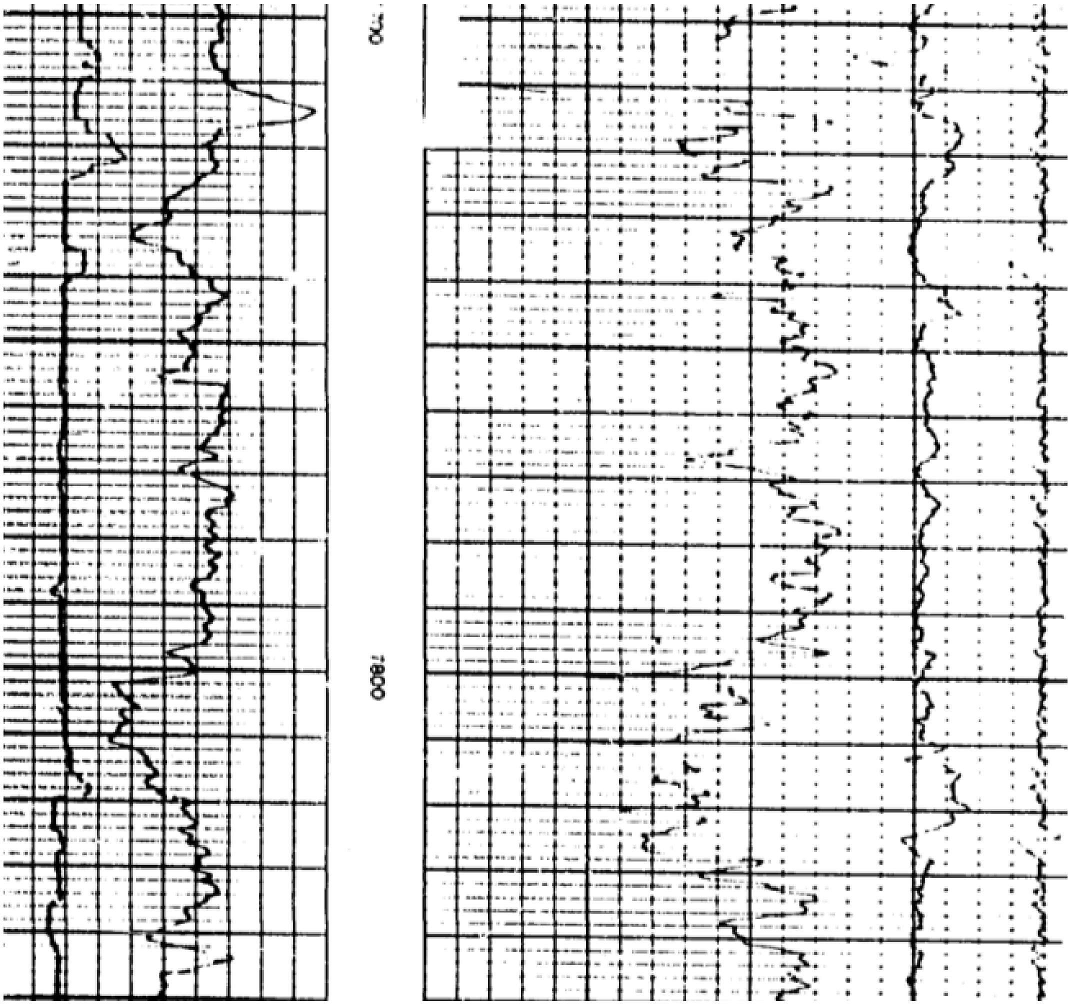


**Figure 4.6 Electrical log for cored section of Sarkey's Inc., Fancher #1-17. The electrical log does not fully represent the heterogeneities seen in the sedimentary structures within the cored interval.**

### ***Wessely Energy Corp. Ellington #1-35***

The Ellington well was drilled in Dewey County and cored from a depth of 7844’ to 7885’. The well had produced oil until 1985 and gas until 1986.

From the top of the core at 7844’ to a depth of 7865’ sand is dominant, with increasing shale content up core. Near the top the interstratified sandstone and shale displays horizontal laminations and slump features. Most slump features are found near the top of the cored section. The sands are fine to very fine grained but show no pattern of grain size sorting. Sideritic clasts are also seen and are highly variable in size.

The 15’ interval underlying the top section displays an overall increase in shale content. Carbonaceous materials are also more prominent in this section. The interstratified zones contain ripples, small-scale cross-bedding and soft sediment deformational features. These sands are fine grained and moderately sorted, compared to the zones above and below.

Ripples and small scale cross bedding characterized the interval from approximately 7880’ to 7890’. An abrupt facies change at the upper end of this interval, with core changing from a more massively bedded sandstone to a very interstratified and cross bedded sandstone and shale.

After the core reaches a depth of 7890’ a dark shale becomes dominant. Primary sedimentary features include horizontal laminations with minor bioturbation occurring as burrows.

**Figure 4.7 Large sideritic clasts present at 7852'. The fracture in the center is likely a post-cored feature.**

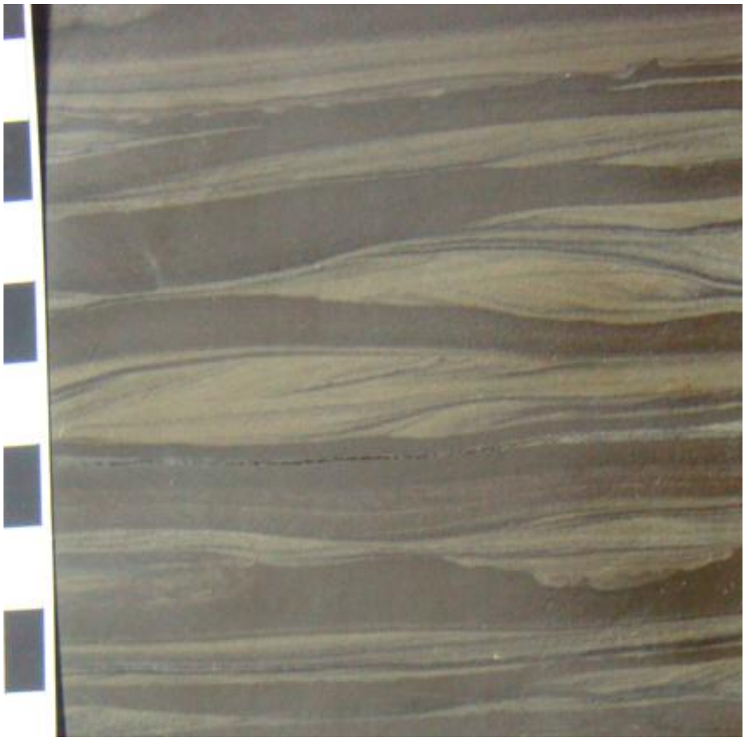


**Figure 4.8 Wavy laminations with smaller scale cross bedding and climbing ripples. Minor load casting is also present. At depth 7883'.**

### *Pam Oil N. Shrimp #9A*

Pam Oil, Shrimp well was drilled in the northeastern section of the study area, where the Tonkawa sandstone is at shallowest depth. The core had not been cut to reveal a flat surface to analyze sedimentary structures, making interpretation and observation difficult. The available cored interval was not continuous, allowing for analysis of sections from 2300' to 2329' and from 2683' to 2756'.

The first 30' of core, to a depth of nearly 2330', was generally similar throughout. It consisted of a very fine grained sandstone, light in color. Making the core more interesting was the abundant organic material and mica content found throughout the section. In areas of increased shale content the core becomes very fissile and seems to separate into sheet like layers. These horizons are very minor, never exceeding 2 cm in thickness. Some areas of interlaminated sandstones and shales displayed slight cross bedding. Mud chips were also observed, usually in occurrence with larger organic fragments.

Further down hole the sedimentary structure and composition varies slightly. The interval from 2683' to 2718' consists of similar very fine light colored sand. High angle cross bedding is present in an approximately 8 cm thick zone at 2684'. Elsewhere there is little interlamination of sands and shales. A natural vertical fracture is also persistent in this section, and seems to follow a thin zone of calcification.

At a depth of 2718' the organic content greatly increases. Shale also becomes more dominant, occurring in very horizontal and parallel laminations. Some minor cross bedding is present, with little indication of soft sediment deformation. This continues similarly to a depth of 2736', with the exception of a minor very coaly shale horizon, at 2735'. This segment is contains very dark shale and is fissile. Some of the core may be missing due to the deteriorating nature of this segment.

There is an abrupt change in the core at a depth of 2736'. Fine sand becomes more prevalent and there is little interlamination of sand and shale. At 2742' the core becomes more varied. There is a thin horizon of a pebble conglomerate. The conglomerate was poorly sorted but generally well rounded. The clast lithologies were not examined. Within several centimeters of the conglomerate large organic fragments, including woody pieces can be seen.

Fine grained sand again dominates the core from a depth of 2751' to the base. Within this section soft sediment deformation, including ball and pillow structures can be observed. Flaser bedding and flame structures are also seen. Close to areas of high deformation coarser sands are observed.

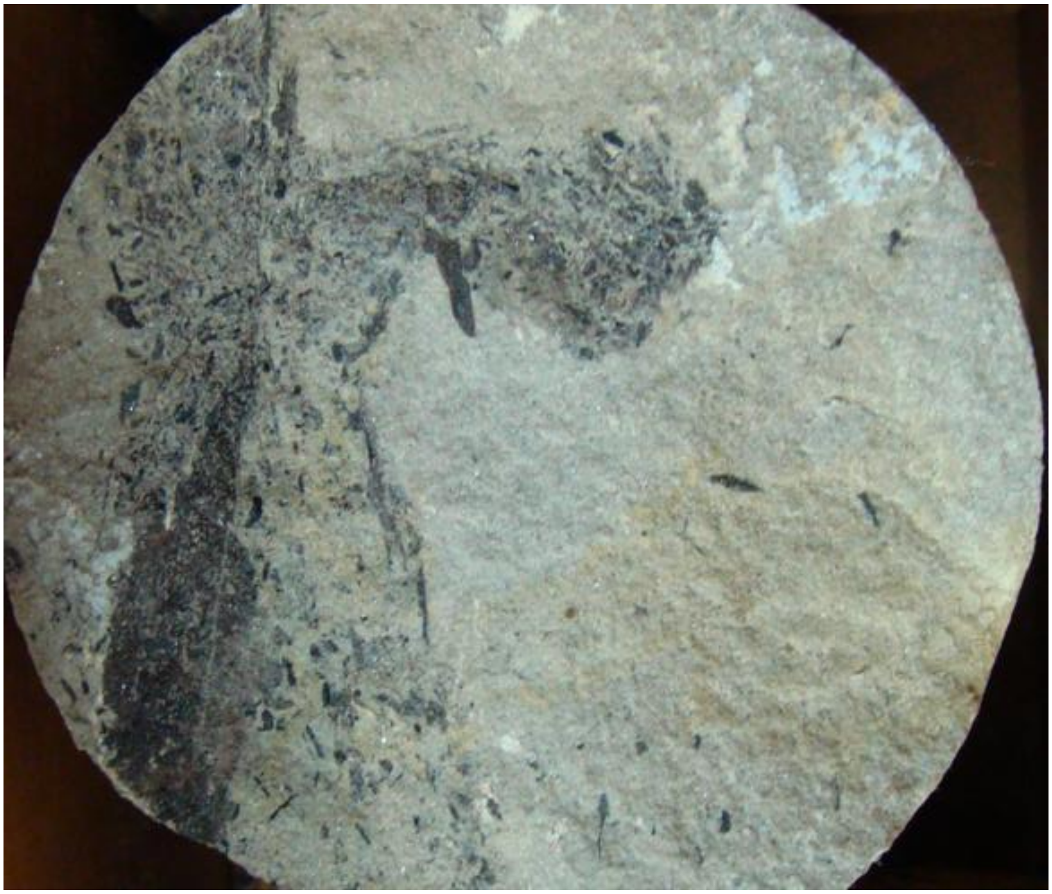


**Figure 4.9 Woody organic material seen at depth of 2305'. Coffee grain organics and minor amounts of mica can also be seen. Core is 3" in diameter.**

I

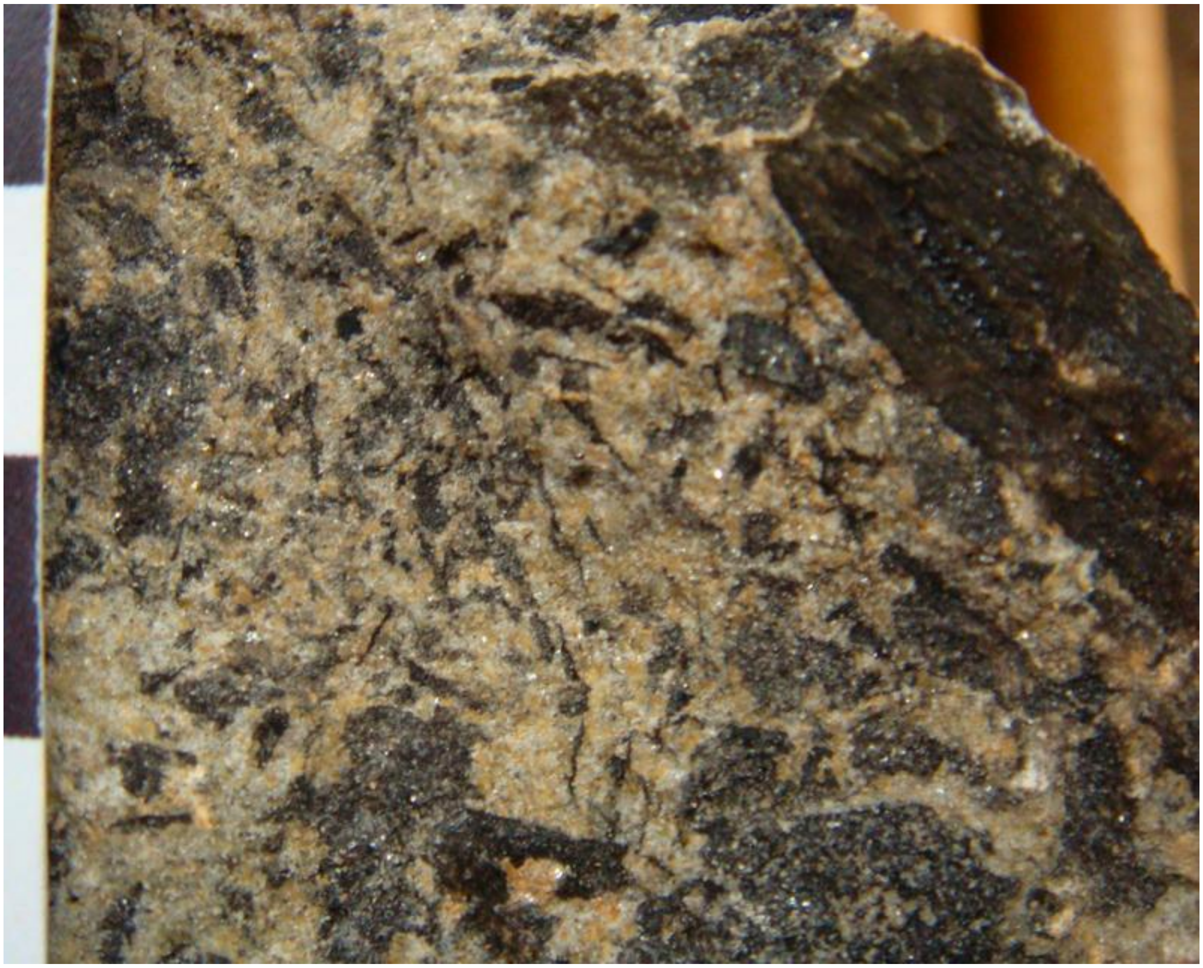


**Figure 4.10 Larger organic fragments at depth of 2745' seen directly down hole from the pebble conglomerate. Scale is in cm.**

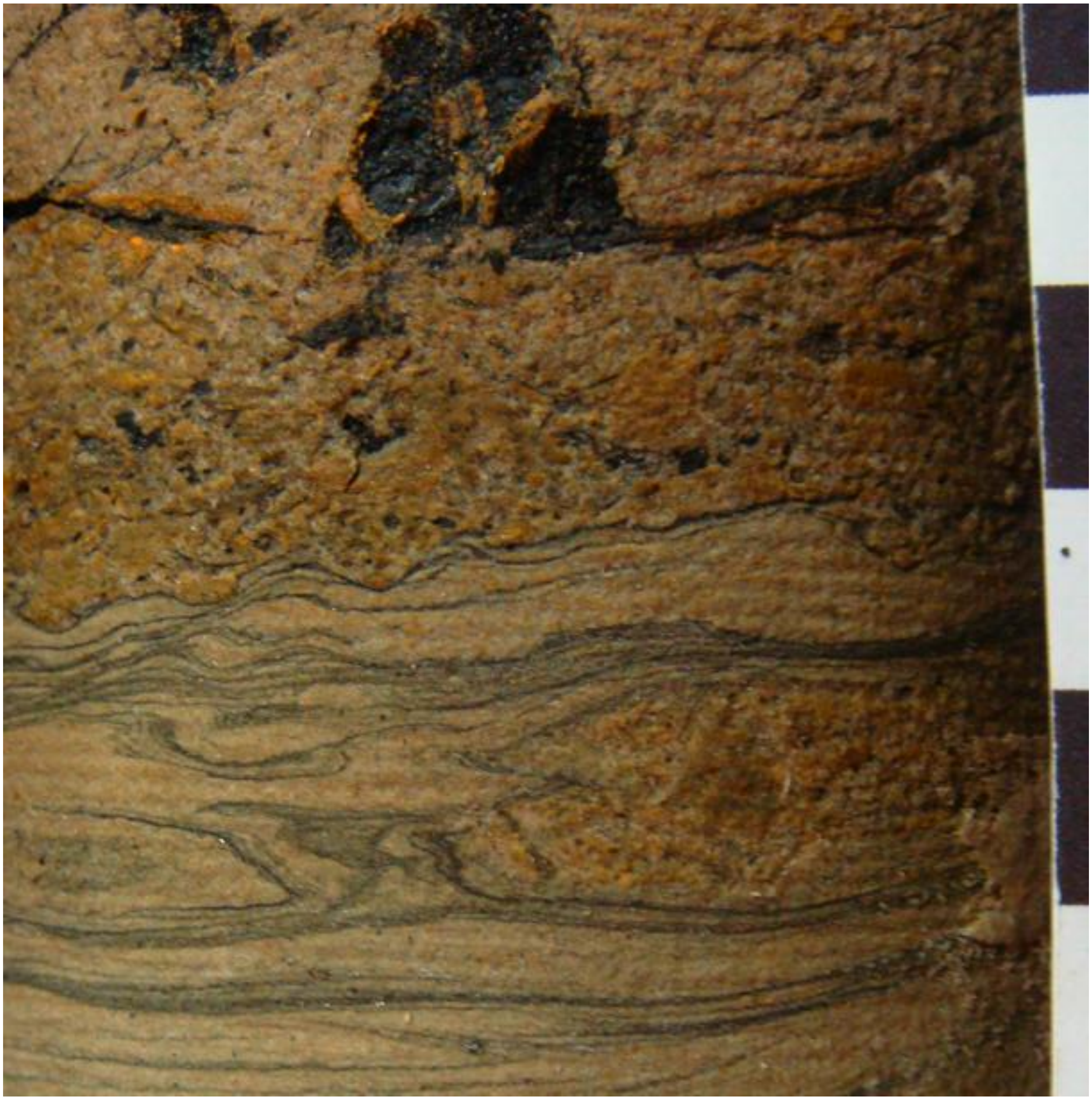


**Figure 4. 11 Showing greatly changing flow conditions. Coarse sand, including large organic fragments overlying very thin shale laminations. From depth of 2747'.**

### *Sun Dickerson #7*

The Sun Dickerson well was drilled in Kay, County. The well was cored through the interval from 2292' to 2378'. The core was split in half for a prior analysis making it very useful for interpretations.

The upper most section of the core from depth 2992' to 2317' consists of interlaminated very fine grained sandstone and shale. The bedding ranges in thickness from 'shoestring' or very thin shales and sands to sand beds showing thicknesses up to 4 cm. Bedding near 2992' starts out as very parallel and then grades quickly to thinly bedded but very affected by soft sediment deformation.

**Figure 4.12 Very thin sand and shale laminations seen at a depth of 2296.5' showing abundant soft sediment deformation.**

As the shale content increases bioturbation and deformation become more prevalent. Flaser bedding and cross bedding are also most common in the upper section of core. From depths of 2308’ to 2312’ sand is more dominant and shale layers increase in thickness, up to 3 cm.

**Figure 4.13 From a depth of 2303’ showing bioturbation and fine scale shale laminations.**

At a depth of 2317’ shale becomes drastically more prominent, in places making up more than 95% of the core. Bedding tends to be very parallel with minor or no deformation present. This continues to a depth of 2328’ with sand content slightly increasing down hole. Siderite is seen giving some shale layers a slightly red hue and also as more rounded reddish clasts. In this interval there is a fissile coal layer approximately 15 cm thick at a depth of 2320.5. After the coal horizon, shale again becomes dominant with minor very red siderite nodules. The shale rich interval fluctuates between a fissle appearance and being massively bedded. Sand laminations become visible at 2327’.

The interval between depths of 2328’ and 2335’ shows an increase in sand content, bioturbation and soft sediment deformation. The soft sediment deformation is most obvious in the load casting structures, flame structures and minor soft faulting.

**Figure 4. 14 Load casting and some flame structures as well as minor soft sediment faulting are all seen at a depth of 2331’ in the Sun Dickenson core.**

The core quickly grades to a very fine sand dominated interval from 2335’ to 2373’. Very little shale is seen throughout this section, if present is usually in discontinuous seams. As depth approached 2373’ the sand is more gray in color, likely due to an overall increase in mud within the system.

From a depth of 2374’ to the base of the cored interval the sedimentary structures and composition are unusually varied. Initially the core is again an interlaminated sand and shale displays wavy to flaser bedding some slight pillow structures to load casting features are also seen.  This abruptly grades into a very coarse sand and clast conglomerate.   Clast sizes are quite variable in the conglomerate, ranging from approximately 2 cm at the largest to millimeter size. Clasts were not analyzed for composition, but it was noted that some were soft enough to be easily scratched with a nail.   The cored interval stops in the conglomeratic interval

**Figure 4.15   A sample of the conglomeratic interval at the base (2378’) of the Sun Dickerson core.**

### *Earlsboro Oil & Gas Corp. Curtis-Stark # 1*

The Curtis-Stark well was completed on July 23, 1970 to a depth of 5552 ft in Woods County. The cored interval studied extends from a depth of 5054’ to 5113’. All but the lower 10 feet of the core has been cut into slabs making interpretations easier. The lower 10 feet remain as whole core.

The upper most section of core is actually part of the Haskell Limestone that then grades upwards to very black shale. This unit is a dense variegated brown fossiliferous algal brownstone that grades to a sand dominated limestone (Fies, 1988). Fossils seen in the section include crinoids, brachiopods and rugose corals. The coral is only seen in the top of the section and is generally larger, reaching .5 inches in length, and nearly whole. As you increase in depth fossils decrease and become more fractured. For approximately 1-2 inches above the lower contact, at 5058’, the fossil amount again increases.

The core displays predominantly similar features from 5058’ to 5070’. Wavy interlaminated shale sandstone dominated the sedimentary fabric. Flowage and flame structures and load cast deformation are present across interval. Sandstone beds reaching a maximum thickness of about 1.5’ feature abundant flaser bedding. Trough cross bedding is common throughout the unit.

A fine-grained sandstone with shale flasers is present from approximately 5073’ to 5075’. Shale becomes less common and is seen in much thinner beds than in previous sections of the core.

Strata from 5075’ to 5090’ consists of a thin sandstone beds interrupted by wavy to horizontally laminated shale layers. The sands are dominantly fine grained with some small scale trough cross bedding. Deformation features are not extensive through the section. Minor flowage and convolute bedding with slight load casting is present. Few flame structures are also seen.

The interval from approximately 5090’ to 5010’ is mainly a horizontally laminated dark sandy shale unit. Flowage and load casting features are seen, but are generally not prevalent. Minor bioturbation is seen scattered throughout the section.

The lowermost section of the core from approximately 5101’ to 5113’ is comprised of thinly bedded pinstripe dark brown-black shale. There are no sediment deformation or bioturbation seen in this interval. The contact with the overlying sediments is generally gradational.

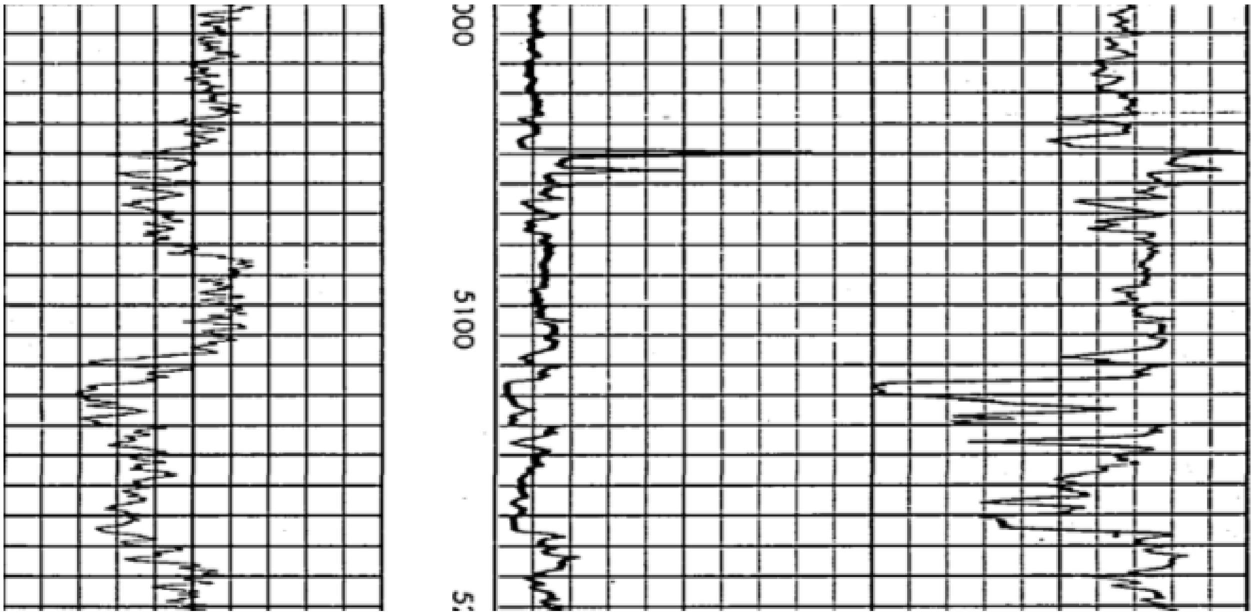


**Figure 4.16 Electrical log profile through cored section of the Earlsboro well. The electrical log does not show the small-scale heterogeneities seen within the core.**

# DISCUSSION

There are several reasons to believe the Tonkawa sandstone has been deposited in an environment affected by both fluvial and estuarine forces. Sedimentary structure interpretation was the main characteristic examined when looking for possible depositional environments for the Tonkawa Sandstone. Sand geometry and petrology were also reviewed.

## Sand Geometry

The Tonkawa sandstone is generally thickest at the zone about 70-150 feet below the Haskell marker. Sandstone units seen directly above this zone are not seen to exceed five feet in thickness and add little to the net-sandstone thickness. In the southern extent of the study are the sands display a predominantly northeast to southwest trend that vary in width from one to four miles wide. Overall the Tonkawa interval shows a gradual thickening to the south and southeast. Variation in thickness of the sandstone is attributed to the underlying sandstones and shales. Net-sandstone thicknesses range from 0 to just over 50 feet in Dewey County. Single sandstone bodies are on average not seen to be more than 35 feet thick. Tonkawa interval thickness vary throughout the study area and are thinnest, at approximately 150 feet in the northwest, as a carbonate bank lithology seems to become present.

Sheet like geometries are seen throughout the study area. Yet, overall the Tonkawa Sandstone tends to be elongate and lenticular. Sheet geometries have led some to interpret the Tonkawa as having a marine interpretation (Fies, 1988). Distributary mouth bars that have coalesced often times will generate this characteristic. Slight slope angles and a low tidal input are also capable of producing this type of deposit (Coleman and Prior, 1982). A more thorough analysis of changes within the thickness of the sheet like sands shows that they too have a more subtle northeast-southwest orientation. This is further indication of a northeast source area.

Electrical logs show basal contacts that are primarily gradational, with few sharp contacts suspected in the eastern portion of the study area. Isopach mapping indicates lateral contacts are both sharp and gradational.

## Internal Sedimentary Structures

Common sedimentary features seen within the Tonkawa sequence include, interstratification of sandstone and shale, horizontal laminations, medium and small scale cross-bedding, soft sediment deformation features, slightly inclined bedding, sideritic or intraformational clasts and few burrows.

Soft sediment deformational features are likely due to quick and at times turbulent, flow. These features are only seen in the interstratified zones and predominately shaley zones. Irregular laminae and flame structures are most common. Small rip-up clasts, slumps and ball and pillow structures are also seen within the Tonkawa Sandstone. Rip up clasts are more common within intervals with a higher siderite component.

Interstratification is most common where there is a strong increase in shale content. This may be due to the variability in deposition when there is an influx of shale. Lenticular and horizontal laminations, flowage structures and minor cross-bedding is commonly seen.

Burrowing was not common throughout the core, although a highly bioturbated section is seen in the northern extent of the study area.

Shale beds within the Tonkawa are usually thinly laminated and silty. Beds tend to split on clay draped bedding planes, which are often heavily micaceous. In some intervals very thin organic rich shales locally containing wood or plant fragments occurred. In several intervals they are seen to be fissile. Sandstones are more likely to be massively bedded.

Grain size within the Tonkawa tends to be well sorted ranging from a coarse silt to a fine sand, and is dominated by the fine sand component. Vertical variations of grain size exist throughout the core and both fining upwards and coarsening upwards sequences are seen. Individual grains are subangular to subrounded, and the sandstone can be classified as mature.

Observations including the interbedding of terrigenous and marine sediments indicate that both fluvial and marine forces generated the depositional environment seen. The overall lack of burrowing indicates rapid deposition. Smaller fining upwards laminations within overall coarsening upwards packages suggest that the depositional environment was controlled by sediment influx and water depth (Walton and Griffith, 1983). Laterally changing conditions in marine margin environment are probably the cause of the depositional features observed and described in literature. Overall rapid sediment accumulation created a progressive environment.

# Modern Analogs

When examining sedimentary structures to determine the depositional environment it is helpful to look at modern analogs that produce similar features. DeBoer (2009) looked at sedimentary structures in the Cook Inlet, Alaska. He examined structures seen on the surface of mud flats and tidal bars.

Tidal events will commonly deposit thin laminae of a fining-upward sediment. High-energy flood created by rising tides will erode, transport then first deposit sand particles. The tidal energy eventually decreases until reaching high stand settling out the finer sediments of mud and clay (DeBoer, 2009).

Biogenic structures are rare in sediments that experience a high rate of deposition.

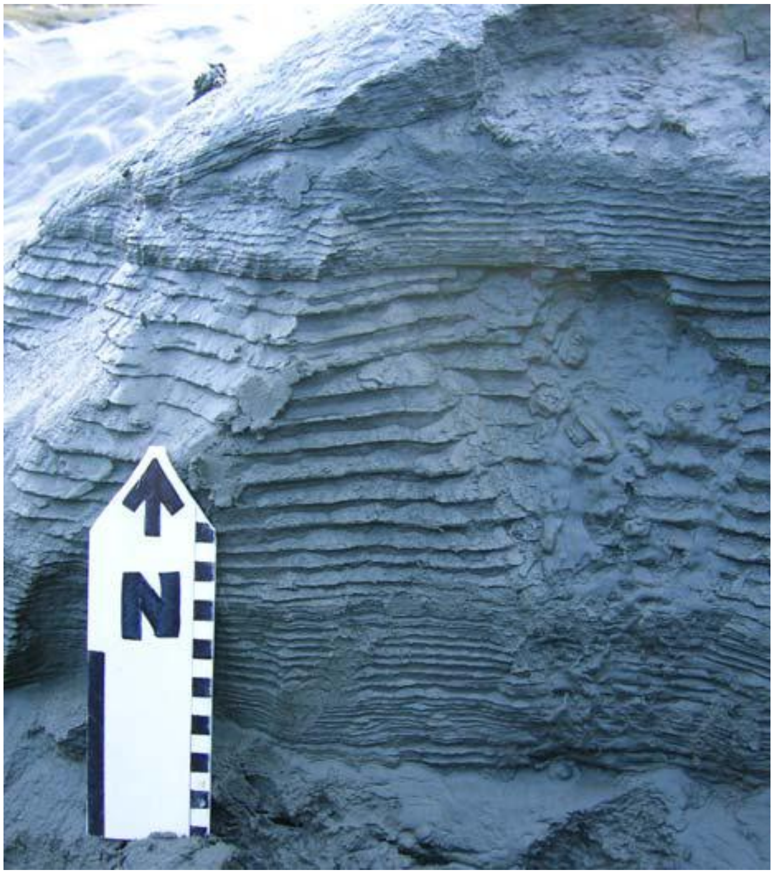


**Figure 5. 1 Rhythmite section from Glacier Creek. Scale is cm on the right side of the arrow (DeBoer, 2009).**

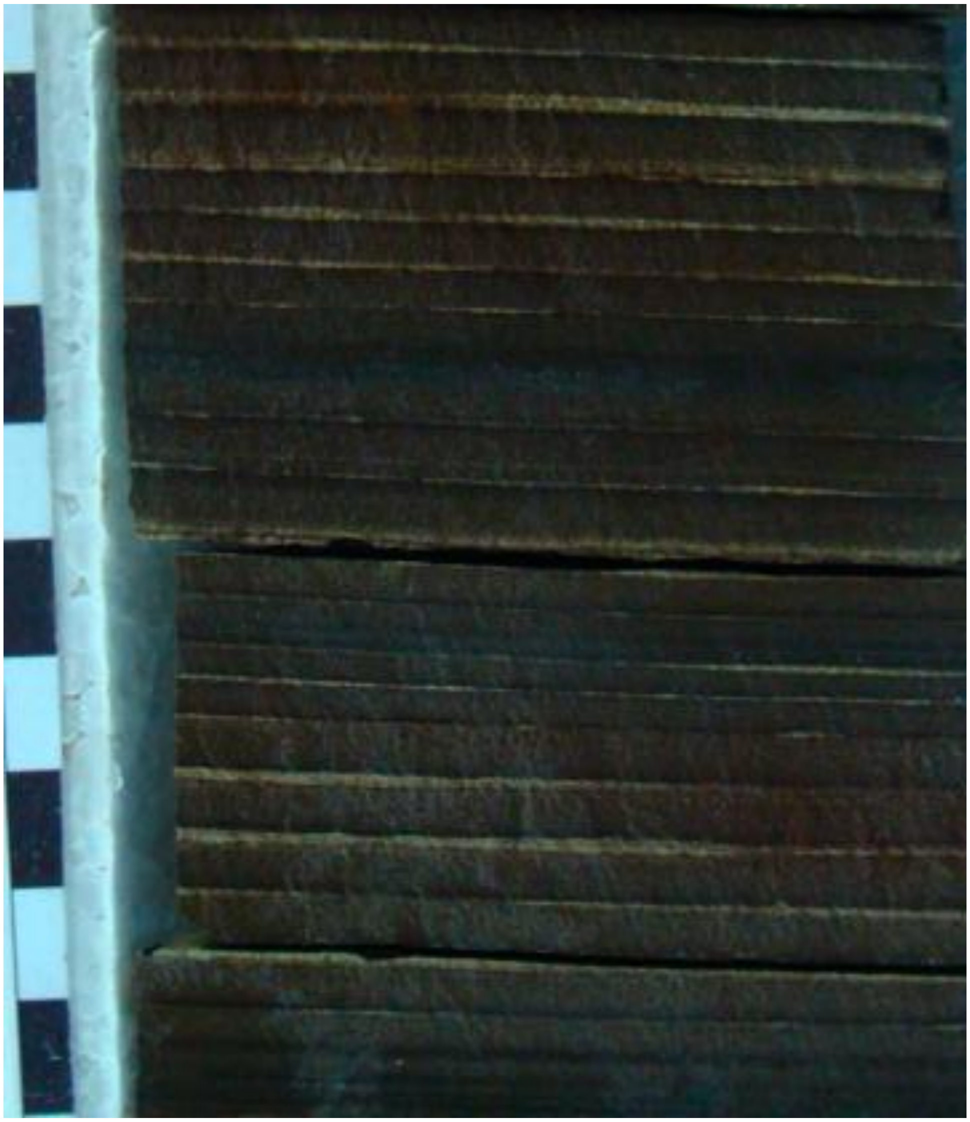


**Figure 5.2 Sun Dickenson at a depth of 2318’.**

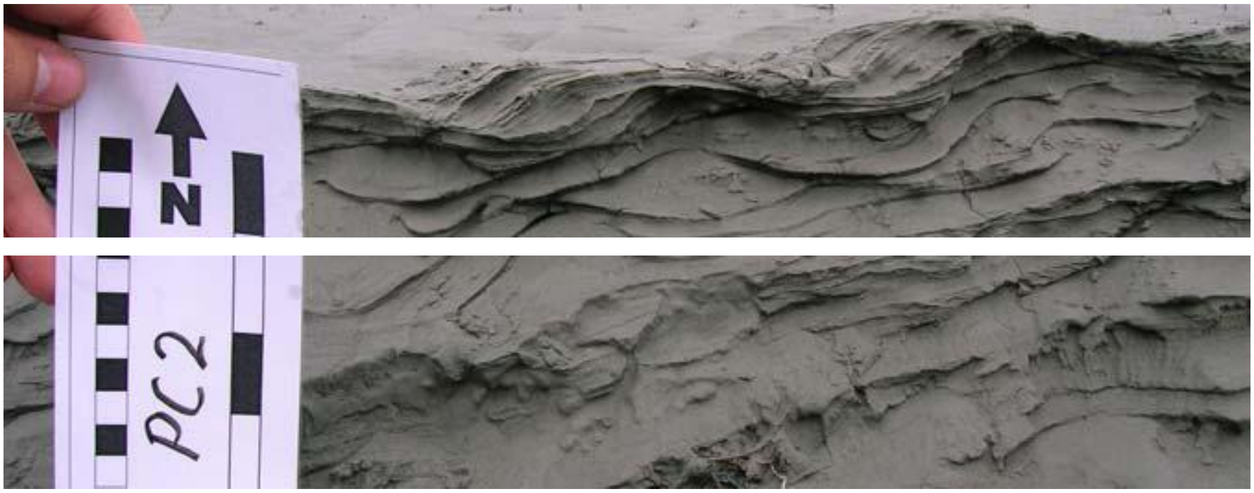


**Figure 5.3 Climbing ripples seen in Cook Inlet (DeBoer, 2009).**

**Figure 5.4 Wavy laminations in the Sun Dickenson well at a depth of 2374'.**

**Figure 5.5 Soft sediment deformation at a cut bank in Glacier, Creek, Cook Inlet, AK. Flow rolls and flame structures overlying undeformed sediment (DeBoer, 2009)**

**Figure 5.6 Wavy to flaser bedding overlain by soft sediment deformation and horizontal laminations with load cast structures seen in Sun Dickenson at a depth of depth 2304'.**

Ripples on the surfaces of mud bars are only seen when generated by the late ebb flow of a tide. This type of surface may also be the wavy mud drapes that the core will tend to break along.

**Figure 5.7 Asymmetrical lingoid current ripples, shovel is 20 cm at the base (DeBoer, 2009)**

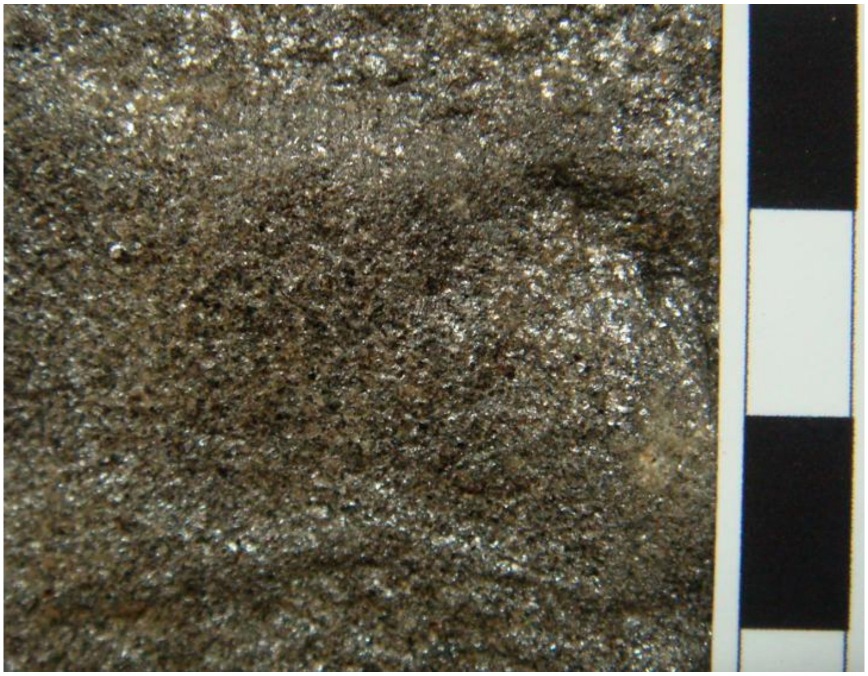


**Figure 5.8 Ripples seen on the bedding plane of the Wessely Ellington core at a depth of 7849’. The bedding planes were heavily micaceous and included darker ‘coffee ground’ organics.**

## Petrology

Several previous works (Fies, 1988; Padgett, 1988; Wiggins, 2004) have included detailed petrology descriptions of the Tonkawa Sandstone. Padgett (1988) created thin sections from cores located in Dewey County and Fies (1988) created several thin sections from cores in Woods and Woodford Counties. Both studies plotted the sandstone as sublitharenite on a Quartz-Feldspar-Rock Fragment ternary diagram.

The Tonkawa interval sandstones are very fine to fine and subangular to subrounded and are generally well sorted. Major constituents within the sands include quartz, rock fragments, feldspars and muscovite. Chlorite matrix occurs in minor amounts. The quartz grains are by far the most abundant and generally monocrystalline. Polycrystalline quartz occurs throughout the core but to a much lesser extent (Fies, 1988; Padgett, 1988; Wiggins, 2004). The most abundant feldspar is altered orthoclase. Less abundant and less altered albite occurs in some cores on the northern shelf (Fies, 1988). Muscovite is abundant throughout the study area. Shale flasers and mud laminations contain the greatest concentration of the accessory mineral. Minor accessory minerals include biotite, chlorite, chert and zircon. The originial detrital matrix is predominantly chlorite, although most was replaced or removed after burial (Fies, 1988; Wiggins, 2004). Rock fragments are seen in several cores and have been identified by Fies as being of both metamorphic and sedimentary origin. Metamorphic clasts included phyllite and schist. Illitic mudstone occurred as rip up clasts and was usually deformed due to compaction (Fies, 1988).

Glauconite found in trace amounts and the abundance of fossil fragments in several abbreviated sequences suggest a partial marine influence. The abundance of carbonaceous material within some sequences is suggestive of a nearby terrigenous source. Small coal chips and wood fragments were visible in minor amounts in some sandstone beds. Organic material is almost always associated with an increased mud content, usually with mud drapes or flasers.

Authigenic constituents and porosity were also analyzed by Fies, Padgett and Wiggins. The study by Wiggins is outside of the current study area. The most common diagenetic product is calcite. It is found in poikilotopic masses and is the major constituent in the pore space (Fies, 1988; Padgett, 1988). Siderite is seen in all cores described. Larger masses occur as flattened spherical shapes varying greatly in size in sand dominated intervals. The siderite cement occurs in pore spaces as rhombic crystals. Silica cement appears to have formed early in the diagenic process as quartz overgrowths. Chlorite is commonly seen as a pore-lining authigenic clay.

Kaolinite is observed as a pore-filling clay and is seen locally to replace orthoclase (Padgett, 1988). Pyrite, usually associated with organic matter, is seen in thin section throughout all samples taken by Fies and Padgett. Pyrite will form in anaerobic conditions when organic material is abundant (Hinshaw, 1997).

Porosity in the Tonkawa Sandstone varies considerably throughout the study area (Padgett, 1988). This is likely due to the complex geometries and heterogeneities of the interstratified shales and sands. Porosities are significantly lower where carbonate acts as the pore-filling cement. Higher porosities are generally found in the southern extent of the Anadarko Basin (Rotterman, 1997). There are only minor amounts of primary porosity remaining within the sands with the majority of porosity being solely secondary (Fies, 1988). Evidence from the precipitaion of quartz overgrowths, carbonate and pyrite indicate that intergranular porosity has been significantly reduced (Leder and Park, 1986).

## Proposed Depositional Environment

The Tonkawa Sandstone is interpreted as a tidal dominated delta to estuarine environment. The estuarine environment is more prominent when an overall transgressive period is present. Lower sections of the Tonkawa Sandstone interval may be interpreted as a fluvial dominated deltaic system.

Sedimentary features seen in the cored intervals are not indicative of a shallow marine offshore bar or barrier bar environment. Soft-sediment deformation structures imply sediment loading, slumping, and movement, which are usually linked with rapid deposition and instability (Padgett, 1988).

Padgett described a core from Dewey County as representing the extreme distal portions of a second delta lobe. The core, Farris #2-2, contained thinner sandstones displaying intraformational clasts, horizontal laminations and massive and small-scale cross bedding. In the same core the Haskell Limestone is interpreted as a shallow open-marine transgressive event.

On the northern shelf of the basin the sonic potential curves are often not well developed. The gamma ray curve was used as a sufficient substitute.

## Relationship to the Tonganoxie Sandstone

The Tonganoxie Sandstone of eastern Kansas and the Tonkawa are both found in the Douglas Group at similar stratigraphic levels. This makes correlation between the two seem natural. The Tonganoxie Sandstone was deposited in a northeast to southwest trending paleovalley that had been filled during a transgressive period in the Virgilian. Outcrop exposures in eastern Kansas of the Tonganoxie allow for extensive sedimentary structure analysis.

Tonganoxie strata examined by Lanier et al. (1993) were found to have characteristics of a tidally influenced environment. Lanier described submillimeter thick normally graded rhythmites with ripple and cross laminated intervals and draped laminations.

Previous interpretations have interpreted the Tonganoxie as a fluvial dominated deltaic system, but closer examination has yielded a more tidally influenced depositional environment. This history of varied interpretation is similar to the Tonkawa sandstone.

The Tonkawa sandstone trends from northeast to southwest, this leans toward the idea that the sediments came from an area to the northeast of the study area. The Tonganoxie has been discussed as being related to the Tonkawa (Lins, 1950; Winchell, 1957) and therefore is believed to be a main transport source.

The Tonganoxie and Tonkawa are both located just beneath the Haskell limestone and display similar characteristics. Both are generally recognized as a very fine to fine grained, sometimes heavily micaceous sandstone. The sedimentary structures seen in both units are similar.

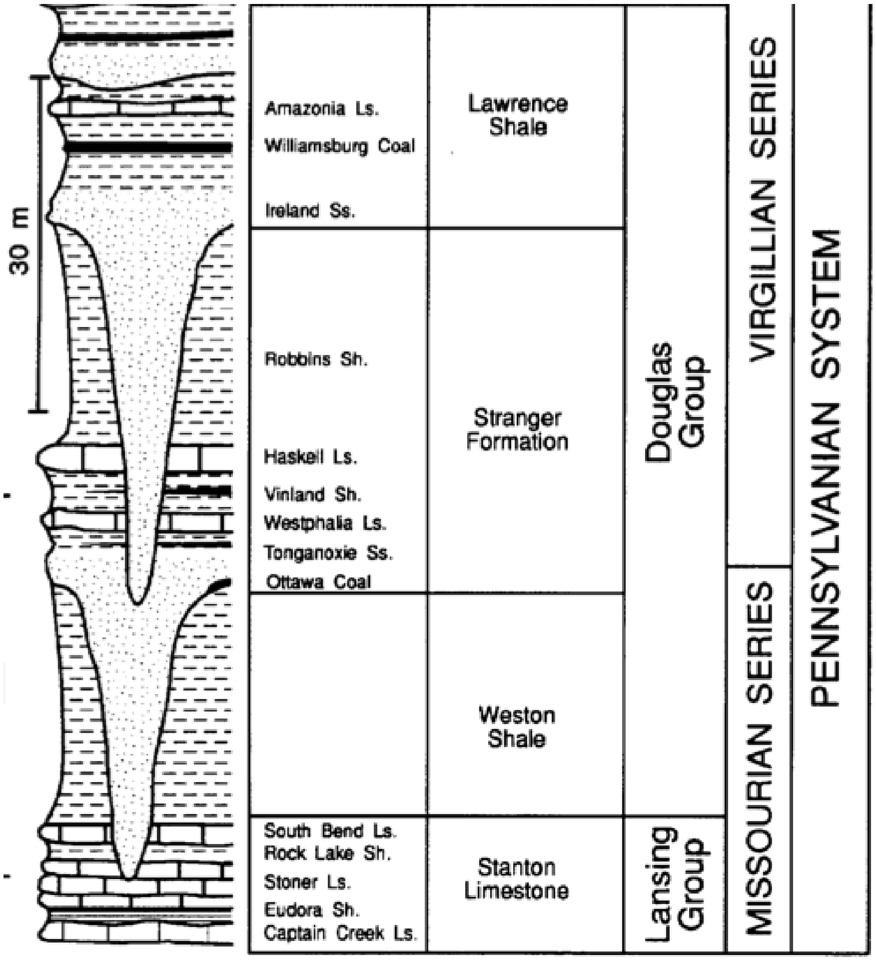


**Figure 5.10 Idealized stratigraphic section including the Douglas Group in Kansas. The Tonganoxie Sandstone in Kansas and the Tonkawa Sandstone in Oklahoma are stratigraphic equivelents.**

# CONCLUSION

The primary purpose of this study was to determine a depositional environment based principally on sedimentary structures seen in core data in a large study area encompassing much of northwest Oklahoma. The Tonkawa Sandstone was determined to have been deposited in an estuarine environment with both fluvial and tidal forces affecting sedimentation. A gradual transition may be seen throughout the region from the Tonganoxie outcrops in northeastern Kansas to the extreme southwestern extent of the study area. The Tonkawa Interval is the lowest transgressive-regressive package within the Douglas Group of the Virgilian Series of Pennsylvanian age.

Core data proved to be the most useful, as they are the only way to look at the very fine scale laminations and features characteristic of tidal energies. Electrical logs are best for correlating sand intervals across long distances and for looking at trends in overall deposition. Although the detailed core descriptions only represent a small fraction of the regional study area, the interpretations can be projected for the interval.

Previous studies have narrowly focused on possible predominantly fluvial or deltaic forces to create the broad sedimentary sequence seen in the midcontinent. Examining smaller scale details within this sequence provides a more broad range of depositional environments.

# References

Adler, F. J., 1971, Future Petroleum Provinces of the Midcontinent, region 7; in, Future Petroleum Provinces of the United States- Their Geology and Potential, I.H., Cram, ed. V. 48, p. 1,568-1,580.

Andrews, R.D., 1997, Fluvial-Dominated deltaic (FDD) oil reservoirs in Oklahoma: Oklahoma Geological Survey, Special Publication 97-3, p. 1-11.

Andrews, R.D., and N.H. Suneson, 2002, Interpretation of depositional environments of the Savanna Formation, Arkoma basin, Oklahoma, from outcrops and surface and subsurface gamma-ray profiles: OGS Oklahoma Geology Notes, v. 62, p. 4-18.

Ball, S. M., 1964, Stratigraphy of the Douglas Group (Pennsylvanian/Virgilian) in the northern Midcontinent region: Ph.D. dissertation, University of Kansas (Kansas Geological Survey Open-file Report 64-1)

Boyd, D. T., 2002, Oklahoma Natural Gas, Past, Present and Future. Oklahoma Geology Notes, v. 62, n. 4.

Boyd, D. T., 2008, Oklahoma 2007 Drilling Highlights; Oklahoma Geological Society Shale Shaker, March-April 2008.

Busch, D. A., 1974, Stratigraphic Traps in Sandstones- Exploration Techniques; AAPG Bulletin, v. 55, p. 1137-1154.

Campbell, J.A., 1997, The Tonkawa play: Regional geology: Oklahoma Geological Survey, Special Publication 97-3, p. 13-27.

Chenoweth, P. A., 1979, Geological Prospecting for Mid-Continent Sandstones; in Hyne, N. J., Pennsylvanian Sandstones of the Mid-Continent; Tulsa Geological Society Special Publication No. 1, p. 13-33.

Clark, G.C., and Aurin, F.L., 1924, The Tonkawa field, Oklahoma: American Association of Petroleum Geologists, v. 8, no. 3, p. 269-283.

Coleman, J. M., and Prior, D. B., 1982, Deltaic Environments of Deposition; in Scholle, P. A., and Spearing, D., ed., Sandstone Depositional Environments; America Association of Petroleum Geologists Memoir no. 31, p. 139-178.

Dalrymple, R.W., Knight, R. J., Zaitlin, B. A., and Middleton, G. V., 1990, Dynamics and facies model of a macrotidal sand-bar complex, Cobequid Bay-Salmon River estuary (Bay of Fundy): Sedimentology, v. 37, p. 577-612.

Dalrymple, R. W., Zaitlin, B. A., and Boyd, R. (1992) Estuarine facies models: Conceptual basis and stratigraphic implications., J. Sedimentology. Pertol., v. 62, p. 1130-1146.

Darling, T., 2005, Well Logging and Formation Evaluation, Gulf Drilling Guides. Elsevier. pp. 326.

DeBoer, D. G., 2009, Deposition and preservation of estuarine sediment, Turnagain Arm, Cook Inlet Alaksa, Kansas State University unpublished MS Thesis.

Ethridge, F. G., 1992, Core Descriptions: Part 5 Laboratory Methods *in* Development Geology Reference Manual, AAPG Special Publication. pp. 198-200.

Emery A. F., 2002, Transgressive-Regressive (T-R) Sequence Stratigraphy *in* Proceedings of the 22nd Annual Bob F. Perkins Research Conference, Society for Sedimentary Geology, p. 151-172.

Feldman, H. R., Gibbling, M. R., Archer, A. W., Wightman, W. G., and Lanier, W. P., 1995, Stratigraphic architecture of the Tonganoxie paleovalley fill (Lower Virgilian) in Northeastern Kansas: AAPG Bulletin, v. 79, no. 7, p. 1019-1043.

Fies, M.W., 1988, Depositional environments and diaganesis of Tonkawa format (Virgilian) in Woods and parts of Woodward Counties, Oklahoma: Oklahoma State University unpublished MS thesis.

Gibbons, K. E., 1962, Pennsylvanian of the North Flank of the Anadarko Basin; Oklahoma Geological Society Shale Shaker, v. 12, no. 5, p. 2-19.

Griffith, G. L., 1981, The Tonganoxie Sandstone in Portions of Sedgwick, Butler and Greenwood Counties, Kansas. Wichita State University unpublished MS Thesis.

Heckel, P.H., 1994, Evaluation of evidence for glacio-eustatic control over marine Pennsylvanian cyclothems in North America and consideration of possible tectonic effects: SEPM *Concepts in Sedimentolgy and Paleontology* v. 4, p. 65-87.

Hinshaw, C., 1997, Regional synthesis of marine Tonkawa Sand in the Anadarko Basin: Oklahoma Geological Survey, Open File Report 3-97.

Hosterman, J.F., 1924; The Tonkawa Oil and Gas Field, Oklahoma. AAPG Bulletin, v. 8, n. 3.

Khaiwka, M. H., 1968, Geometry and Depositional Environment of Pennsylvanian Sandstones in Northwestern Oklahoma: University of Oklahoma unpublished PhD Dissertation.

Kumar, N., and Slatt, R.M., 1984, Submarine-fan and slope facies of Tonkawa (Missourian-Virgilian) Sandstone in deep Anadarko Basin: AAPG Bulletin, v. 68, no. 12, p. 1834-1856.

Lane, S.D., 1978, Relationship of the Carbonate Shelf and Basinal Clastic Deposits of the Missourian and Virgilian Series of the Pennsylvanian System in Central Beaver County, Oklahoma: Oklahoma State University unpublished MS thesis.

Lanier, W. P., Feldman, H. R., Archer, A. W., 1993, Tidal Sedimentation from a Fluvial to Estuarine Transition, Douglas Group, Missiourian-Virgilian, Kansas: Journal of Sedimentary Petrology, v. 63, p. 860-873.

Leder, F., and Park, W. C., 1986, Porosity Reduction in Sandstone by Quartz Overgrowth: AAPG Bulletin, v. 70, no. 11, p. 1713-1728.

Lins, T. W., 1950; Origin and Environment of the Tonganoxie Sandstone in Northeastern Kansas; Kansas Geological Survey Bulletin, v. 134, Part 3, p. 125-159.

Lukert, L.H., 1949, Subsurface cross sections from Marion county, Kansas, to Osage county, Oklahoma: AAPG Bulletin, v. 33, p. 131-152.

Moore, R.C., 1964, Paleoecological aspects of Kansas Pennsylvanian and Permian Cyclothems; In D.F. Merriam (Ed.), *Symposium on Cyclic Sedimentation*. Kansas Geological Survey Bulletin, v. 169, no. 1, p. 287-380.

Padgett, P., 1988, Petology, Diagenesis and Depositional Environment of the Tonkawa Sandstone in Southwestern Dewey County, Oklahoma: Oklahoma State University unpublished MS thesis.

Pate, J.D., 1959, Stratigraphic traps along the north shelf of the Anadarko Basin, Oklahoma: AAPG Bulletin, v. 34, p. 39-59.

Rascoe, B., Jr., 1962, Regional Stratigraphic Analysis of Pennsylvanian and Permian Rocks in Western Mid-Continent: Colorado, Kansas, Oklahoma, Texas; AAPG Bulletin, v. 46, no. 8, p. 1357-1370.

Rascoe, B., Jr. and Adler, F. J., 1983, Permo-Carboniferous Hydrocarbon Accumulations, Mid-Continent, USA. AAPG Bulletin v. 67, n. 6, p. 979-1001

Reading, H.G., 1986, Sedimentary Environments and Facies, Second edition, Blackwell Science, Cambridge, MA, pp. 615.

Reineck, H.E., and Singh, I.B., 1975, Depositional Sedimentary Environments, Springer-Verlag, New York, Heilelberg, Berlin. pp. 321.

Rottmann, K., 1997, Geology of the Tonkawa sand reservoir, Blackwell Oil Field: Oklahoma Geological Survey, Special Publication 97-3, p. 29-45.

Serra, O., (Ed.) 1985, Schlumberger Sedimentary Environments from Wireline Logs. pp. 211

Swanson, D.C., 1967, Some Major Factors Controlling the Accumulation of Hydrocarbons in the Anadarko Basin. Oklahoma Geological Society Shale Shaker, v. 13, n. 3.

Walker, R.G., 1975, Generalized facies models for resedimented conglomerated of turbidite association. GSA Bulletin, v. 86, p. 737-748.

Walton, A. W. & Griffith, G., 1983, Deltaic Deposition in the Tonganoxie or "Stalnaker" Sandstone (Stranger Formation, Virgilian): TXO Robinson C-1, Harper Country, Kansas: Kansas Geological Survey Subsurface Series 6, p. 193-215.

Wiggins, C. L., 2004, Distribution, Depositional Environment, and Reservoir Properties of the Pennsylvanian Tonkawa Sandstone in South Peek Field, Ellis and Roger Mills Counties, Oklahoma. Shale Shaker p. 1-21.

Winchell, R.L., 1957, Relationship of the Lansing Group and the Tonganoxie ("Stalnaker") sandstone in South-central Kansas: State Geological Survey of Kansas, B. 127, pt. 4.

Woodroffe, C. D., Chappell, J. M. A., Thom, B. G., and Wallensky, E., 1989, Depositional model of a macrotidal estuary and flood plain, South Alligator River, Northern Australia: Sedimentotoly, v. 36, p. 737-756.

# Appendix A - Detailed Core Descriptions

As each core was examined a detailed Microsoft Excel spreadsheet organized the data. For each foot of core the depth was noted, several estimates about overall core content and a more detailed description were recorded. Exceptions were made when core was very similar for a length of more than one foot, in this case the detailed description encompass several feet.

The percent shale gives an estimate of shale, clay and mud within a core. These were not differentiated due to the difficultly of identifying such small differences in whole and slab core.

## Texas Oil Saylor "A" #1

**TEXAS OIL SAYLOR "A" #1**

| DEPTH (FT.) | % SAND | % SHALE | MICA PRESENT | ORGANICS PRESENT | DESCRIPTIONS |
|---|---|---|---|---|---|
| 7893 | 40 | 60 | Y | N | some shale ends surfaces are very smooth and display not mica or organics and seem harder, not flakey; other shale surfaces are much darker and more micritic with small amounts of organic matter. The bedding is wavy with some disconnected shale pieces in the sand. Sand is light grey to darker when more closely inter-bedded with the shale. Grains are fine. does not react to acid |
| 7895 | 70 | 30 | | | Shales are inter-bedded frequently in the sand. Sand is light and appears in thicker beds, few sideridic appearances in very narrow bands. Some ends look bioturbated, small rounded indentions |
| 7898 | 40 | 60 | | | Shale increases as you move up box, some beds are 4 cm thick, upper section seems to have more parallel bedding, lower in box bedding is slightly wavy and very small slump/load cast structures can be seen in areas where there are more sand and thinner beds of shale. |
| 7901 | | | | | Sand increases still light grey color fine grained sand. Shale bedding is flaser and noncontiguous in areas max shale bed is 1 cm. |
| 7904 | | | | | Lots of soft sediment deformation in areas with more shale (sanded section) some minor |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | bitoturbation or small load casting. Sections with more massive sandstone bedding, with minor amounts of shale in either small flaser chunks or very thin laminations |
| 7907 | | | | | Mainly sand with a few (1-2) beds of thicker (1.5-2cm) shale/mudstone. Caps of thicker shale/mudstone have small pitted surface. Sand does not fizz |
| 7910 | | | | | Shale increases as you go down hole. Sand is similar to above. Shale laminations generally increase as you go down hole. Some are flaser and there are very small crossbreds. Caps may be slightly bioturbated |
| 7913 | | | | | Shale increases significantly, mainly planar laminations. When sand is present it is darker and muddy. |
| 7917 | | | | | Quickly changes back to nearly all sand. Sand is light in color and fine to slightly med grained. Core breaks along very thin and flakey shale (coal?) layers, these also can contain a lot of mica |
| 7920 | | | | | Box is very similar to #9 mainly sand little to no shales if present they are very thin laminations. |
| 7923 | | | | | Box starts very similar to # 9 & 10 shale becomes more present down whole several beds that are 1-2cm in thickness display wavy bedding. There are several very thin layers that have wispy laminations. Size and abundance of organics increase |
| 7927 | | | | | Base sand looks similar to boxes 9 & 10 maybe slight increases in amount of shale/mud within the sands. Also several very small sideridic clasts appear. Going down whole shale significantly increases sand within the shale beds is slightly darker, wavy bedding. nothing fizzes |
| 7930 | | | | | Mainly sandstone end caps are heavily micritic some have larger (2-3mm) pieces of organics, few thicker shale/mudstone beds. Planar to wavy bedding |
| 7933 | | | | | shale is slightly red when it occurs in mainly sand section, where more shale is present shale beds vary in thickness from thin (1-2mm) to 1.5 cm bedding is planar to slightly wavy some minor soft sediment deformation and slight bioturbation or load casting |
| 7936 | | | | | base is more sandy with thin shale laminations soft sediment deformation and load casting, shale |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | greatly increases and sand only occurs in small lens or wavy laminations |
| 7942 | | | | | some ends are much darker and more flakey, others look more like mudstones and are smooth with an hummocky overall surface laminations are wavy and vary in size |
| 7956 | | | | | starts out with more shale but quickly changes to nearly all light grey fine grained sand for about a foot, the sand does seem to have more darker flecks. In sands there are several very round sideridic clasts. Down hole become more shale rich with wavy laminations and small load casting. picture form down hole |
| 7948 | | | | | base looks similar to down hole of 18, quickly changes again to very sandy with many sideridic clasts; nothing fizzes |

## WESSELY ENERGY CORP. ELLINGTON #1-35

Core is split from 7844' to 7874'. Whole core is interpreted from 7874' to the base.

| DEPTH (FT.) | % SAND | % SHALE | MICA PRESENT | ORGANICS PRESENT | DESCRIPTIONS |
|---|---|---|---|---|---|
| 7844 | 95 | 5 | Y | | Light gray, well sorted fine grained. Few small (<.25in) siderite clasts. Some muscovite seen on end caps of core. No shale laminations. |
| 7845 | 40 | 60 | Y | Y | Shale content significantly increases, with some shale beds being greater than 1 in. Planar to lenticular bedding. |
| 7847 | 50 | 50 | Y | Y | Shale laminations up to .25 in. Bedding is generally planar with some sand lenses. Some soft sediment deformation is seen. End caps are heavily micritic with some visible organic material. Thicker shale-free sand beds are also seen. |
| 7849 | 60 | 40 | Y | Y | Shale beds vary from >1 inch to flaser bedding. Slumped sand and shale. Sand creates bulbous depressions into the shale. Minor amount of organics seen. |
| 7850 | | | Y | Y | Abrupt change from slumped shale and soft sediment deformation to generally clean sand. Sand size is variable ranging from very fine to medium-fine. |
| 7851 | 95 | 5 | Y | Y | Sand is generally uniform. Little to no shale, if present seen as mud flecks. Some very small siderite clasts are seen. |
| 7852 | 95 | 1 | Y | | Several large siderite clasts occur, with an abrupt wavy contact with the sand. Mud occurs as very thin flaser laminations; some look flakey as if a coal lamination. |
| 7854 | 95 | 1 | Y | | Very similar to what is seen above. Few larger mud clasts. |
| 7855 | 50 | 50 | Y | | Shale occurs in planar to lenticular bedding, in some areas separated by string sands. Flaser bedding is also present in laminations dominated by sand. End caps are undulating lightly micritic. |
| 7857 | 95 | 1 | Y | | Sand with minor amounts of flaser bedding. End caps are heavily micritic. |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 7859 | 95 | 1 |  |  | Generally clean fine-grained sand. Minor flaser bedding, few very small mud and sideritic clasts. |
| 7861 | 90 | 1 |  |  | Increasing sideritic clasts within the sand. Clasts vary in size and shape from very small to > 1 in long and from flattened to more spherical. Minor amount of flaser bedding seen. |
| 7862 | 90 | 1 |  |  | Core is similar as above to 7865' |
| 7865 | 85 | 15 |  | Y | Shale is present as laminations at most 1 cm thick. Some display light load casting features. Most of the core has separated along bedding planes. |
| 7867 | 70 | 30 | Y | Y | Thin flakey darker layers are likely coal. Organics are visible along bedding planes, several pieces are large. Thinner shale laminations are present. |
| 7868 | 80 | 20 | Y |  | Thin shale beds, some small-scale cross bedding present. Flaser bedding with some separated mud FLECKS. Shale has a red tint (SIDERITIC?) in some areas. Minor ripples. |
| 7870 | 85 | 15 | Y |  | Very thin flaser bedded shales and mud drapes. Thicker (>.5cm) wavy sideritic laminations. Sand is still fine to very grained. |
| 7871 |  |  | Y |  | Similar as above. Mica content on bedding planes varies dramatically. Generally there is little to no organic material. |
| 7873 | 60 | 40 | Y | Y | Shale beds vary from nearly horizontal to slightly dipping. Ripples, load casting, some soft sediment deformation and flaser bedding are seen. Bedding planes are undulating and generally micritic. |
| 7874 | 40 | 60 | Y | Y | Shale and sand interactions similar as above. Some organic material seen on bedding planes. |
| 7876 | 10 | 90 | Y | Y | Much thicker shale sequence separated by generally paper thin sands. Bedding planes are heavily micritic and some larger carbonaceous material is seen. |
| 7878 | 20 | 80 |  |  | Planar shale laminations are separated by thin sands (no greater than 1 cm). Minor soft sediment deformation is seen. |
| 7880 | 30 | 70 | Y | N | Fine-grained sand with few sideritic clasts. Dark shale horizontal laminations, with some small sand lenses. Bedding planes are uneven and show minor mica content. Minor burrowing possible. |
| 7881 | 90 | 5 | Y | Y | Light gray fine sand with very dark flaser carbonaceous material. COAL DRAPES? Increasing sideritic material occurs as sub round to slightly flattened clasts. Several mud FLECKS present. |
| 7883 | 95 | 1 |  |  | Massive sand sequence, with few mainly flattened |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | sideritic clasts. Very minor carbonaceous lamination. |
| 7884 | 90 | 10 | | | Mostly fine sand. Several thin shale or carbonaceous seams. Bedding planes are undulating and fairly micritic. |
| 7886 | 80 | 20 | | | Abrupt change from slumped shale and soft sediment deformation to generally clean sand. Sand size is variable ranging from very fine to medium-fine. |
| 7888 | 90 | 10 | Y | Y | Mostly fine sand. Few small flattened sideritic clasts. Some mud FLECKS. Thin non-continous shale laminations. Minor organics. |
| 7889 | 5 | 90 | Y | Y | Predominantly inter-bedded shale and dark sand/siltstone. Laminations are generally horizontal, several are more lenticular. Little to no mica or organic material present on bedding planes. Some evidence of burrowing. In areas where sand in more dominant flaser bedding is present. |
| 7890 | 10 | 90 | Y | Y | Core is similar to the base. The core is not split; therefore interpreting sedimentary structures is difficult to impossible. |

## Pam Oil Shrimp

**PAM OIL SHRIMP**

| DEPTH (FT.) | % SAND | % SHALE | MICA PRESENT | ORGANICS PRESENT | DESCRIPTIONS |
|---|---|---|---|---|---|
| 2300 | 60 | 40 | Y | Y | Clean very fine light gray sand, inter-bedded with generally thin shale layers |
| 2303 | 80 | 20 | Y | Y | Sand continues to be very fine grained, shale bedding is not abundant. End caps display coffee grain organics and some larger plant like pieces. |
| 2306 | 85 | 15 | Y | Y | Very little micas intermingled within the sands and organics are sparse. Sands continue to be very clean. Slight shale bedding, wavy to flaser in areas |
| 2309 | 85 | 15 | N | N | End caps do not show mica organic material. Shale is seen in hairline thin strands, mostly parallel some more flaser |
| 2312 | 70 | 30 | Y | Y | Shale occurs in thicker, but still less than 1cm layers and is becoming more fissile. End caps are generally shale dominated and if not show mud flakes, coffee grain organics and are slightly micritic. |
| 2315 | 90 | 10 | Y | Y | Core is fine sand, becoming more micritic. End caps display mud chips that are contain organic material. Mud chips can also be seen within the sand intervals. |
| 2318 | 80 | 20 | Y | Y | Shale content increases and is seen in thin horizons causing the core to be more fissile. End caps are shale dominated. |
| 2321 | 85 | 15 | Y | Y | End caps are heavily micaous. Shale layers increase in thickness but still do not exceed 1 cm. Very fissile- some areas have split like notebook pages. Still very sand dominated. |
| 2324 | 85 | 15 | Y | Y | Minor coal seams possible, section has been heavily plugged. Mud chips and larger |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | organic materials present. |
| 2327 | 90 | 10 | Y | Y | Shale present at end caps may show some bioturbation or impression markings. Minor mica and organic material present. |

**Core is not continuous**

| | | | | | |
|---|---|---|---|---|---|
| 2689 | 90 | 10 | N | N | Core is similar from very 2689 to 2692, nearly completely sand with no sedimentary structures |
| 2692 | 70 | 30 | N | N | Inclined shale bedding seen. Beds are very thin, and slightly wavy. Slight deformation is present, light load casting. |
| 2695 | 95 | 5 | N | N | Core split along a natural, vertical thin zone of calcite. Sand is very dull gray and fine. |
| 2698 | 98 | 2 | N | N | Sand is very similar for several feet. Clean, light gray in color very minor amounts of shale mixed in |
| 2701 | 95 | 5 | Y | Y | Very minor amounts of mica and shale, with possible organic material present. No bedding features. Mica is also very light in color. Similar to 2708 |
| 2708 | 90 | 10 | Y | N | Another thin vertical zone of calcite is seen creating a fracture within the core. Shale appears in very thin sub mm thick layers. These layers then to be very fissile and paper like. End caps are moderately micritic but no coffee grain organics are seen. |
| 2711 | 98 | 2 | N | N | Zone of sand similar to those seen above. Little to no shale content, no sedimentary features. |
| 2715 | 95 | 5 | Y | Y | Thin layers of very dark paper-like shale. Layers are parallel to slightly wavy. Mica is prevalent along with very fine grained coffee grain organics. |
| 2718 | 85 | 15 | Y | Y | Mostly sand interlaminated with thin shale layers. Shale horizons display parallel bedding and contain some larger organic fragments. |
| 2721 | 85 | 15 | Y | Y | Organic fragments become increasingly larger, some up to a cm in thickness. Sand intervals are micritic. Bedding features become present. Shale displays flaser and |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
|  |  |  |  |  | cross bedding, possibly climbing ripples. In parts shale is in paper-like sheets. |
| 2724 | 90 | 10 | Y | Y | Thinly interlaminated sands and shale. Shale layers are mm scale and parallel. |
| 2727 | 85 | 15 | Y | Y | Organics are again larger in size, up to 1 cm thick, although most are smaller. Sand is still very fine grained and fairly micritic. Organics are interspersed within sand layer. Rounded mud chips? Are also present. Similar to 2733' |
| 2733 | 80 | 20 | Y | Y | Horizons of increased shale content, with shale appearing in parallel beds. Core is broken along very thin possible coal seams. Coffee grain organics are predominant in sandy zones, possible woody structures identified. |
| 2736 | 95 | 5 | Y | Y | Clean sand little to no organics or shale bedding. |
| 2739 | 95 | 5 | Y | Y | Sand zones become dominant, core breaks along shale surfaces, most are heavily micritic. Organics have significantly decreased in size. No indication of sub parallel bedding features. |
| 2742 | 95 | 5 | Y | Y | Interesting horizon approximately max. 5 cm thick of pebble conglomerate. Clasts are rounded some elongate and hard. Matrix supported. Further down core abundant organic material, some obviously woody fragments within the sand. Little to no shale bedding. |
| 2745 | 80 | 20 | N | Y | Coal seams inter-bedded with coarsening sand. Coal seams in some area create pockets of sand. Shale is also seen in layers sometimes up to 2-3cm thick displaying wavy, flaser and cross bedding. Where shale occurs in hair like strands it is often very convolute. |
| 2748 | 70 | 30 | Y | Y | Shale occurs in very thin fissile, paper like sheets as well as thicker more bound layers. In horizons of increased shale content, climbing ripples, cross bedding and load casting are all seen. Organics are very fine grained occurring where shale is more fissile. |
| 2751 | 60 | 40 | Y | Y | End caps have broken along wavy bedding planes or possible mud drapes. Little mica or organics are present. Mud drapes are |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | common as shale is not continuous, flaser bedding is common. |
| 2754 | 40 | 60 | N | N | Dense shale beds become more common, as do sedimentary structures. Flaser and cross bedding are common in the interlaminated zones. Some climbing ripples are also seen. Very convolute and slumping structures are seen within isolated intervals. Impression structures, possible scour marks are also seen. |

# Sun Dickerson # 7

**SUN DICKERSON # 7**

| DEPTH (FT.) | % SAND | % SHALE | MICA PRESENT | ORGANICS PRESENT | DESCRIPTIONS |
|---|---|---|---|---|---|
| 2292 | 75 | 25 | | | Interstratified sandstone and shale. Sand is very fine grained. Shale occurs in nearly horizontal laminations. Some slight normal grading is present. Sand contains higher mud content. Flaser drapes are also present |
| 2293 | 85 | 15 | | | Clean fine sand, some fine shale laminations, mostly all horizontal. One is more inclined and wavy. |
| 2294 | 70 | 30 | Y | | Sand and shale are interstratified; laminations are horizontal and vary in spacing, thickest beds are 1.5cm, thinnest at 3/4cm. Normal grading is seen. Rhythmites? |
| 2295 | 40 | 60 | Y | | Shale becomes more dominant. Nearly horizontal laminations, some minor deformations as convolute bedding. Slightly normal grading. Abruptly changes to a thin (6-8cm fissile very black coal seam. |
| 2296 | 55 | 45 | | | Abruptly changes from black coal to interlaminated and slightly sideritic sandstone and shale. Laminations are very deformed and some slight load casting and soft sediment slumping is seen. |
| 2297 | 35 | 75 | | | Very fine interlaminated sandstone and shales with some sideritic streaking. Laminations show slight soft sediment deformation, but are generally horizontal. |
| 2298 | 20 | 80 | | | Core is shale dominated displaying very fine and horizontal sandstone strings. Very minor load casting and lenticular bedding is seen. |
| 2299 | 15 | 85 | | | Interstratified sandstone and shale with some convolute bedding. Flame structure? Impressions that affect multiple laminations. |
| 2300 | 15 | 85 | | | Similar to above, some laminations are overlain by sideritic clasts, as the shale laminations are a deep red tint. Increasing lenticular bedding. Laminations are on the millimeter scale |
| 2301 | 20 | 80 | | | Laminations increase slightly in thickness, reaching .5cm. Shale dominated and horizontal. Some faint normal grading is seen as well as millimeter scale sand load casting. |

| | | | | | |
|---|---|---|---|---|---|
| 2302 | 50 | 50 | | | Sand content increasing as shale laminations become very thin (sub millimeter). Slight burrowing possible? Faint cross-bedding. Sand eye. |
| 2303 | 40 | 60 | | | Sand increases as approaching 2304. Extreme convolute bedding in a 4cm horizon over flaser bedding. Load casting seen above. |
| 2304 | 70 | 30 | | | Fine sand interspersed with wavy shale laminations and flasers. |
| 2305 | 55 | 45 | | | Light cross-bedding and flasers seen in sand dominated area with some sideritic coloring. As shale increase so does minor load casting |
| 2306 | 30 | 70 | | | Thicker shale beds (2-3cm) between more fine sandy flaser and wavy shales. |
| 2308 | 45 | 55 | | | Horizontal sandy shale laminations. At thin and cm scale. |
| 2309 | 65 | 35 | | | Very sandy shales interlaminated by cleaner fine sands. Laminations are slightly wavy with minor load casting. |
| 2310 | 20 | 80 | | | Sudden increase in shale content, very black with slight sideritic staining. Minor flasers in sand layers. |
| 2312 | 90 | 10 | | | Shale followed by thick sand bed. Very little shale seen only in flaser laminations at the sub millimeter scale. |
| 2314 | | | | | Almost mottled sand and shale leading to vary shale lamations. Shale displays slightly cross bedded and convoluted flasers |
| 2315 | 90 | 10 | | | Very fine sands with sparse wavy shale laminations, showing slight load casting. Hair line cross bedding/mud draping. Sharp erosional contact occurs between 2317' and 2318' |
| 2318 | 5 | 95 | | | Extremely horizontal shale laminations 1-2 cm thick are interlaminated between hairline sands. Slight sideritic coloring |
| 2319 | 10 | 90 | | | Similar to above, with increasing minor load casting and thinning shale beds. |
| 2320 | | | | | Sideridic nodules in thicker shale. Approximately 15 cm thick coal bed. |
| 2321 | 2 | 98 | | | Think shale become more fissile towards 2323'. Maybe hairline fractures. |
| 2323 | 5 | 95 | | | Shale becomes lighter in color. Sideritic staining and sub angular sand nodules. Mud chips may also be present |
| 2324 | 3 | 97 | | | Shale becomes more fissle through 2324' some end caps are flakey. Shale is dark. Possible coal presence? |
| 2326 | 3 | 97 | | | Increasing sideridic presence overlying already present features. Sub millimeter scale interstratification seen with minor deformation. |
| 2327 | 2 | 98 | | | Siderite, some with color lighter near the center, appear as sub round clasts imbedded within dominate shale interval. |

| | | | | | |
|---|---|---|---|---|---|
| 2328 | 10 | 90 | | | Siderite appears in rounded to elongate nodules interfering with the fine scale sand/shale interstratification. |
| 2329 | 20 | 80 | | | Very fine sands and shales interlaminated with slight load casting and burrowing. Sideritic chips and nodules are seen interfering and overlying laminations. |
| 2331 | 40 | 60 | | | Increasing sand content. Abrupt changes from thin horizontal laminations to extreme soft sediment deformation. Light sideritic staining. |
| 2333 | 50 | 50 | | | Increasing soft sediment deformation and bioturbation. Laminations tend to be very fine. |
| 2334 | 95 | 5 | Y | Y | Abrupt change to fine sand. Very minor shale flassers and rounded to elongate mud chips. End caps show some coffee grain organics and mica presence. |
| 2336 | 95 | 5 | | | Very fine sand interspersed minor wavy flaser shale interruptions. Round nodules containing mud and an angular mineral appear. |
| 2337 | 98 | 2 | | | Core is similar to a depth of 2373'. |
| 2373 | 60 | 40 | | | Abrupt change from very fine sand to a wavy interlaminated and flaser sand/shale. Minor load casting is also seen. |
| 2374 | 50 | 50 | | | Strong mixture between wavy and parallel bedding. Flaser shale and minor load casting. |
| 2375 | 70 | 30 | | | Sand bedding becomes thicker up to 2cm with shale also appearing in thicker layers up to approximately 1.5 cm. Flaser bedding also seen. Sharp erosion contact seen with coarse sand down hole. At contact there is a layer of soft sediment deformation including load casting and flame structures. |
| 2376 | 90 | 10 | | | Coarse sand dominates at approximately 10 cm thick section, also possible larger mud chips seen within section. Shale is flakey and has been easily eroded. |
| 2377 | 70 | 30 | | | Again the core changes sharply. Very fine sand interlaminated with shoestring to cm thick shale beds. Abundant soft sediment deformation, mainly load casting. |
| 2378 | | | | | Core ends with coarse conglomerate. Sand becomes very coarse and clasts vary greatly in size, up to approximately 2cm in length. Clasts are generally angular, while smaller clasts tend to be more round. Many clasts seem to be moderately soft, scratched with a file. |

## Earlsboro Oil and Gas Corp. Curtis Stark #1

EARLSBORO OIL & GAS CORP. CURTIS STARK #1

| DEPTH (FT.) | % SAND | % SHALE | MICA PRESENT | ORGANICS PRESENT | DESCRIPTIONS |
|---|---|---|---|---|---|
| 5055 | 0 | 100 | Y | N | Very dark fissile shale. Almost coal like. Becoming more solidified and fossiliferous near 5056. Laminations are horizontal. |
| 5056 | 40 | 60 | | | Black Shale grades into a red-brown variegated sand. Larger fossils are seen in shale, with only smaller more fragmented pieces seen in the sand. Sand is generally fine to very fine. |
| 5057 | 95 | 5 | | | Unstructured sand and including fragmented fossils. Sand becomes more uniform with few fossils. Smaller fossils increase for about two inches at the base. Abrupt change to interlaminated shale at 5058. |
| 5058 | 50 | 50 | | | Horizontal laminations of shale varying in thickness from 2cm to paper thin. A sand BURROW? Cuts through several layers. Some small cross bedding is seen and flaser laminations. Sand is lighter in color than above, but still fine grained. |
| 5059 | 70 | 30 | | | Shale layers become less frequent and more grouped. Laminations are wavier than above. |
| 5060 | 50 | 50 | | | Shale laminations are wavy to horizontal, Some cross and flaser bedding seen. Shale layers near the base have a distinct red tint. |
| 5061 | 60 | 40 | | | Much of the 5061' interval is missing. Thinner shale layers with some flaser bedding and mud FLECKS. Load casting structures. |
| 5062 | 70 | 30 | | | Wavy shale laminations, some through cross bedding and load |
| 5063 | 85 | 15 | | | Sand bed approximately 20 cm thick. Thin shale laminations at the base. |
| 5064 | 85 | 15 | | | Wavy shale laminations and flaser bedding. Some |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | flowage structures. |
| 5065 | 70 | 30 | | | Wavy to horizontal laminations. Some trough cross bedding and load casting structures. |
| 5066 | 40 | 60 | | | Shale bedding is generally horizontal with some lenticular sands. Flaser and trough cross bedding are seen. |
| 5067 | 30 | 70 | | | Similar to above. Shale becomes increasingly red near the base. |
| 5068 | 60 | 40 | | | Wavy inclined shale laminations. Flaser bedding, load casting and cross trough bedding seen. |
| 5069 | 45 | 55 | | | Similar to above with increasing shale content. Thicker (4cm) horizontal shale bed at base. |
| 5070 | 80 | 20 | | | Shale becomes very thin and wispy. Cross trough bedding seen. Some load cast structures seen in more red shale towards the base. |
| 5071 | 60 | 40 | | | Thicker sand beds (3-8cm) seen with shale laminations. Thicker sand bed displays mud wisps. |
| 5072 | 60 | 40 | | | Wavy laminations and minor cross trough bedding. Some lenticular mud flecks. |
| 5073 | 70 | 30 | | | Shale laminations with small bulbous sandy features. Grades quickly to mainly sand with thin mud wisps. |
| 5074 | 90 | 10 | | | Generally sand with some very thin mud beds. Load casting and flame features |
| 5075 | 90 | 10 | | | Generally sandy with some larger flame structures near the base. |
| 5076 | 70 | 30 | | | Significant trough cross bedding, some load casting and minor flame structures |
| 5077 | 50 | 50 | | | Horizontal shale laminations over a more sandy sequence with flame structures trough cross bedding and significant load casting. Sideridic clasts and small lenticular sands near the base. |
| 5078 | 90 | 10 | | | Some minor flame structures and load casting in wavy shale laminations. |
| 5079 | 50 | 50 | | | Several small bulbous sideritic clasts. Significant trough crosses bedding in thicker (2-3 cm) sands. Several beds near the base show flowage structures. |
| 5080 | 80 | 20 | | | Trough and planar cross bedding seen. Load casting, pillow and flowage features seen. |
| 5081 | 80 | 20 | | | Similar as above. Two closely spaced thicker (3-4 cm) shale laminations occur. |
| 5082 | 90 | 10 | | | Thin flaser horizontal shale laminations. Trough cross bedding and some CLIMBING RIPPLES? Minor load casting. |
| 5083 | 80 | 20 | | | Cross tough bedding, climbing ripples and some |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
|  |  |  |  |  | flowage structures. |
| 5084 | 50 | 50 |  |  | Horizontal inter-bedded fine sand and shale layers with tough cross bedding. |
| 5085 | 70 | 30 |  |  | Wavy shale laminations over a thicker (10-12 cm) sand bed. Shale laminations display minor load casting and some trough cross bedding. Flame structures and flaser bedding is seen near the base of the section. |
| 5086 | 60 | 40 |  |  | Wavy and inclined beds with some significant load casting and flowage structures. |
| 5087 | 50 | 50 |  |  | Significant soft sediment deformation including load casting, and flame structures. |
| 5088 |  |  |  |  | Wavy shale laminations with some small load casting structures. |
| 5089 | 85 | 15 |  |  | Some trough cross bedding and mud FLECKS. |
| 5090 | 30 | 70 |  |  | Pinstripe shale laminations with some lenticular sands. Where sand is predominant trough cross bedding and light flame structures are seen. |
| 5091 | 10 | 90 |  |  | Sand occurs within shale laminations in lenses and several more bulbous shapes. |
| 5092 | 5 | 95 |  |  | Horizontal shale laminations, with sand occurring mainly in lenses. Little deformation. |
| 5093 | 5 | 95 |  |  | Very similar to above. Some load casting and soft sediment deformation near the base. Core is similar to depth. |
| 5094 | 5 | 95 |  |  |  |
| 5093 | 5 | 95 |  |  |  |