SEQUENCE STRATIGRAPHY AS A CONTROL OF DEPOSITIONAL FACIES IN THE OLIGOCENE VICKSBURG FORMATION, TCB FIELD, KLEBERG COUNTY, TEXAS

By

RYAN EDWARD BIRKENFELD

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Oklahoma State University

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Thesis Approved:

Zuhair Al-Shaieb

Thesis Adviser

Jim Puckette

Darwin Boardman

Alfred Carlozzi

Dean of the Graduate College

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I thank and love my family for their help and encouragement through my college experience. Thank you Dad, Mom, Kristin, Kevin, and Kyle for your unconditional love and support.

Thanks to Brandon and Harriet for being my friends.

Thank you Lord.

DEDICATION

This thesis is dedicated to the memory of Pauletta M. Wilson (March 10, 1918 – August 20, 1995) who was my grandmother and inspiration. She is sorely missed by all who knew her and loved her. My memories of our times together will always be cherished images, and I will take them with me throughout my walks of life. May God bless you

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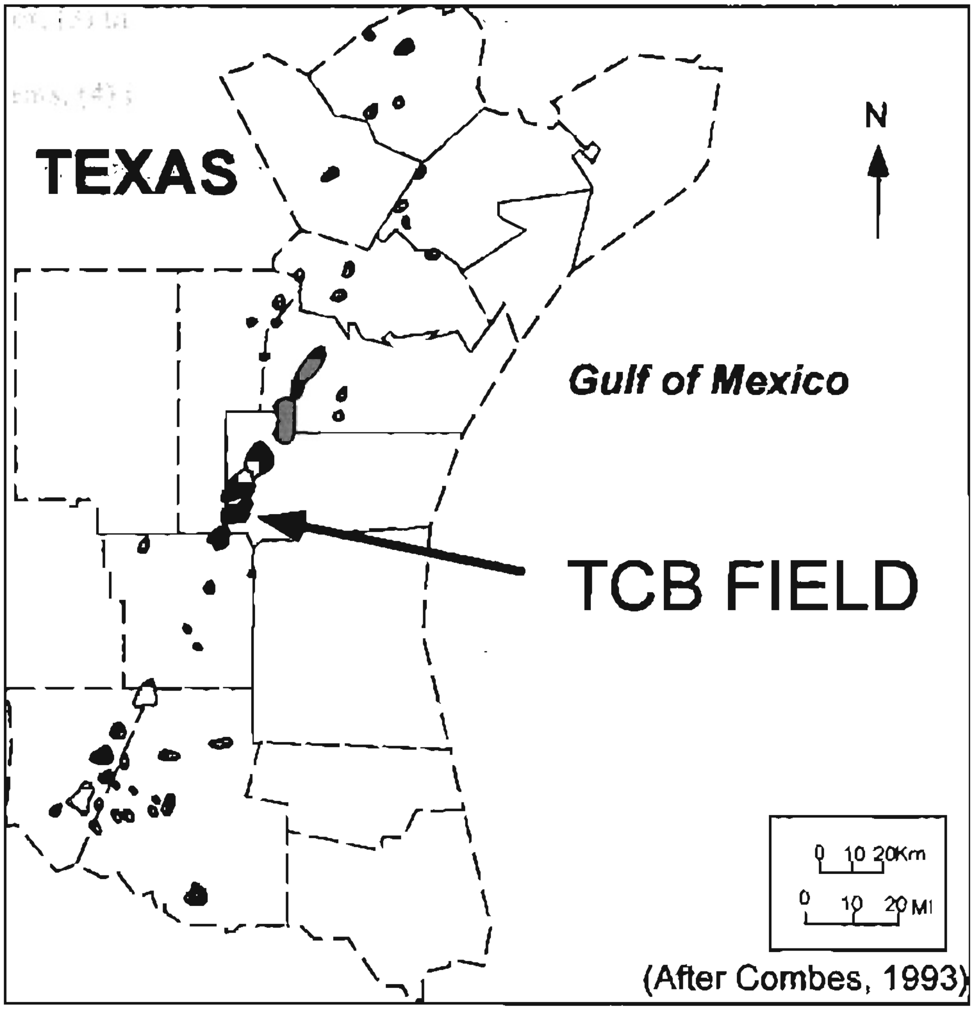
Chapter 1

INTRODUCTION

General Statement

Vicksburg Formation sandstone reservoirs are producers of oil and gas over a large area of the southeastern Gulf Coast of Texas and Louisiana (Taylor and Al-Shaieb, 1986) (Figure 1). The most recent dating of these deposits is 32.8 to 30.3 m.y., which corresponds to the Early Oligocene time (Langford and Combes, 1994). The Vicksburg Formation, an operational name, was deposited unconformably on the Eocene Jackson Formation and lies conformable with the overlying Oligocene Frio Formation above (Coleman, 1990; Han, 1981; Taylor and Al-Shaieb, 1986). The Vicksburg Formation in South Texas, which is the area of interest for this study, consists of deltaic to shallow marine facies that were deposited on an unstable shelf margin. Syndepositional deformation of these deposits was due to growth faulting which developed faulted rollover anticlinal structures. These structures coupled with the stratigraphic variability of the area are responsible for the trapping of hydrocarbons (Taylor and Al-Shaieb, 1986; Winker and Edwards, 1983). A better understanding of the stratigraphic and facies relationships of the Vicksburg Formation in South Texas is needed to optimize hydrocarbon recovery potential of the area.



(After Combes, 1993)

Figure 1. Vicksburg trend of production and location of the TCB field in relation.

The purpose of this study is to (1) form assemblages of lithofacies based on those found in cored intervals of rock, (2) characterize the wire-line log response of these lithofacies, (3) interpret 3-D seismic sections in to sequence stratigraphic depositional components, (4) integrate core based wire-line log lithofacies assemblages and 3-D seismic interpretations with a sequence stratigraphic model to form a sequence stratigraphic interpretation for the Oligocene Vicksburg formation in the TCB field area of South Texas.

Study Area

The Rio Grande Embayment was an active sub-basin for deposition during the Oligocene time. Within this sub-basin lies the focus of this study, the Tijerinia-Canales-Blucher Field. The Tijerinia-Canales-Blucher (TCB) Field is located in the lower Gulf Coast Plain of South Texas in Kleberg and Jim Wells Counties (Figure2). TCB Field has produced in excess of 482 BCF gas and 119 MMBL from the Frio and Vicksburg Formations since its discovery in 1942 (Int. Oil Scouts Assoc., 1997 and Petroleum Information/Dwight's, 1998). The production is from multiple pay zones within the various sandstone packages of the Vicksburg Formation that range in depth from 7800 feet to 11,800 feet (Taylor and Al-Shaieb, 1986).

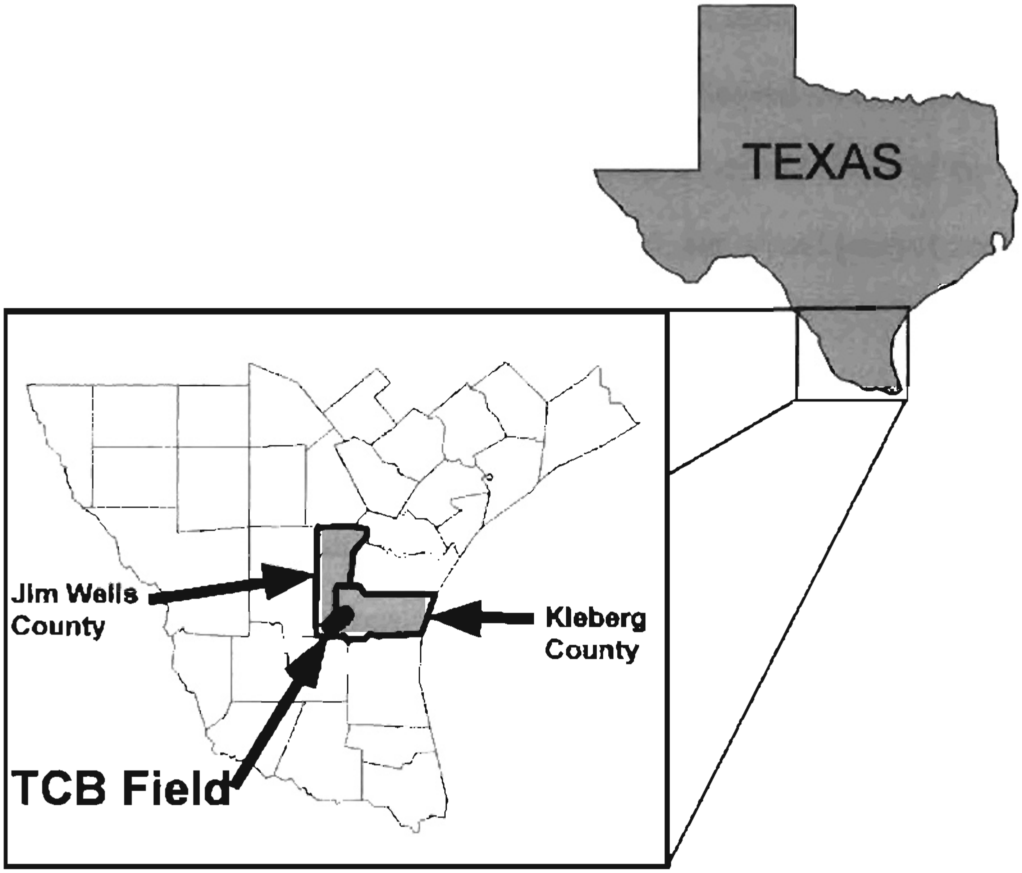


Figure 2. Location of TCB field in Kleberg and Jim Wells Counties, Texas

Previous Investigations

The economics of the Vicksburg reservoirs have made them the focus of much interest. This interest has been translated into numerous studies and investigations of the many structural, sequence stratigraphic and sedimentological characteristics of the formation. Much of the research has been kept proprietary, but several papers have been released pertaining to the Vicksburg Formation in South Texas.

The Vicksburg Formation in the Rio Grande Embayment was deposited in an active growth faulted zone, a study of growth fault characteristics was done by Shelton in 1984. The Vicksburg was deposited in an active zone of syndepositional deformation. The interplay between syndepositional deformation with increase in sedimentation was completed by Diegel and others (1995) and Winker and Edwards (1983). With the introduction and application of Sequence Stratigraphy in the 1970's, the Vicksburg Formation has been studied regionally and locally. Studies by Coleman (1990 and 1993), Coleman and Galloway (1990), Galloway (1989), Posmentier and Allen (1993), Rahmanian and others (1996) and Vail and Wornardt (1990) have given useful interpretations or models to be used for the sequence stratigraphy of the Vicksburg. Taylor and Al-Shaieb (1986) reported the sedimentology and diagenetic history of the Vicksburg Formation in the South Texas TCB field. Research has been done on shelf margin deltaic depositional environments by Coleman and Prior (1982), and studies done within the Vicksburg Formation in other fields south of the area of interest (Combes, 1993; Han, 1981; Langford and Combes, 1994) were used in this study.

Significance of Study

The Vicksburg sandstone reservoirs in South Texas produce oil and gas from many intervals of clean, porous, and highly permeable sandstone (Taylor and Al-Shaieb, 1986). This study describes the depositional environments and sequence stratigraphic interpretations that were derived from core, 3-D seismic data used to produce a shelf margin based sequence stratigraphic model for facies prediction.

The depositional environment interpretation in the TCB field resulted from an interaction between sedimentation and syndepositional deformation at the early Oligocene shelf margin as unconsolidated Eocene shales slid and flowed under Lower Vicksburg formation deposition (Langford and Combes, 1994). Understanding shelf-margin deltaic deposits is economically important because hydrocarbons can accumulate in structural traps developed as a result of the deformation that accompanies deposition. The Vicksburg formation is a prolific source of oil and gas in Texas so comprehending this style of deposition will assist in reservoir prediction in similar geologic settings.

Methodology

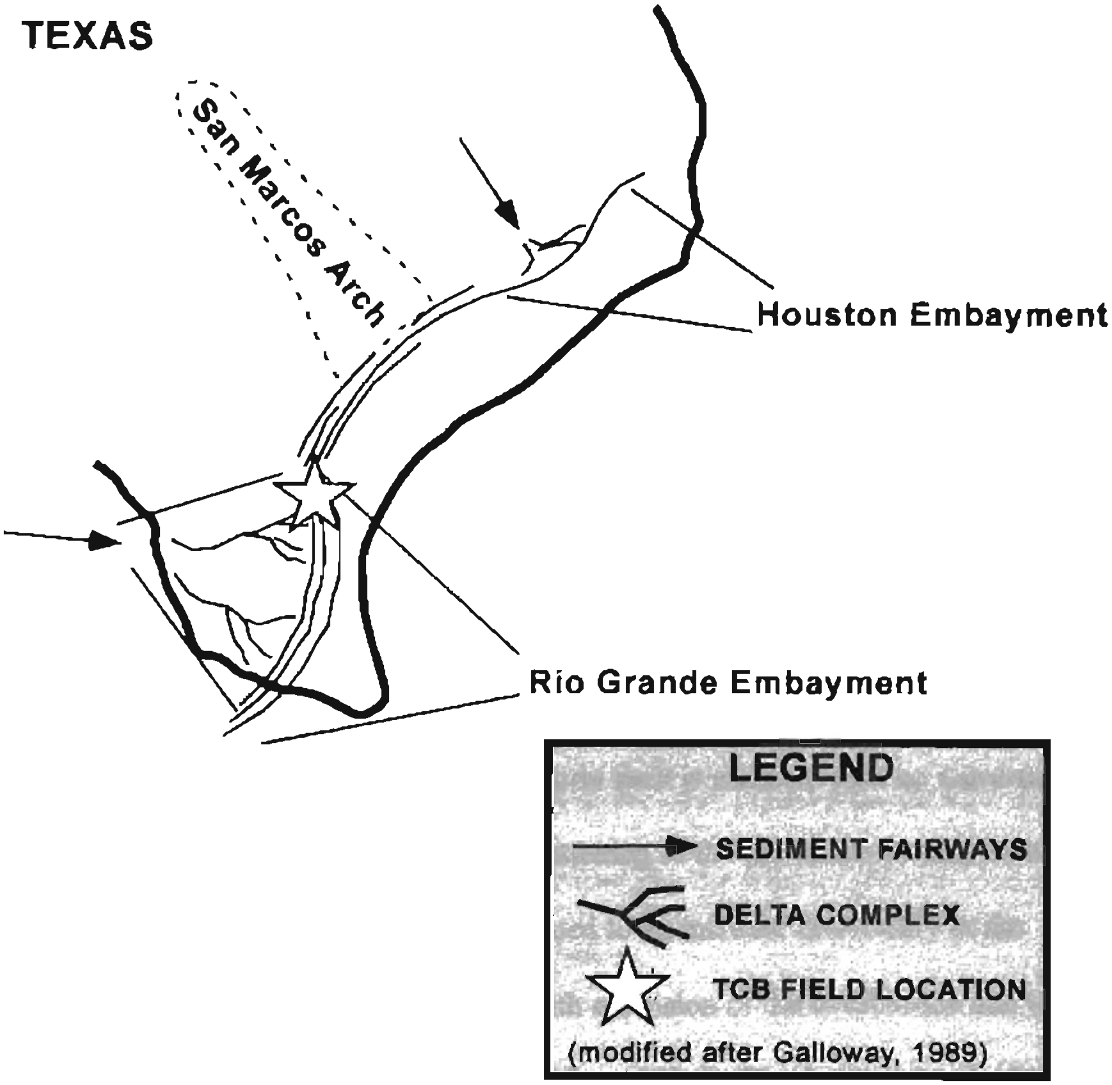
Six cored wells were analyzed to establish the lithofacies and interpret the depositional environments of the sandstone intervals of interest. These Vicksburg sandstone intervals within the TCB field were classified into depositional environments based on criteria from Coleman and Prior (1982) and Langford and Combes (1994). Core analyses were calibrated to corresponding wire-line logs within the TCB field. Well log lithofacies responses were used to interpret sequence stratigraphic depositional histories. Well log data were used to construct isopach maps for the sandstone intervals of interest within the field to establish depositional trends. 3-D seismic data were used to interpret the regional sequence stratigraphy and structural timing within the field. Three isochron maps were constructed using the available seismic data to evaluate the sequence stratigraphy and structure of the TCB field area. Cores, wire-line logs, seismic stratigraphy, isopach / isochron maps were all applied to formulate a working sequence stratigraphic controlled depositional model of the Vicksburg formation in the TCB field.

Chapter 2

GEOLOGIC SETTING

Structural Setting

The Vicksburg formation of the Gulf Coast was deposited during the Early Oligocene. It lies below the Oligocene Frio Formation and above the Eocene Jackson Group. The area along the Gulf Coastal Plain of Texas were the TCB field is located contains three distinct structural features. The first of which is located in the eastern central portion of the state's Coastal Plain. This feature is a sub-basin named the Houston embayment. Moving farther south along the coast is the San Marcos Arch. This feature is a deep-rooted structural nose that provided a stable platform for deposition during the Oligocene. The Rio Grande Embayment is found farther south along the Coastal Plain. This feature is another sub-basin for Oligocene sediment deposition and is the focus of this study. The major difference between the two Oligocene depositional sub-basins is the amount of section expansion. The Rio Grande Embayment contains Vicksburg strata that is expanded more than the Vicksburg strata located in the Houston embayment sub-basin. The rate of sedimentation in the East Texas region was significantly less than that in South Texas. The sedimentation during the Oligocene Vicksburg time is due to a large prograding delta that was located in South Texas and feeding into the Rio Grande sub-basin (Coleman, 1990) (Figure 3).



(modified after Galloway, 1989)

Figure 3. The Vicksburg Depositional System

Faulting played a significant role in the evolution of the Gulf Coastal Plain. Many of the fault systems found in the area was caused by the progradation of sediments over large salt masses causing salt withdrawl induced movement (Diegel, 1995). The salt movement thru time has formed many structural styles of various ages in the Gulf Coast region. In the TCB field area, a non salt based type of fault system is present (Figure 4).

The lower Oligocene Vicksburg Detachment is a shale-based detachment system that can be characterized as containing expanded sequences of sediment that get younger landward. This large shale based detachment is recognized onshore in southern Texas in the lower Oligocene Vicksburg trend and is an example of extreme extension. The oldest units in the Vicksburg were translated horizontally more than 16 km along a fault zone that is 2.4 km in restored width. This amounts in over 600% extension (Figure 5). About 1.2 km of vertical motion occurred during the Vicksburg extension, or 7% of the horizontal extension (Diegel, 1995).

The type of faulting present in the Vicksburg trend is that of listric normal growth faults (Taylor and Al-Shaieb, 1986). A listric fault is characterized by a decreasing angle of dip with depth (Shelton, 1984). The flattening of the dip of the normal faults found in the Rio Grande Embayment can be attributed to an increase in ductility in the sedimentary prism, in this case a shale, with extension of the overburden due to decollement along the ductile horizon (Shelton, 1984). The faults along the Vicksburg trend in the Rio Grande Embayment were active syndepositionally due to rapid sedimentation at the shelf margin on ductile Eocene strata (Winker and Edwards, 1983). The fault systems consist of interconnected faults that generally parallel the present

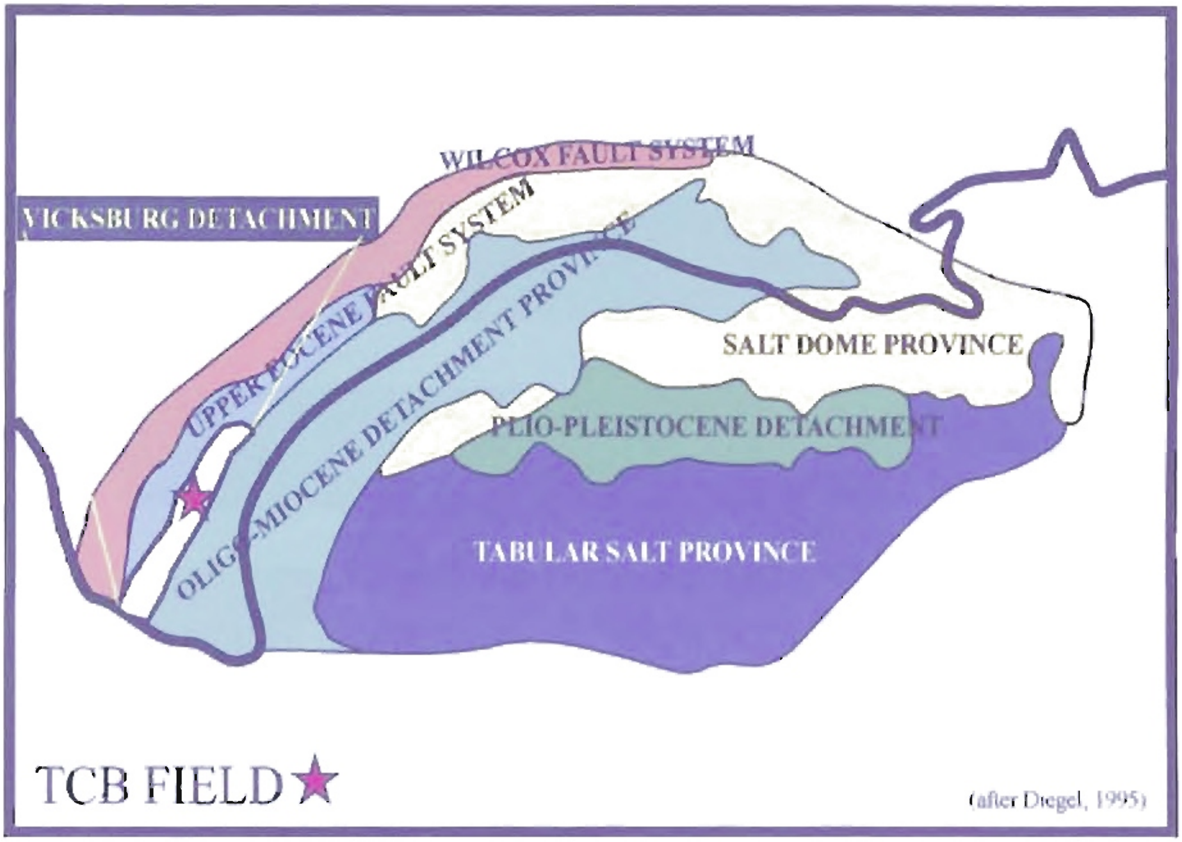


Figure 4. Structural provinces within the Gulf of Mexico Basin, showing the location of the Vicksburg Detachment System and TCB field.

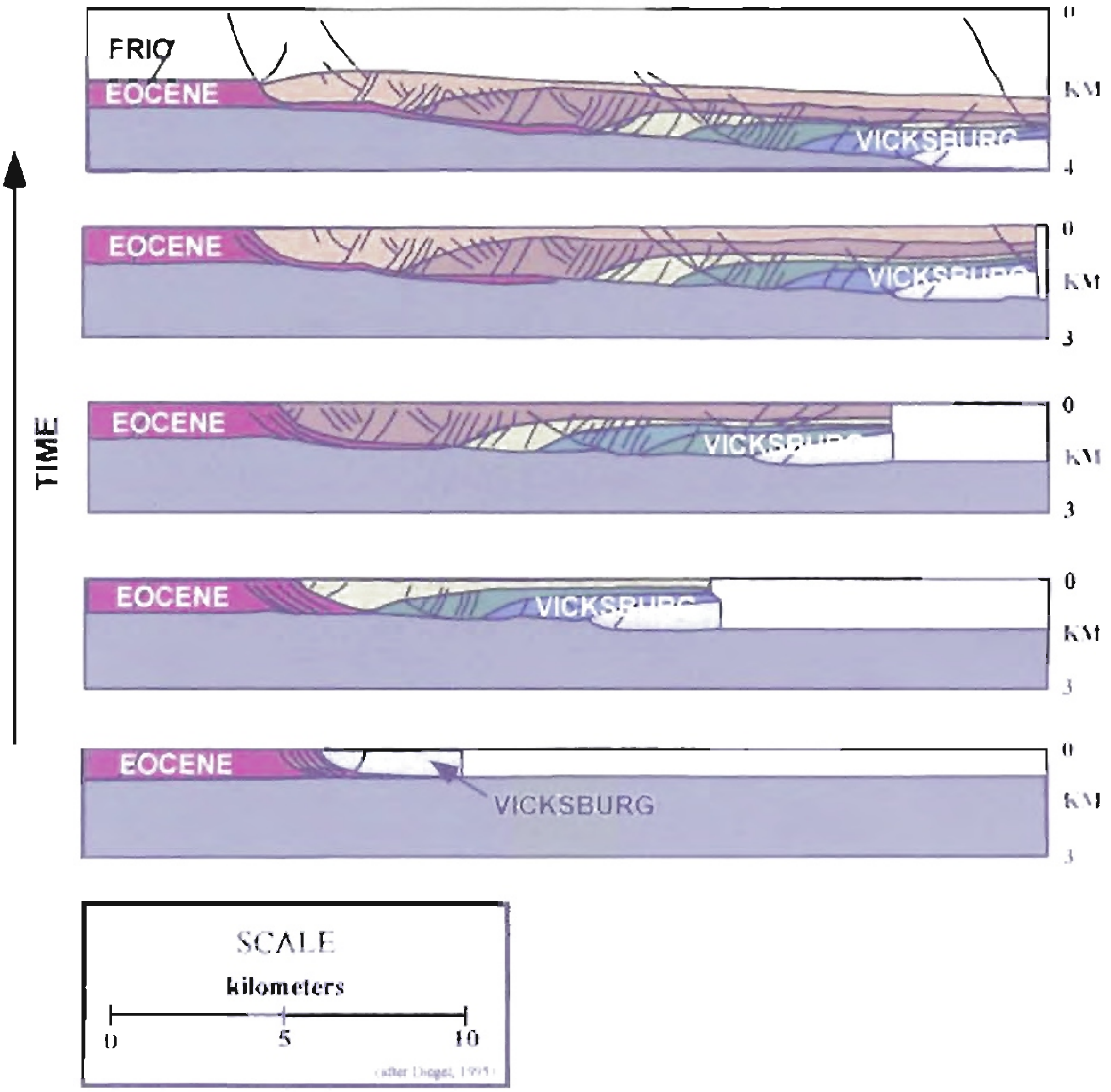


Figure 5. The evolution of the Vicksburg Detachment System through time

coastline and track the shelf margin position at the time of deposition (Winker and Edwards, 1983). This faulting coincided with basinward progradation of the continental shelf margin due to deposition of the lower Vicksburg deltas. The syndepositional movement along the growth faults caused the sedimentary sections to thicken across the fault zones (Combes, 1993) (Figure 6).

A feature associate with syndepositional faulting is that of rollover anticlines (Coleman and Prior, 1982). These features are extremely important to hydrocarbon trapping and are found on the downthrown side of the fault (Coleman and Prior, 1982) (Figure 6). Rollover structures tend to form soon after deposition of sediment on the downthrown side and do not require a considerable amount of overburden and weighting to form. Mass-moved materials flowing from higher levels on the delta front contain high water and gas contents. As the sediment accumulates slightly more thickly on the downthrown side of the fault, early degassing and dewatering take place. Pore water and pore gases escape in the fault area decreasing the volume of sediment and allowing an early change in density to occur nearly contemporaneously with the fault. With greater amounts of sediment added the overburden pressure increases making the fault feature greater and the rollover structure more pronounced (Coleman and Prior, 1982).

Oligocene Tectonics

The Vicksburg sediments of the Gulf of Mexico coastal plain were deposited during the Early Oligocene. It was during the Late Cretaceous and Paleogene that the Gulf Coast Basin assumed its present day configuration. This consisted of the Houston

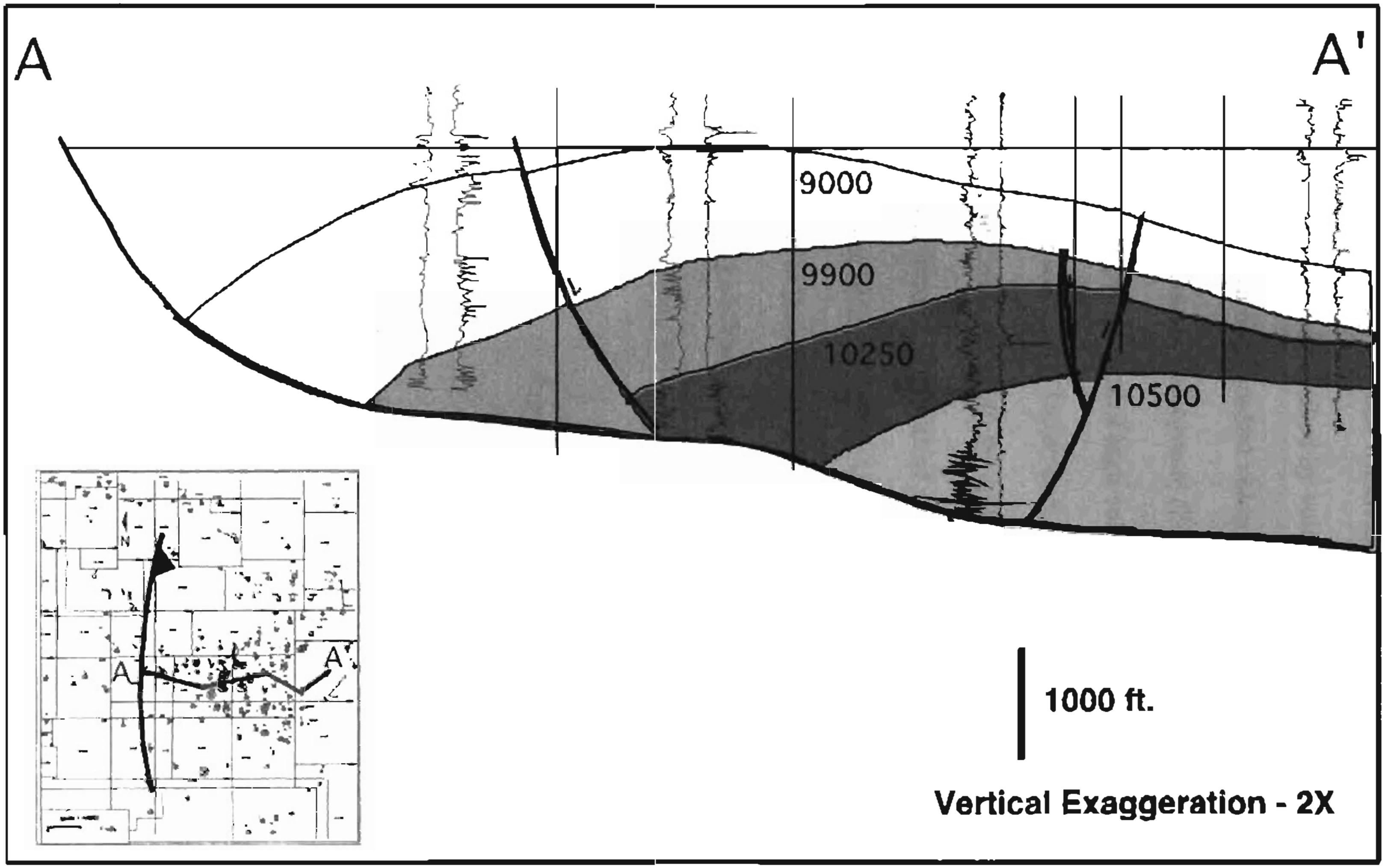


Figure 6. Cross section constructed using well log data illustrating the rollover anticlinal structure and the thickening of sediments along the downthrown side of the TCB field growth fault.

and Rio Grande Embayments separated by the San Marcos Arch. Sediments were deposited in thick sedimentary sections within these sub-basins (Langford and Combes, 1994). The early Oligocene was marked by volcanic activity in West Texas and the Sierra Madres Oriental forming abundant volcanic detritus that traveled into the streams that flowed into the Rio Grande Embayment (Figure 7) (Winker, 1982). This volcanic activity accounts for the provenance of high volcanoclastic lithologies in the Rio Grande Embayment Vicksburg sediments (Taylor and Al-Shaieb, 1986).

According to Coleman (1990) the end of the Eocene was marked by a large unconformity that was formed as a result of a glacially induced sea level drop. This corresponds to the lower boundary of the Vicksburg formation (Coleman, 1990). The overlying Frio was part of the same prograding deltaic system that deposited the upper portions of the Vicksburg sediments; therefore the Vicksburg top is delineated by a paleontological top (Coleman, 1990).

Regional Stratigraphy

The Vicksburg Formation is located as a mappable lithologic unit in many of the Gulf Coastal states from Florida to Texas. It varies in thickness from 100 to 10,000 feet thick along the Gulf Coast, the thickest being in South Texas (Taylor and Al-Shaieb 1986). The Vicksburg does not outcrop in South Texas and occurs only in the subsurface between the Eocene Jackson Group and the Oligocene Frio Formation. Stratigraphic subdivisions in the South Texas subsurface Vicksburg Formation are divided into the Upper, Middle and Lower Vicksburg. The subdivisions of the Upper, Middle and Lower

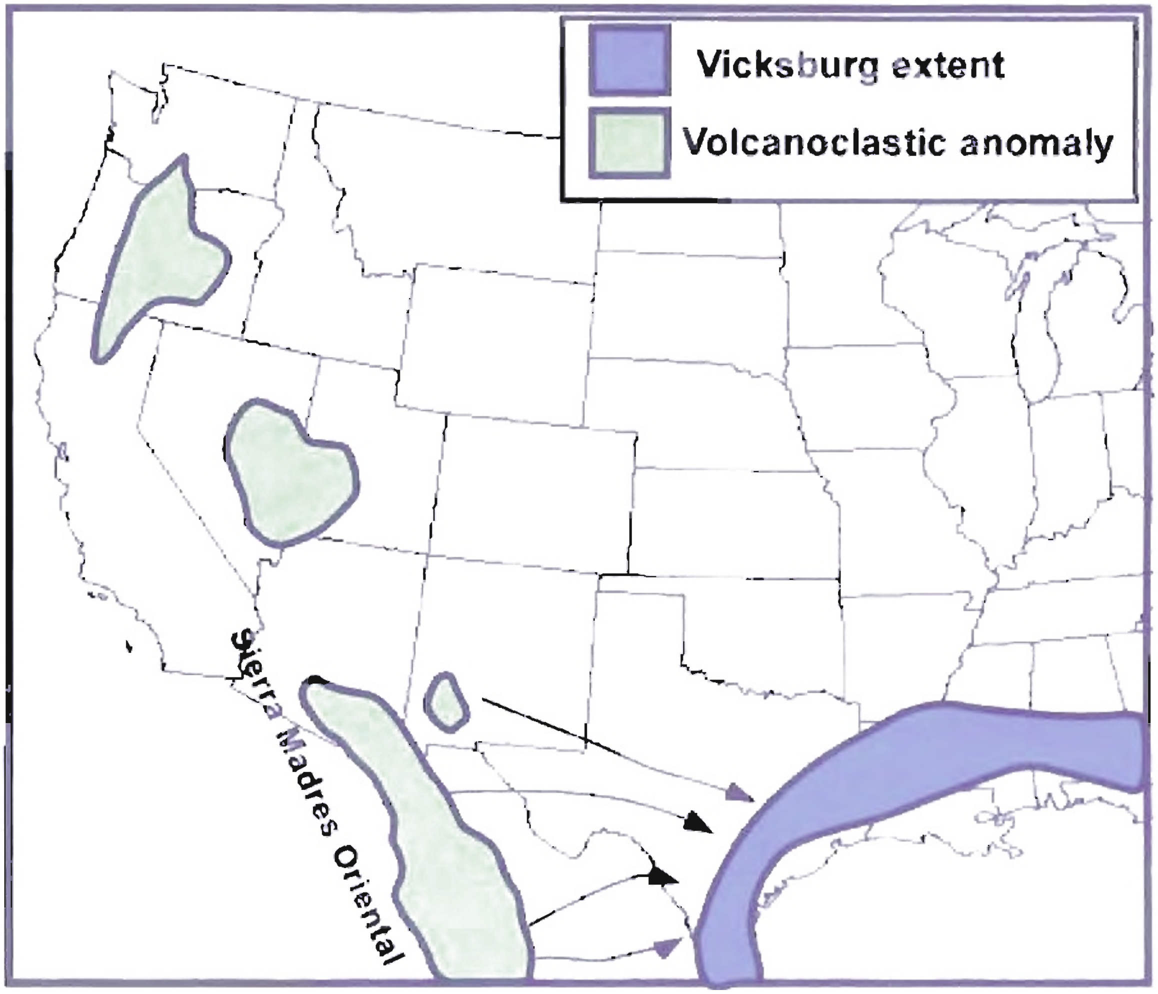


Figure 7. Vicksburg trend showing the volcanoclastic provanance of the Sierra Madres Oriental Volcanic Anomaly.

Vicksburg are further subdivided in the TCB field by local subsurface depth names (Figure 8) of the sands found within the field (Taylor and Al-Shaieb, 1986). These sands and associated depths were identified using wire-line well logs that gave the characteristics of the individual sands within the TCB field (Taylor and Al-Shaieb, 1986).

Local Structure

TCB Field is located within the Sam Fordyce-Vanderbilt Fault zone. The structure of the TCB Field area is that of a large syndepositional listric normal growth fault and the resulting rollover anticline associated with the movement. The anticlinal closures are complicated by older listric and associated antithetic faults that cut through the structure (Taylor and Al-Shaieb, 1986). This structural style is best portrayed by a dip oriented interpreted seismic cross section that traverses the field (Figure 9). The dominant TCB field listric normal fault tends to parallel the ancient and modern shorelines of the Gulf Coast with a displacement between 200 and 400 feet. This listric normal fault has dip angles that vary from 70 to 30 degrees because of the curvature of the movement (Taylor and Al-Shaieb, 1986; Shelton, 1984). The upper terminus of the main TCB field fault dies before entering the Frio (Taylor and Al-Shaieb, 1986). The base of this growth fault dies into the decollement surface along the Eocene Jackson Group contact with the Vicksburg formation (Coleman, 1990).

	TCB FIELD		LOCAL SUBSURFACE NOMENCLATURE
OLIGOCENE	Frio Fm		Frio
	Vicksburg Fm	UPPER	Wilson Sandstone 7900-ft Sandstone 8500-ft Sandstone 8650-ft Sandstone 8800-ft Sandstone 9000-ft Sandstone
		MIDDLE	9400-ft Sandstone 9550-ft Sandstone 9900-ft Sandstone
		LOWER	10250-ft Sandstone 10500-ft Sandstone 10600-ft Sandstone 11000-ft Sandstone 11800-ft Sandstone
EOCENE	Jackson Group		Jackson Shale

(After Taylor and Al-Shaieb, 1986)

Figure 8. Stratigraphic nomenclature of the TCB field area.

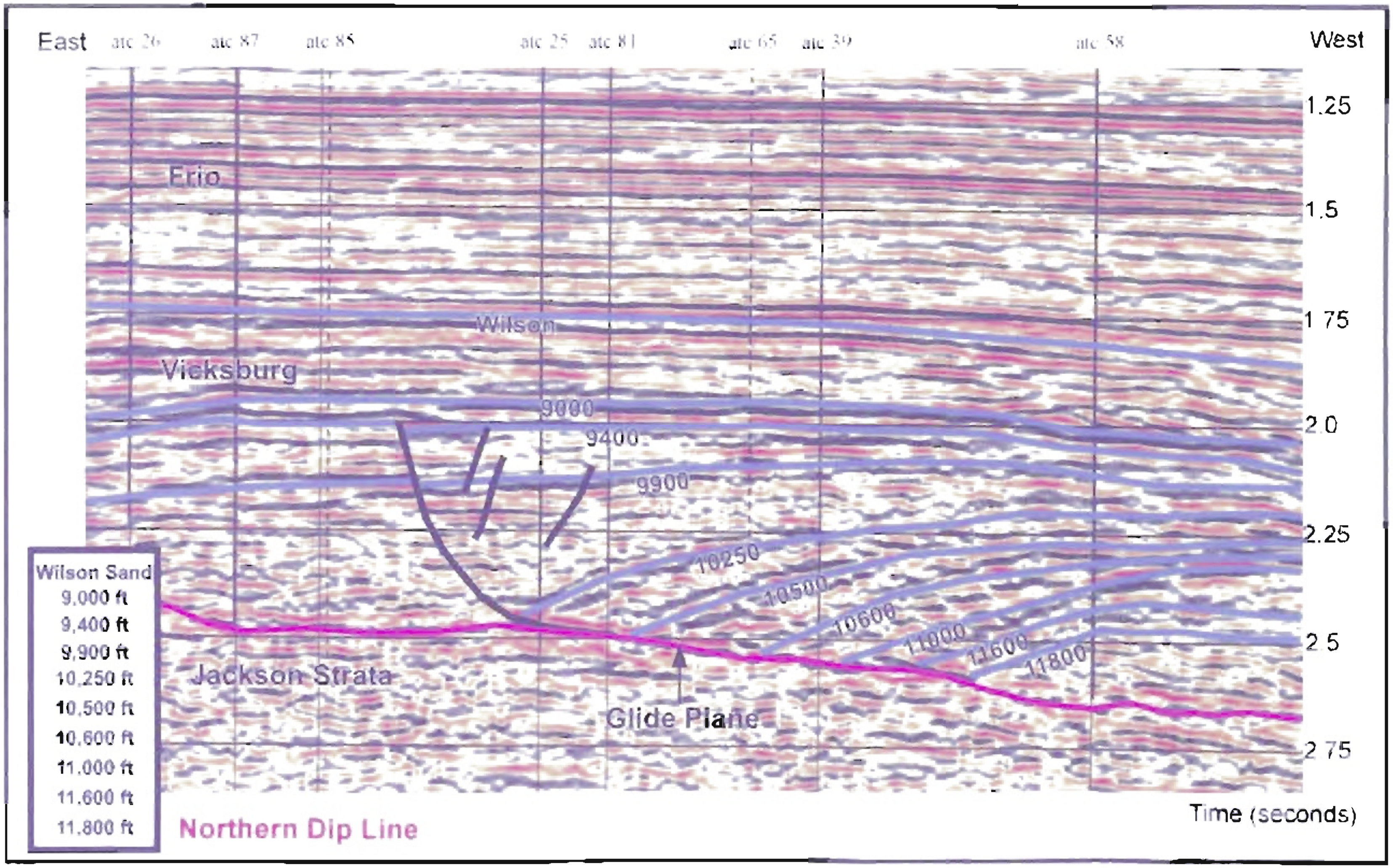


Figure 9 Dip oriented seismic cross section that demonstrates the structural style found in the TCB field area, Kleberg County, Texas

Chapter 3

DEPOSITIONAL FACIES

Introduction

The Vicksburg formation in the TCB field area is siliciclastic in origin. Cored Vicksburg rock intervals from six of the local TCB field units were studied and interpreted for depositional facies (Figure 10). Cores were examined from the three subdivisions of the Vicksburg, the Lower Vicksburg, Middle Vicksburg and Upper Vicksburg. The examined cores were calibrated to the appropriate wire-line log for the interval studied; these interpreted environments represent a general deltaic to shoreface marine depositional setting. Lithofacies observed in the cores / logs were grouped into three basic depositional environments based on Coleman and Prior's (1982) work; the upper delta plain, the lower delta plain and the subaqueous delta plain. These basic environments were subdivided into more specific depositional facies for the purpose of this interpretation.

Upper Delta Plain

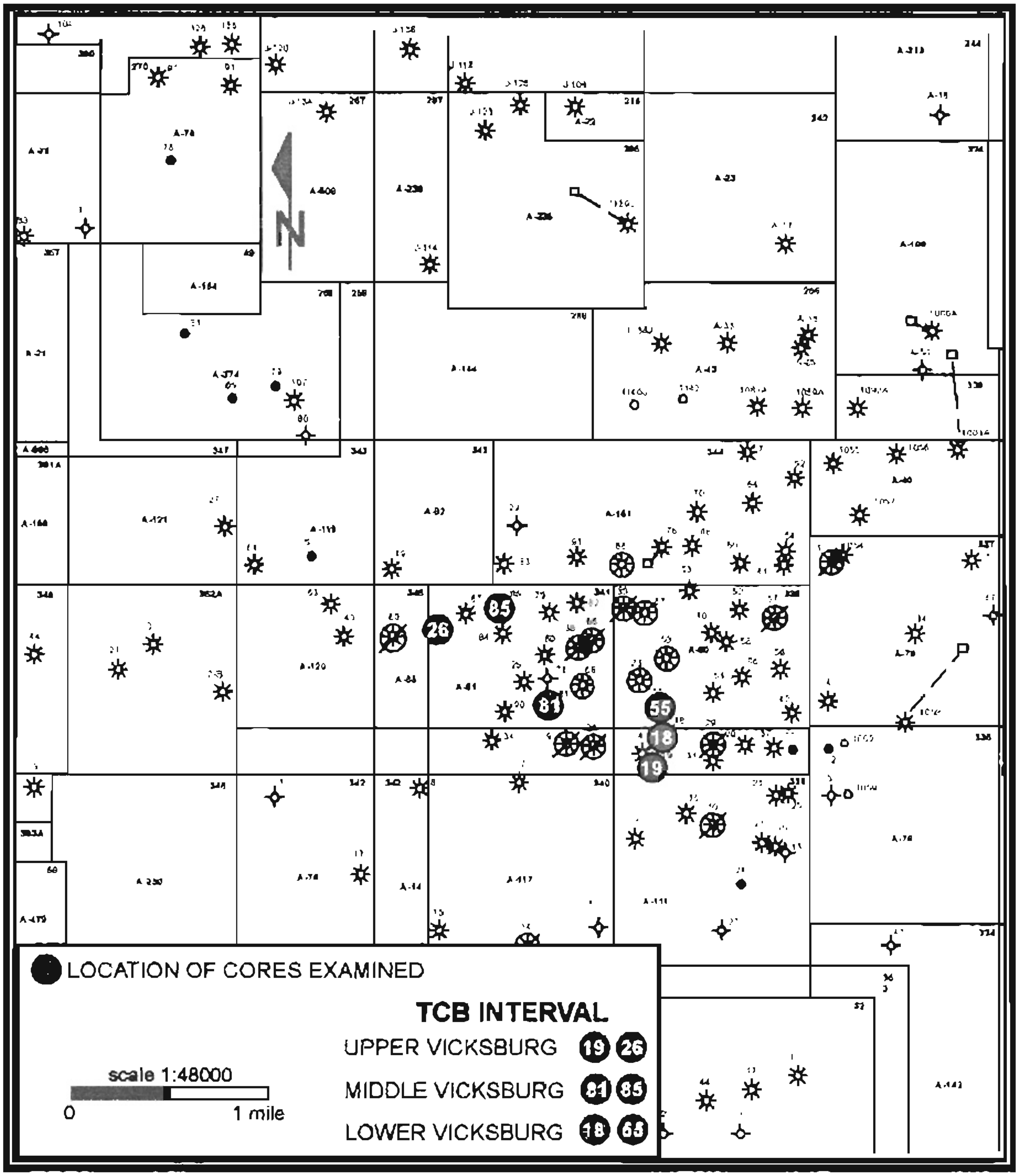


Figure 10. Location map of cores studied, identified as Upper, Middle, Lower Vicksburg interval with well number identification.

This environment of deposition lies above the level of effective seawater intrusion and is largely unaffected by the ocean. This environment is largely subaerial containing sediments that originate from channel fill of meandering channels, overbank flooding, and point bar deposits (Coleman and Prior, 1982).

Lower Delta Plain

The lower delta plain component lies within the realm of river-marine interaction. A common occurrence within this environment is channels become more numerous and show a bifurcation pattern. The environments between the channels consist of bay-fill deposits such as interdistributary bays, crevasse splays and marshes (Coleman and Prior, 1982).

Subaqueous Delta Plain

This portion of the delta plain lies below the low tide level and extends seaward to the area actively receiving fluvial sediments. This area ranges in water depth from 150 ft to 900 ft. This environment is considered as the foundation by which all progradation must travel. The subaqueous delta plain exhibits a seaward fining of sediments of which the farthest basinward is known as the prodelta. Clays settling from suspension into mud-rich deposits dominate the prodelta. The shoreward end of the subaqueous plain forms distal bar deposits (Coleman and Prior, 1982).

Lower Vicksburg Facies

Two core intervals were examined in the Lower Vicksburg (Figure 10). Within these two wells three TCB stratigraphic intervals were studied for depositional systems. These intervals are the 10600 ft. sand, 10500 ft. sand and 10250 ft. sand. The cores taken from E.G. Canales #18 contain parts of three of these Lower Vicksburg intervals (Figure 11). The core from A.T. Canales #55 contains rock from the 10500 ft. sand (Figure 12). From core observation and petrolog analysis for each interval, a depositional system was defined for the Lower Vicksburg.

This portion of the Vicksburg strata is interpreted as a subaqueous prograding to upper delta plain system for each of the three TCB stratigraphic intervals studied. The base of each interval begins as a prodelta mud that shallows upwards into a bar facies that is capped by channel-fill sands. This interval is then capped by another prodelta complex of the next prograding interval. This facies pattern applies to the 10600 ft. interval, 10500 ft. interval and again in the 10250 ft. interval.

The Lower Vicksburg facies interpretation was correlated to the appropriate wire-line log of well #18 and #55 to form characteristic well log lithofacies responses for each interval (Figure 11, 12). A repetitive progradational pattern characteristic of the sand intervals was interpreted from these well log responses. The well log data was also used in the construction of an isopach map of the 10250 ft. interval across the TCB field area (Figure 13). The purpose of this map was to accentuate any depositional trends that may

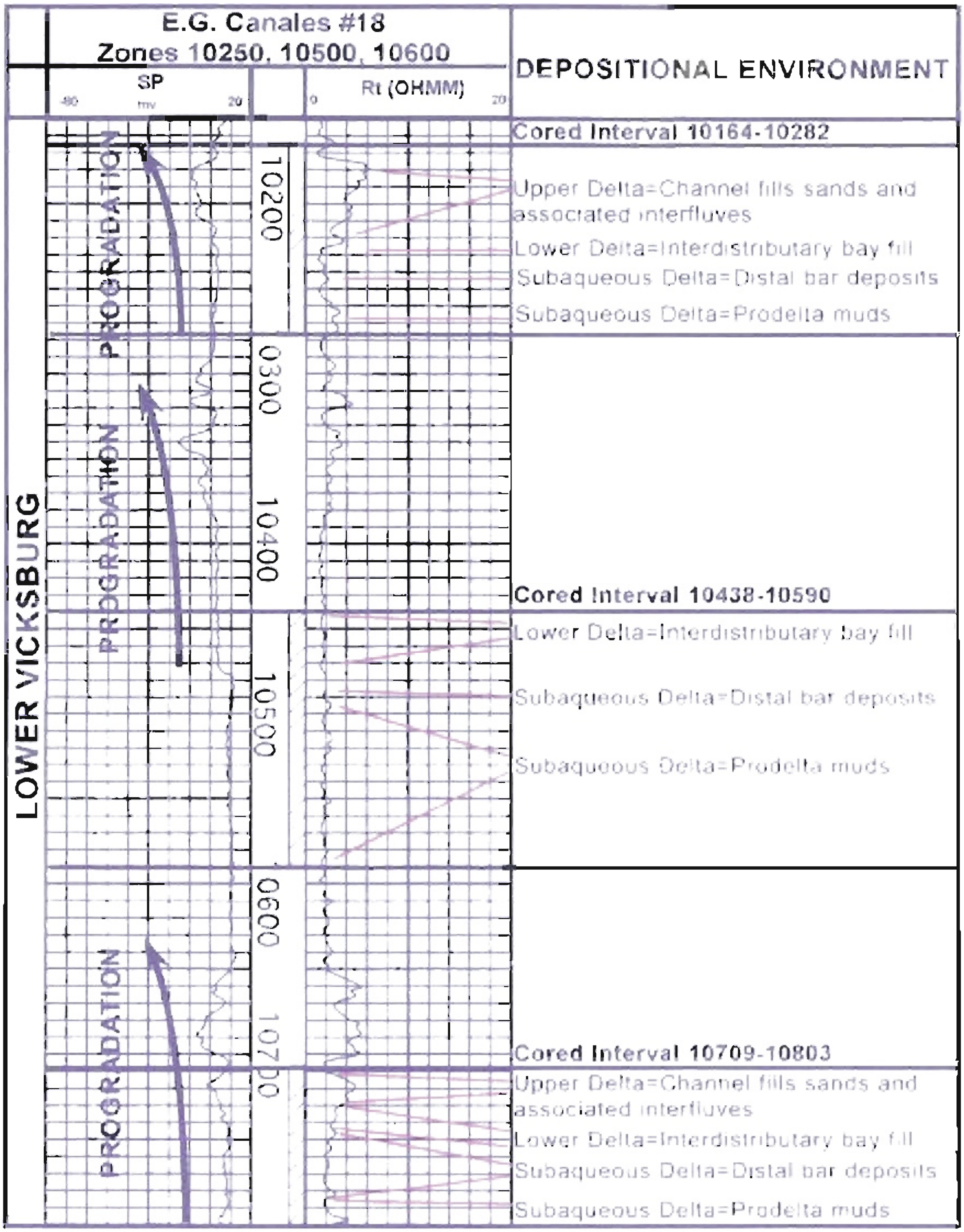


Figure 11. Well log to lithofacies response calibrated to core taken from the labeled interval. Progradational characteristic illustrated.

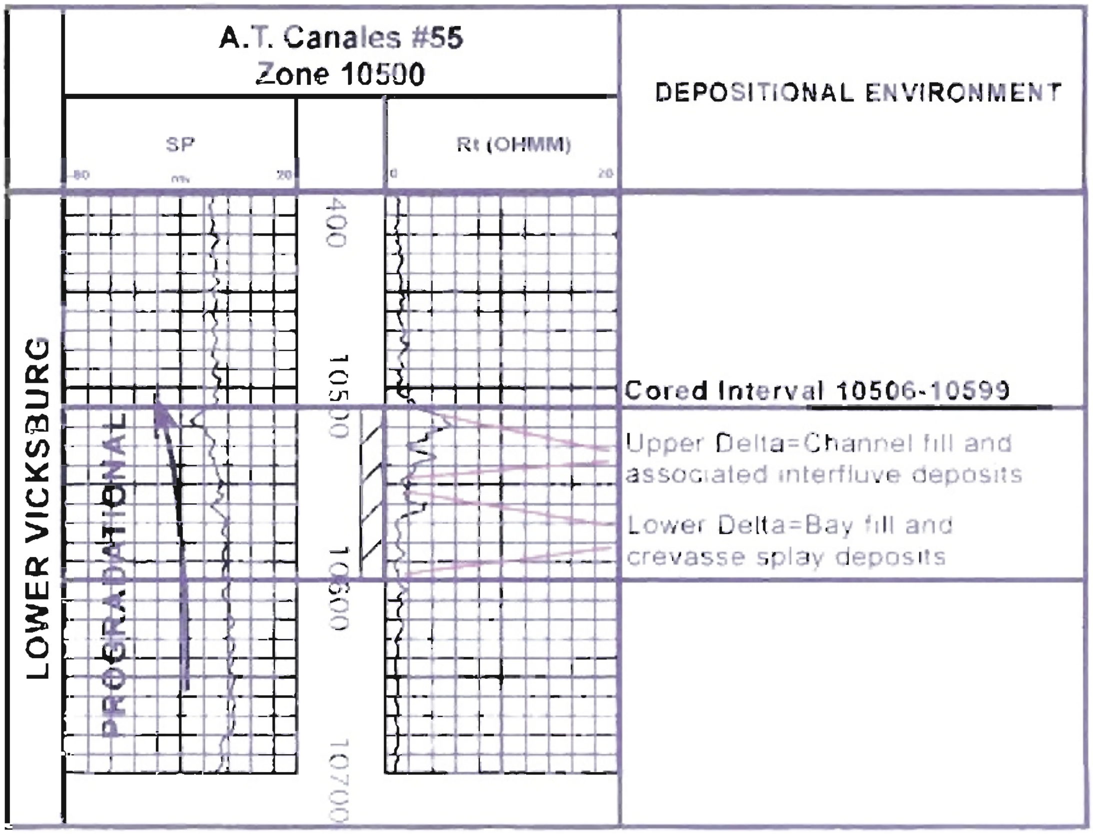


Figure 12. Well log to lithofacies response calibrated to core taken from the 10500 ft. interval. Progradational characteristic of the interval is illustrated.

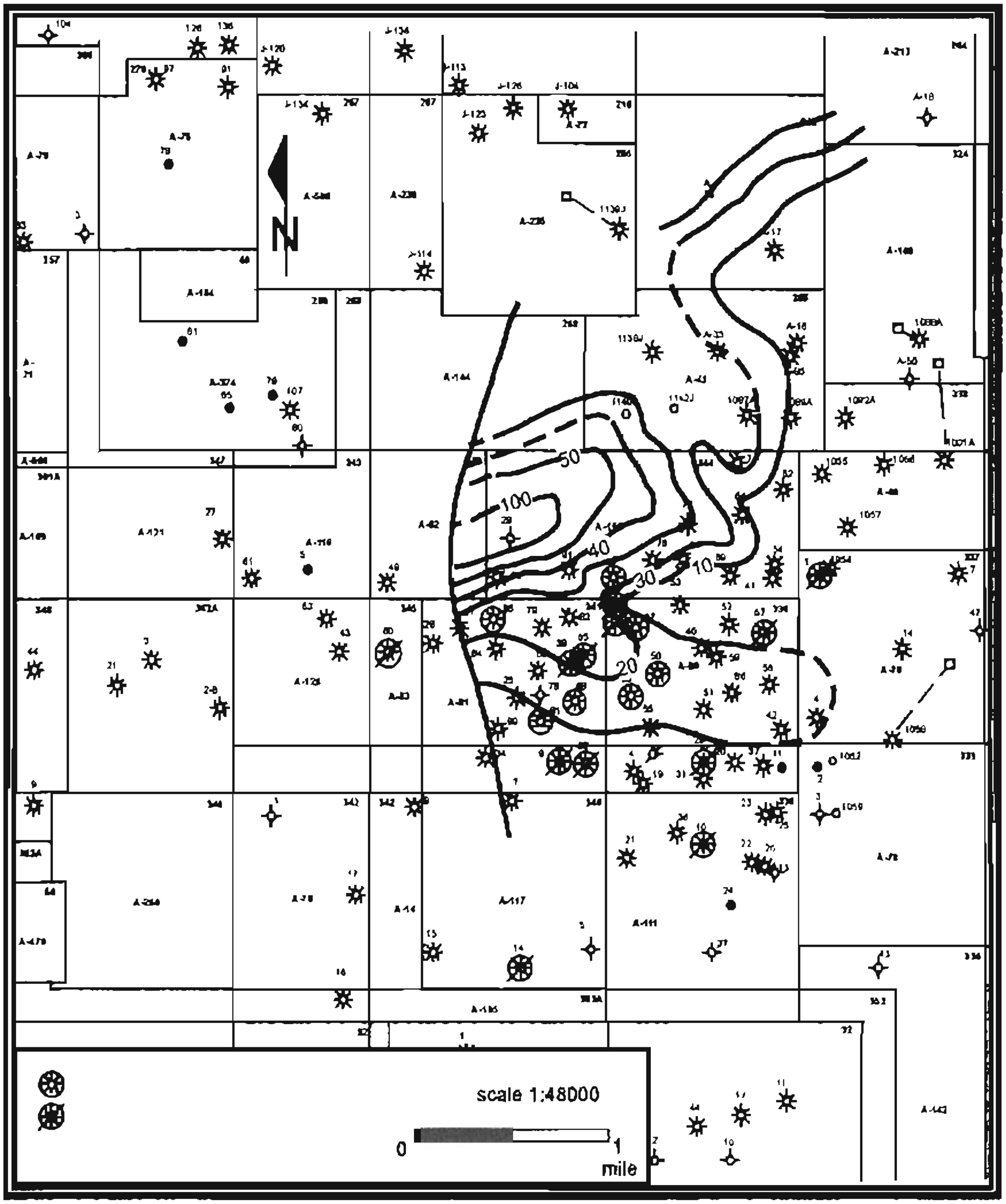


Figure 13. Isopach map showing the prograding deltaic nature of the 10250 ft. Lower Vicksburg interval.

be present. The resulting map illustrates a prograding delta shaped lobe that corresponds to the described progradational nature of the Lower Vicksburg.

Middle Vicksburg Facies

Two cored wells were examined in the Middle Vicksburg (Figure 10). Within these two wells one TCB stratigraphic interval was studied for depositional systems. This interval is the 9900 ft. sand. From the analysis cored sections taken from the A.T. Canales #81 well and the A.T. Canales #85 well 9900 ft. interval a depositional system was defined for the Middle Vicksburg.

This portion of the Vicksburg strata is interpreted as a subaqueous delta plain environment of deposition. This interval is subdivided into a large shallow marine environment that grades into shoreface marine and reverts back to a shallow open marine as sea level fluctuates. The style of deposition within this interval is very repetitive and the sand / mud ratio seems to increase with depth suggesting an overall increase in sea level.

The Middle Vicksburg facies interpretation was correlated to the appropriate wire-line log for well #81 and #85 to form a characteristic well log lithofacies responses for the interval (Figure 14, 15). This lithofacies response illustrates an overall retrogradational trend of deposition in the Middle Vicksburg. The well log data was also used in the construction of an isopach map of the 9900 ft. interval across the TCB field area (Figure 16). The map accentuated the Middle Vicksburg depositional trend of retrograding sediments thickening into the TCB fault zone as they infill the topographic

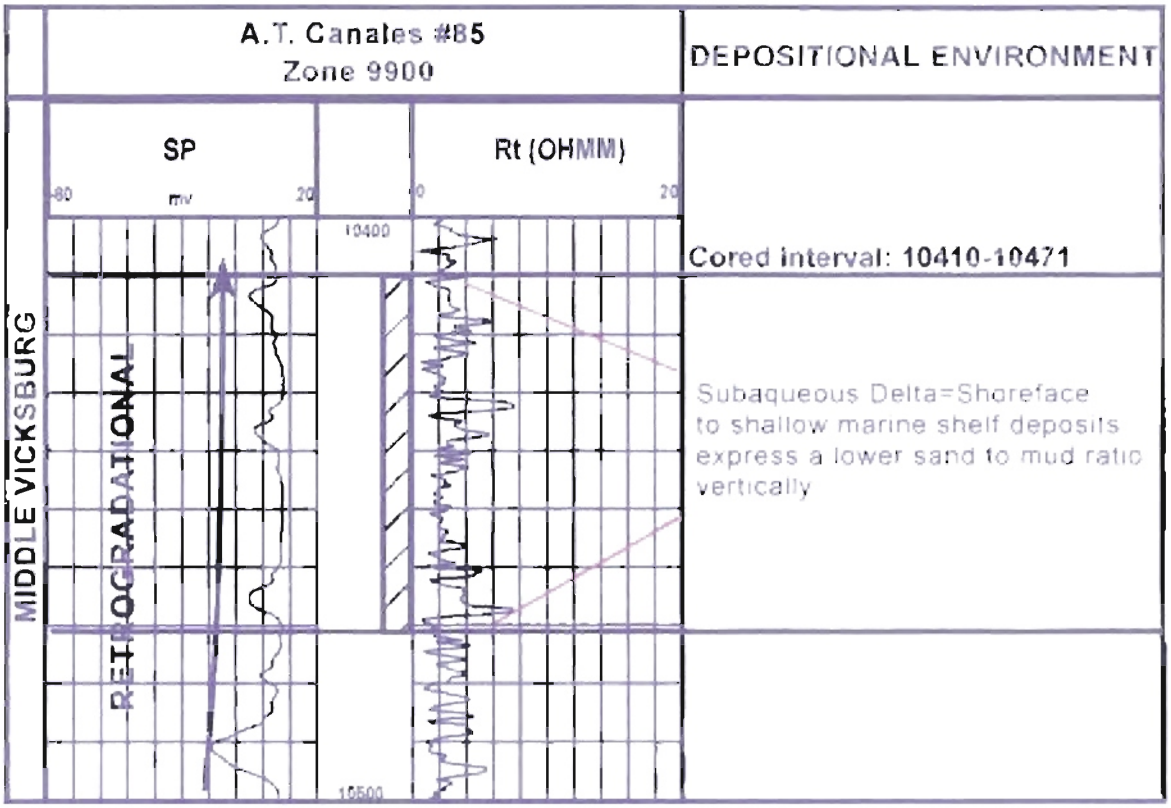


Figure 15 Well log to lithofacies response calibrated to core taken from the 9900 ft. interval. The retrogradational characteristic of the Middle Vicksburg is illustrated.

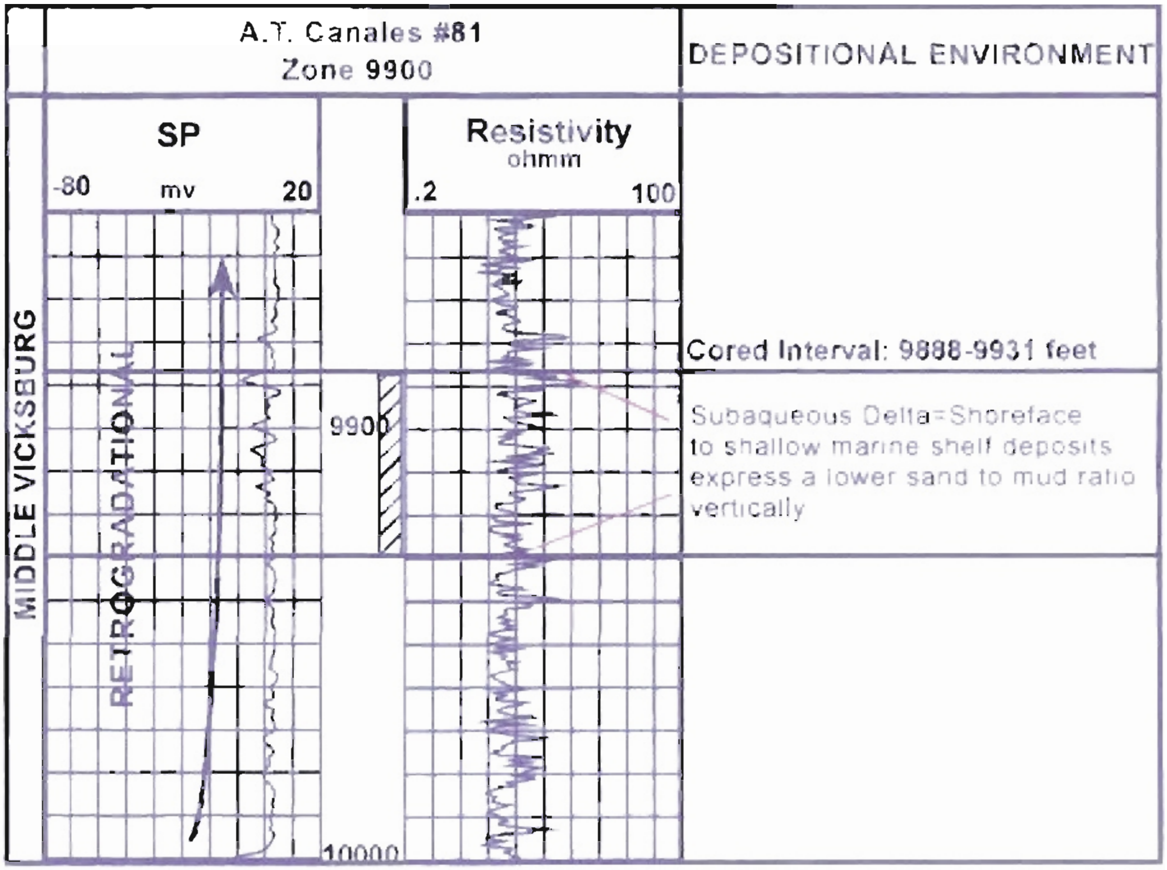


Figure 14. Well log to lithofacies response calibrated to core taken from the 9900 ft. interval. The retrogradational characteristic of the Middle Vicksburg is illustrated

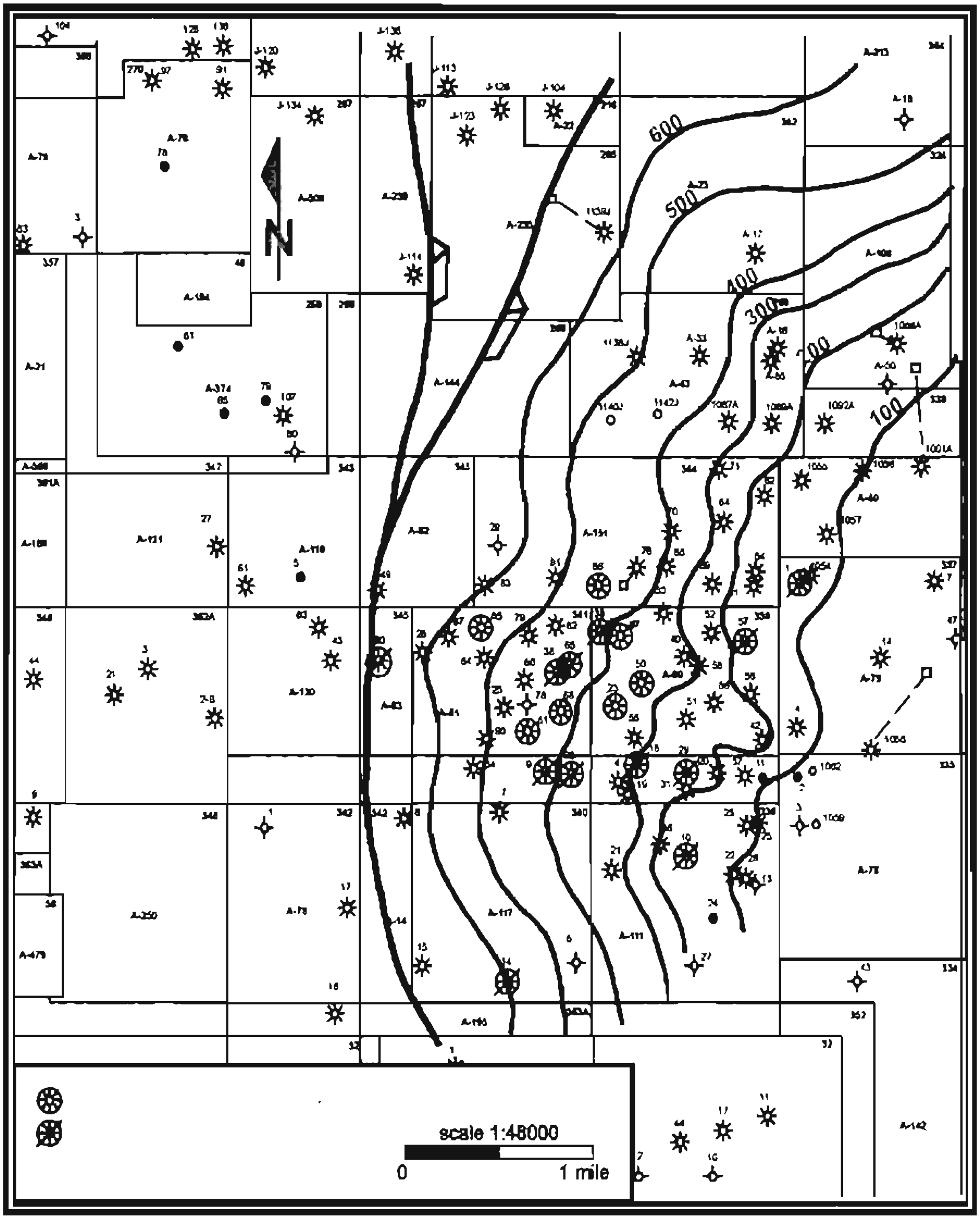


Figure 16. Isopach map of the Middle Vicksburg 9900 ft interval illustrating the retrogradational trend of thickening into the TCB fault and thinning basinward towards the rollover anticline stucture formed by Lower Vicksburg strata.

relief between the hanging-wall and footwall. The map also illustrates the sediments thinning onto the rollover anticline structure formed from the Lower Vicksburg movement.

Upper Vicksburg

Two cored wells were examined in the Upper Vicksburg (Figure 10). Within these two wells are two TCB stratigraphic intervals that were studied for depositional systems. The intervals studied are the 9000 ft. sand and the 8800 ft. sand. The core taken from the E.G. Canales #19 contain rocks from the TCB 9000 ft. interval (Figure 17). The core taken from the A.T. Canales #26 contain rocks from the TCB 8800 ft. interval (Figure 18). From the core analysis for each interval, a depositional system was defined for the Upper Vicksburg.

This portion of the Vicksburg strata is interpreted as a subaqueous delta plain environment that progrades into an upper delta plain environment for both of the TCB sand interval studied. The base of each interval begins with channel mouth bar deposits that grades upwards into channel fill or point bar type deposits. The 8800 ft. interval overlies the 9000 ft. interval. This stratigraphic relationship suggests that each interval represents a separate stage of progradation as the fluvial / deltaic system in the Upper Vicksburg builds upon itself.

The Upper Vicksburg facies interpretation was correlated to the appropriate wire-line logs for well #19 and #26 to form a characteristic well log lithofacies response for the intervals (Figure 17, 18). These lithofacies responses illustrate an overall

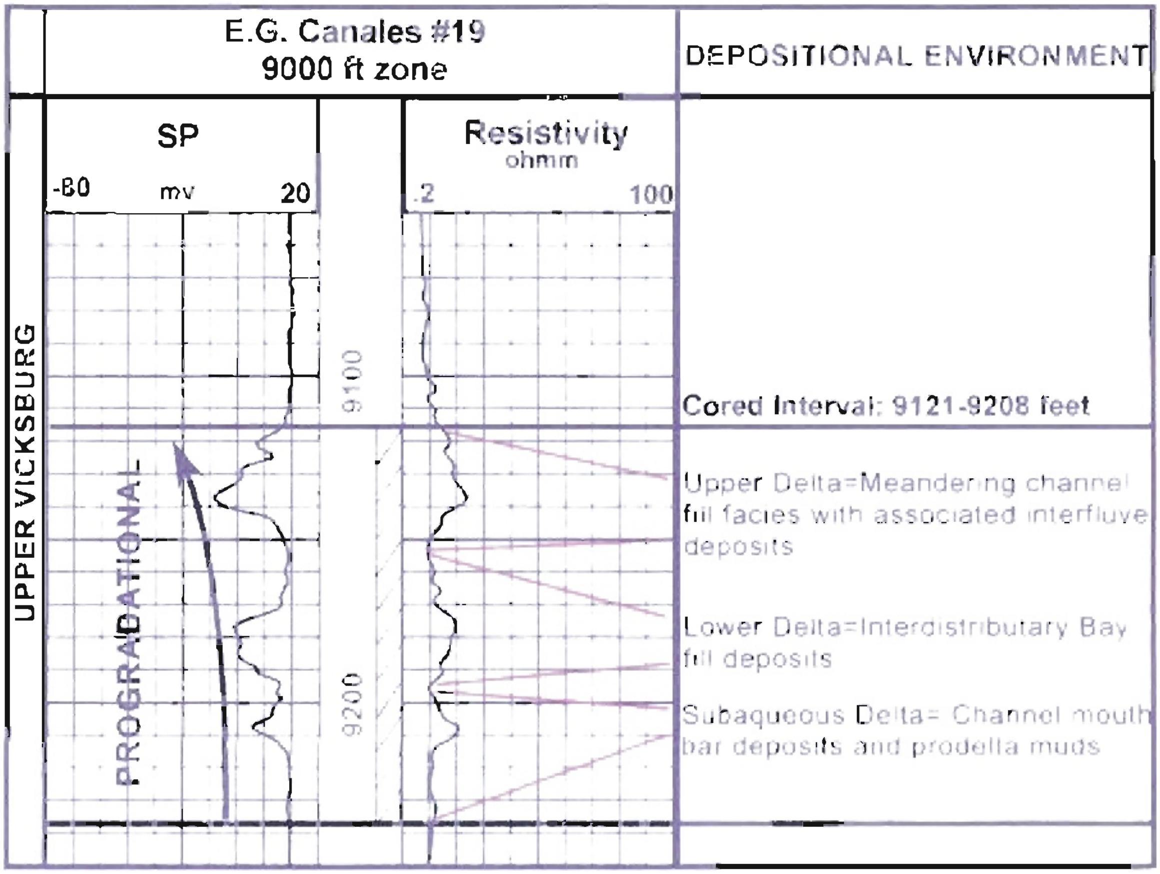


Figure 17. Well log lithofacies response calibrated to core taken from the 9000 ft. interval. The progradational characteristic of the Upper Vicksburg is illustrated.

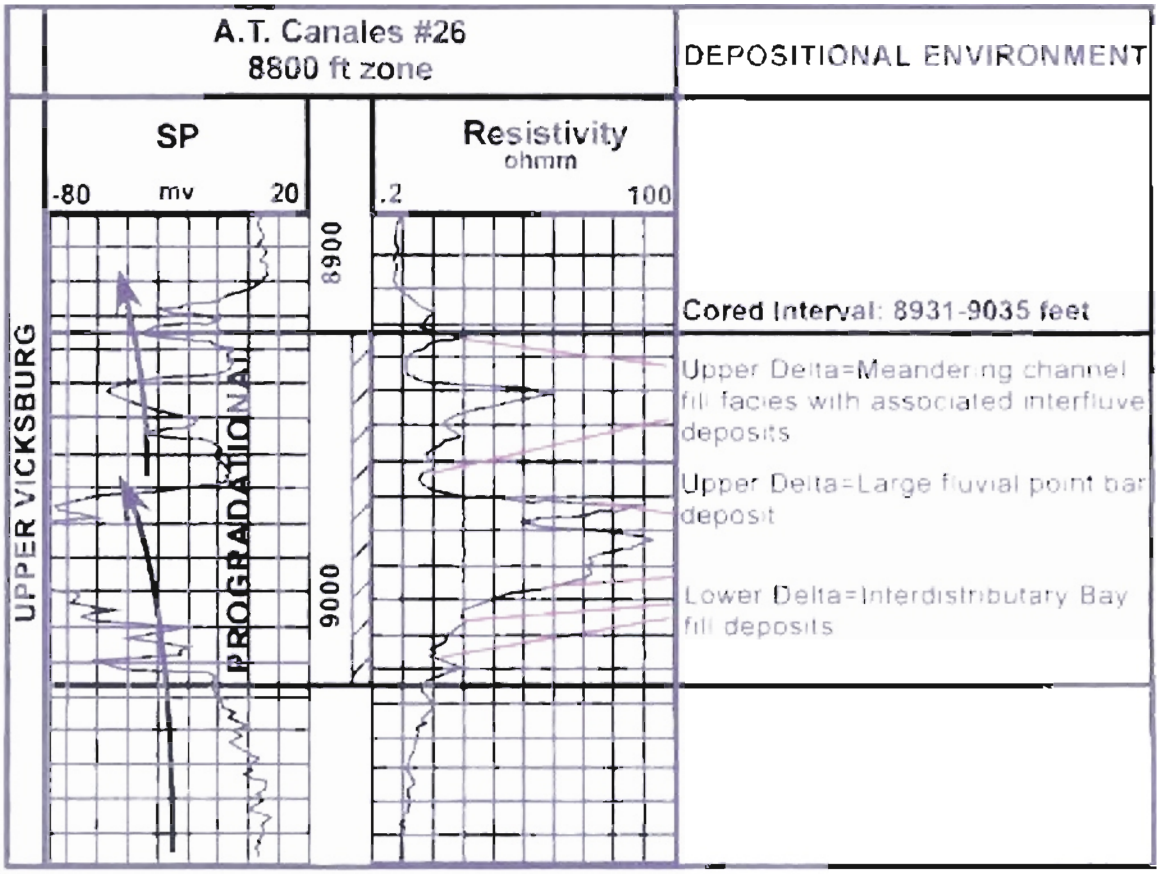


Figure 18. Well log lithofacies response calibrated to core taken from the 8800 ft. interval. The repeated progradational characteristic of the Upper Vicksburg is illustrated.

progradational trend of deposition in the Upper Vicksburg. The well log data was also used in the construction of an isopach map of the 9000 ft. interval across the TCB field area (Figure 19). The map accentuated the Upper Vicksburg depositional trend of a prograding fluvial/deltaic system that continued across the TCB field area during this time.

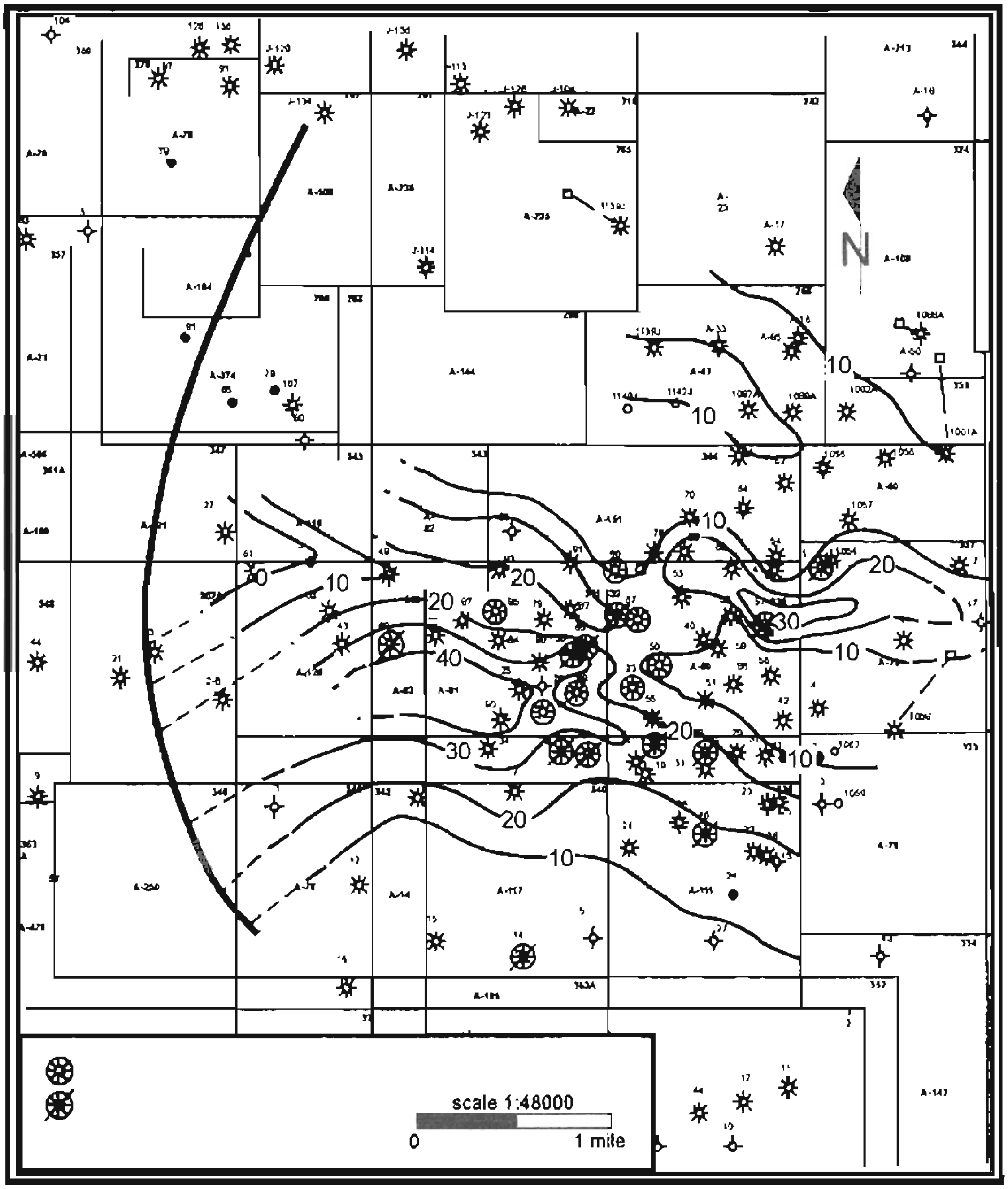


Figure 19. Isopach map of the 9000 ft. interval representing the Upper Vicksburg style of deposition. The overall prograding deltaic trend is illustrated.

Chapter 4

SEISMIC STRATIGRAPHY

Introduction

Seismic stratigraphy is a technique for interpreting stratigraphic information from seismic data. The fundamental principle of seismic stratigraphy is that within the resolution of the seismic method, seismic reflections follow overall bedding trends and consequently approximate time lines. Reflections found within seismic data are a function of impedance. Impedance is the product of rock density and seismic velocity. Seismic reflections are generated at abrupt acoustic impedance contrasts, and variations in impedance contrast will produce reflections of varying amplitude. These correlative impedance variations on seismic data represent lithologic interfaces and not lateral facies changes. Reflections can be interpreted as time-lines that represent time surfaces in three dimensions, separating older rocks from younger rocks. A seismic section can supply chronostratigraphic information, as well as lithostratigraphic information that is derived from the reflection characteristics or amplitude at impedance contrasts. The combination of those data and geometric information present on seismic sections form a powerful instrument for interpreting the subsurface stratigraphic record (Emery and Myers, 1996; McQuillin, 1984).

Source of Data

Seismic data are acquired using a system consisting of three main components: an input source, an array of detectors and a recording instrument. The input source is designed to generate a pulse of sound that meets certain predefined requirements of total energy, duration, frequency content, maximum amplitude and phase for the section of strata that is of interest. Reflected and refracted seismic pulses are the output from the earth that is detected by an array of geophones. A geophone is a recording instrument that records this output signal. Each seismic record is thus a time record of the output signals, which are generated at interfaces of acoustic impedance change within a series of stratigraphic layers (McQuillin, 1984).

Kerr-McGee Oil and Gas Onshore graciously donated the seismic data employed for the study of the TCB field area. The data consists of a regional 3-D seismic survey, which was interpreted in-house geophysicists, and further interpretation was completed for this study. This seismic data was used to create three seismic traverses through wells in the TCB field, and a regional dip line was also created for a larger interpretation of the Vicksburg strata not in TCB field. Three isochron maps were also constructed between seismic surfaces of interest along the Vicksburg trend in South Texas.

Time Depth Conversion

The TCB field area has been a producer since 1942 (Taylor and Al-Shaieb, 1986). This has led to a large amount of borehole data. This data were used to build a well to seismic correlation. This correlation has allowed the local stratigraphy of the TCB field to be attributed to their appropriate seismic reflector in the subsurface. A well velocity survey in A.T. Canales #31 was used in order to solidify the interpretation. A well velocity survey is the most direct method of identifying the relationship between subsurface geology to that of seismic reflection data. This technique involves detecting the amplitude of sound within the borehole from a near surface source (McQuillin, 1984).

The time depth conversion for the TCB field Vicksburg strata used by Kerr-McGee was given for use in this study. A general value of 5 feet per millisecond in two-way time or 10 feet per millisecond one-way time can be used to generally estimate thickness of strata when viewing seismic data. This value will vary with depth as the sound wave travels through different densities of medium. This change in the time-depth conversion with depth is a function of pore fluids, lithology and reservoir pressure (Figure 20).

Seismic Resolution

A necessity for the successful application of seismic stratigraphic principles is an understanding of the resolution of the seismic method. Vertical resolution is very important in the interpretation of seismic data. Vertical resolution is defined as the

Time-Depth Conversion in Two Way Time in TCB Field Area

Depth in Feet	Feet/millisecond (ms)
0-1000‘	3.3‘
1000-2000'	3.3‘
2000-3000'	4.2‘
3000-4000‘	4.5‘
4000-5000‘	4.9‘
5000-6000'	5.2‘
6000-7000‘	5.4‘
7000-8000‘	5.8'
8000-9000‘	5.0'
9000-10000'	4.2'
10000-11000‘	4.5‘
11000-12000‘	4.5‘

NOTE: double the ft./ms values for one-way time

Figure 20. Detailed table of time-depth conversion differences with change in depth in TCB field area, Kleberg County, Texas.

minimum vertical distance between two interfaces needed to give rise to a single reflection that can be observed on a seismic section (Emery and Myers, 1996). Shorter wavelengths or higher frequencies give greater vertical resolution or thinner bed thickness resolution within the seismic section. No matter what frequency the wavelength is, the overall resolution of the wave is one-quarter of that wavelength (McQuillin, 1984). Reflectors that are spaced more closely than one-quarter of the wavelength have responses that constructively build on one another to produce a reflection of higher amplitude; this is known as a tuning effect. Another element that is detrimental to resolution besides bed thickness is the trend of increasing acoustic velocity with depth due to compaction and increased cementation. These two elements cause a lack of vertical resolution (Emery and Myers, 1996).

The vertical resolution of the seismic data used in this study was calculated using the general time-depth conversion of five feet per millisecond and the frequency of the seismic pulse being twenty-five hertz. The result of this calculation is a vertical resolution of a bed thickness of fifty feet or more. Bed thickness was also converted to a two-way time measurement of twenty milliseconds on the seismic section (Figure 21).

The lateral resolution of the seismic method is based on the contact of the acoustic wave with the reflecting surfaces. Lateral resolution is less dependant on interfaces between different impedances, but rather on the wavelength of the acoustic pulse and the depth of the reflector (McQuillin, 1984). The shorter the wavelength or higher the frequency the greater the lateral resolution. The lateral resolution at depth is affected by the attenuation of the seismic pulse by the earth. The ultimate enhancer for lateral resolution is migration of the seismic data. The lateral resolution of migrated data

Data for Vicksburg Formation in TCB field area

By Using Time Depth Conversion of 5 feet per millisecond (ms)
C is Calculated as 5 ft/ms x 1000 ms = **5000 feet/second**
F is given as **25 hertz**

Primary Equations for Finding Resolution of Seismic Pulse

$$\lambda = \frac{C \text{ (feet per second)}}{F \text{ (frequency in hertz)}} \qquad \Delta t = \frac{2 \times \Delta Z}{C} \qquad \lambda/4 = \Delta Z$$

Resolution of Wavelength in Feet

$$\lambda = \frac{5000 \text{ ft/sec}}{25 \text{ hertz}} = 200 \text{ feet}$$

Resolution of Bed Thickness in Feet

$$\Delta Z = \lambda/4 = \frac{200 \text{ feet}}{4} = 50 \text{ feet thick}$$

Resolution of Bed Thickness in Two-Way Time

$$\Delta t = \frac{2 \times 50 \text{ feet thick}}{5000 \text{ ft/sec}} = \begin{matrix} .02 \text{ sec} \\ \text{or} \\ 20 \text{ ms} \end{matrix} \text{ thick}$$

(after Exxon, 1998)

Figure 21. Calculation of seismic resolution for the TCB field area, Kleberg County, Texas.

depends on trace spacing, the migration program, the time / depth of the reflector and the bandwidth of the data (Emery and Myers, 1996; McQuillin, 1984).

TCB Seismic Stratigraphy

A 3-D seismic survey was shot along the Gulf Coastal Plain in South Texas. Within this survey lies the TCB field area. The Vicksburg Formation was interpreted for several seismically imaged reflectors, rollover structures, and antithetic and synthetic faults. The seismic surfaces were calibrated with a core to seismic correlation produced by a synthetic seismogram before being interpreted across the area.

The TCB field was studied by using three dip orientated seismic traverses and one strike orientated traverse. The paths three of the seismic traverses follow are along wells drilled in the TCB field Vicksburg formation (Figure 22). These seismic sections are displayed in a color-coded amplitude display with the interpreted TCB stratigraphy (Figure 23, 24, 25). The higher order colors (whites to yellows to reds) represent higher amplitudes. These high amplitude reflectors are representative of sand-rich lithologic intervals. The grays and blacks represent lower amplitude responses that are indicative of shales or mud rich lithologies. One dip oriented seismic line was taken across the field (Plate I & II). The seismic inline 329 is included in the plates uninterpreted and interpreted with seismic responses displayed in wiggle trace format.

The seismic lines are interpreted in detail across the Vicksburg formation. The Eocene Jackson Shale detachment surface is imaged as a reflector that can be followed across the area. Above this reflector, the general rollover anticline structural style can be

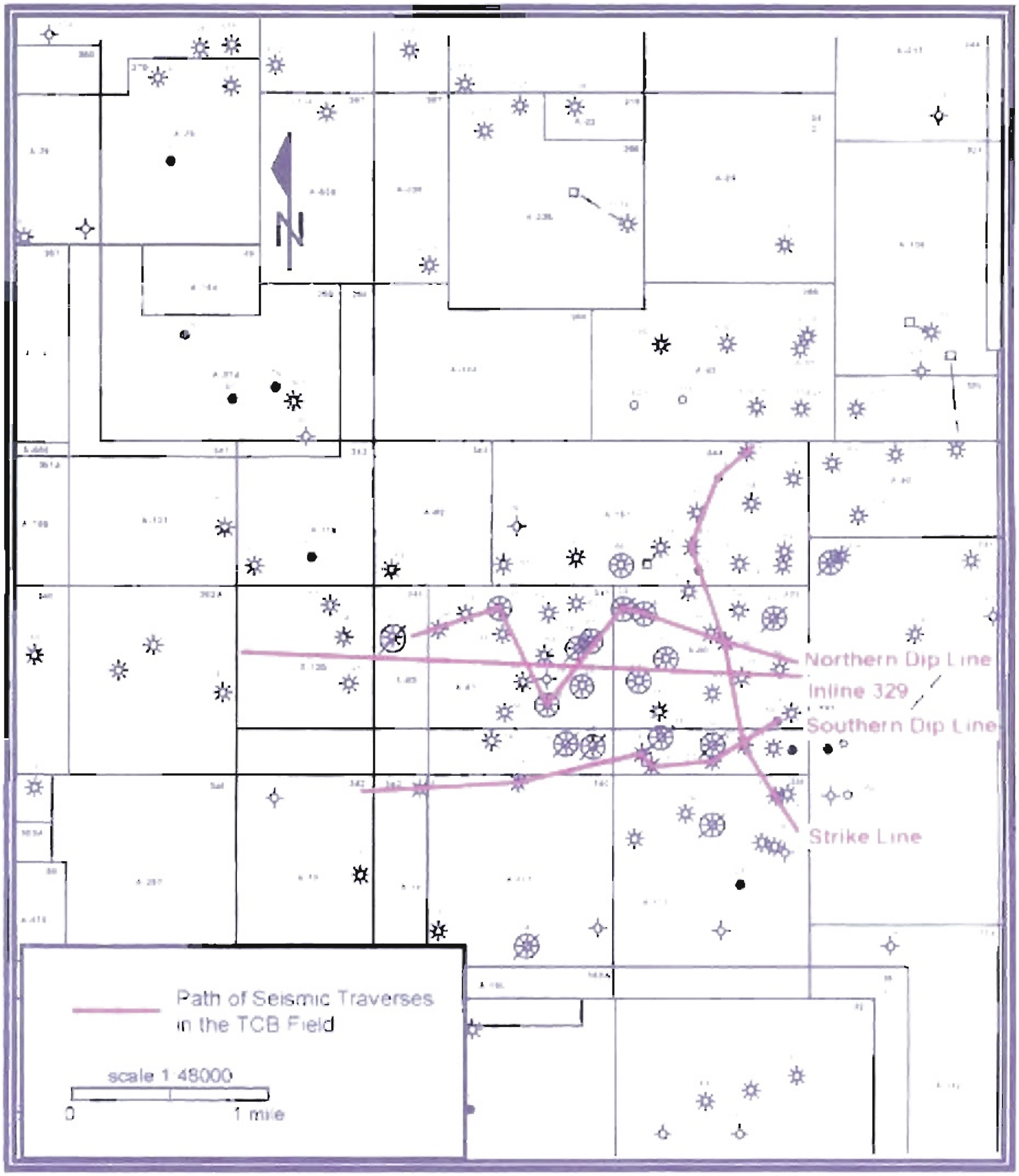


Figure22. Path of seismic sections taken through TCB field area, Kleberg County, TX.

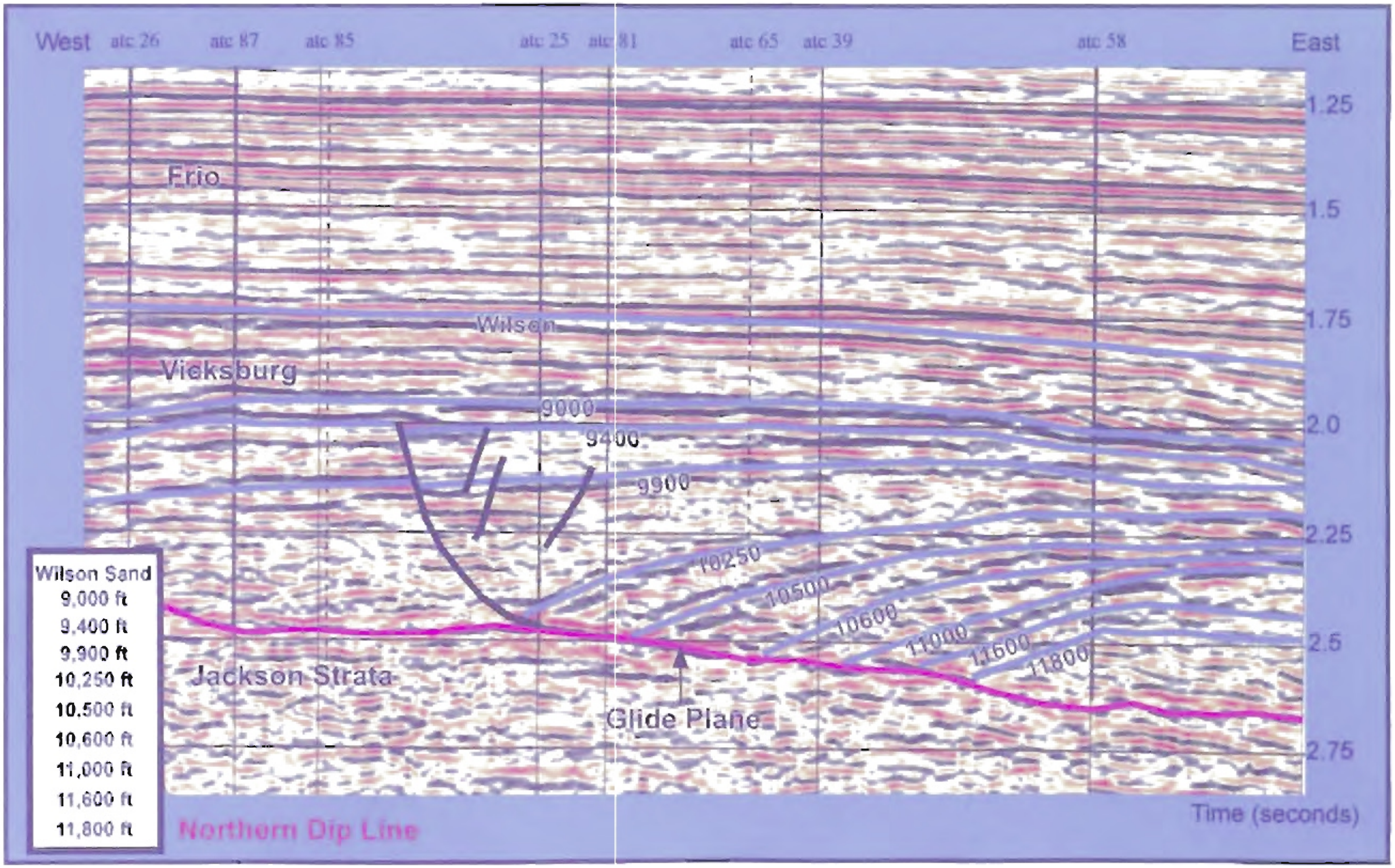


Figure 23 Dip oriented color amplitude seismic section interpreted with TCB field stratigraphy

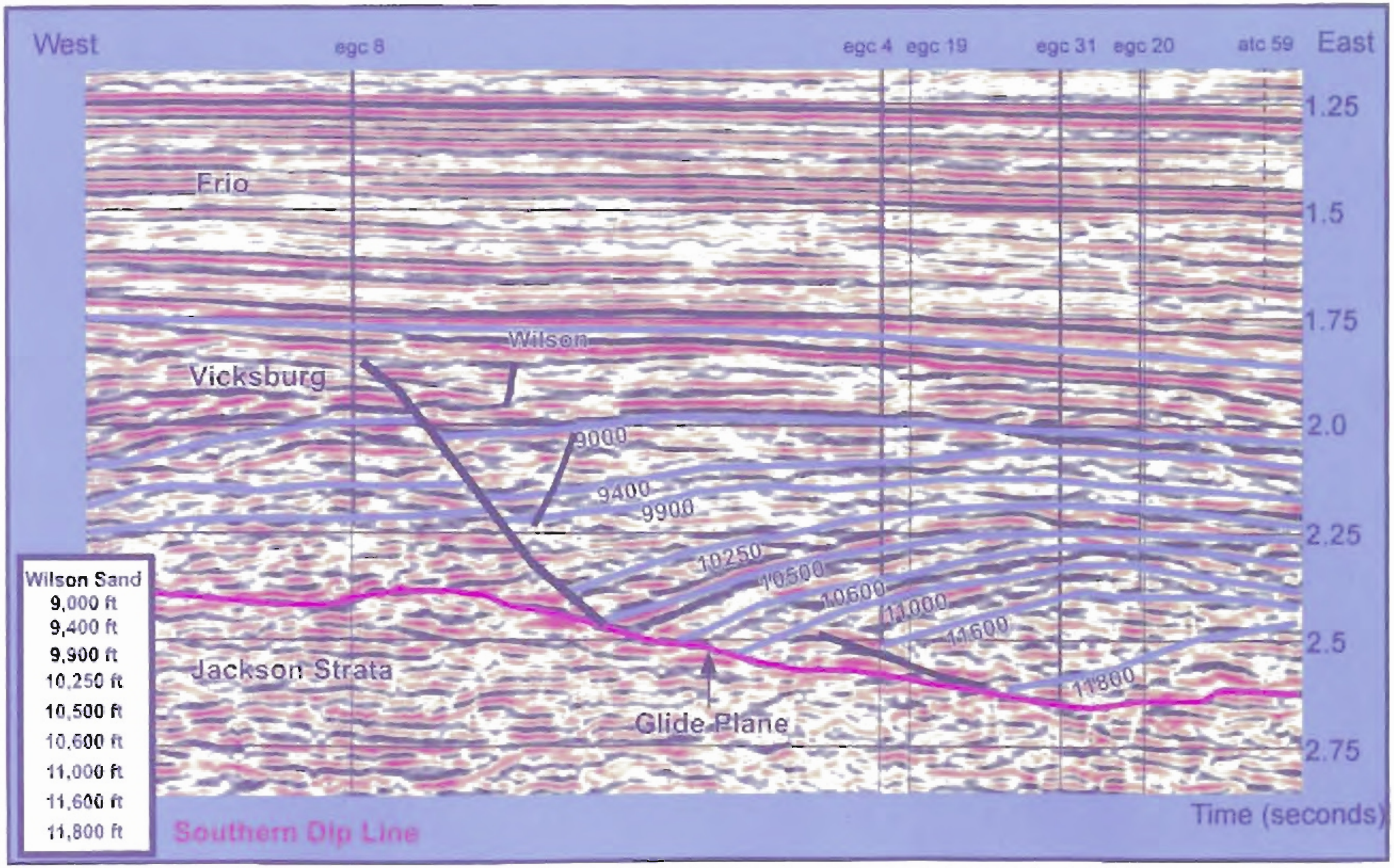


Figure 24. Dip oriented color amplitude seismic section interpreted with TCB field stratigraphy.

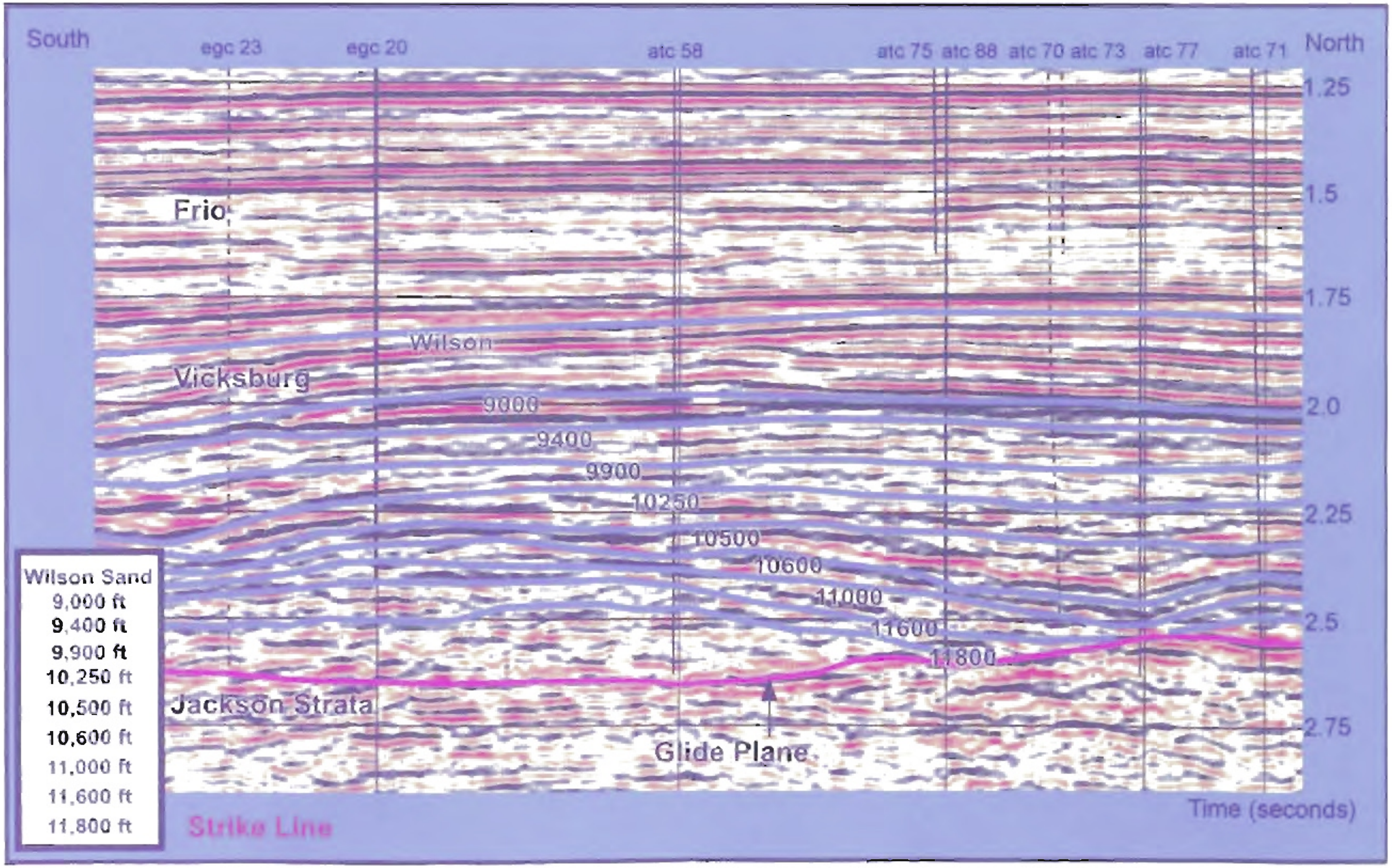


Figure 25   Strike oriented color amplitude seismic section interpreted with TCB stratigraphy

seen. Within this structure, reflectors that correlate to TCB stratigraphic intervals were traced across the seismic section. Offsets in the reflectors are interpreted as antithetic and their associated synthetic faults. Plate II is a detailed interpretation of the dip oriented Inline 329. This seismic section best portrays the structural and depositional style the TCB Vicksburg stratigraphy assumes.

Chapter 5

SEQUENCE STRATIGRAPHY

Introduction

Sequence stratigraphy is the study of stratal patterns in the sedimentary rock record that result from the interaction of accommodation space and sediment supply. Tectonics and eustasy control the amount of space available for sediment to accumulate, and tectonics, eustasy and climate interact to control the sediment supply and how much of the accommodation space is filled (Emery and Myers, 1996).

Tectonism represents the primary control on the creation and destruction of accommodation. Without tectonic subsidence there is no sedimentary basin, and without tectonism there are no processes to create a sediment supply for filling the basin. The pattern of sediment infill into these basins in relation to eustatic sea level is sequence stratigraphy (Emery and Myers, 1996). Exxon Production Research Company proposed the following definitions: (1) "sequence stratigraphy is the study of rock relationships within a chronostratigraphic framework of repetitive genetically related strata bounded by surfaces of erosion or nondeposition, or their correlative conformities": and (2) "a sequence is relatively conformable succession of genetically related strata bounded by unconformities and their correlative conformities" (Van Wagoner et al., 1990).

Sequence Stratigraphic Terminology and Concepts

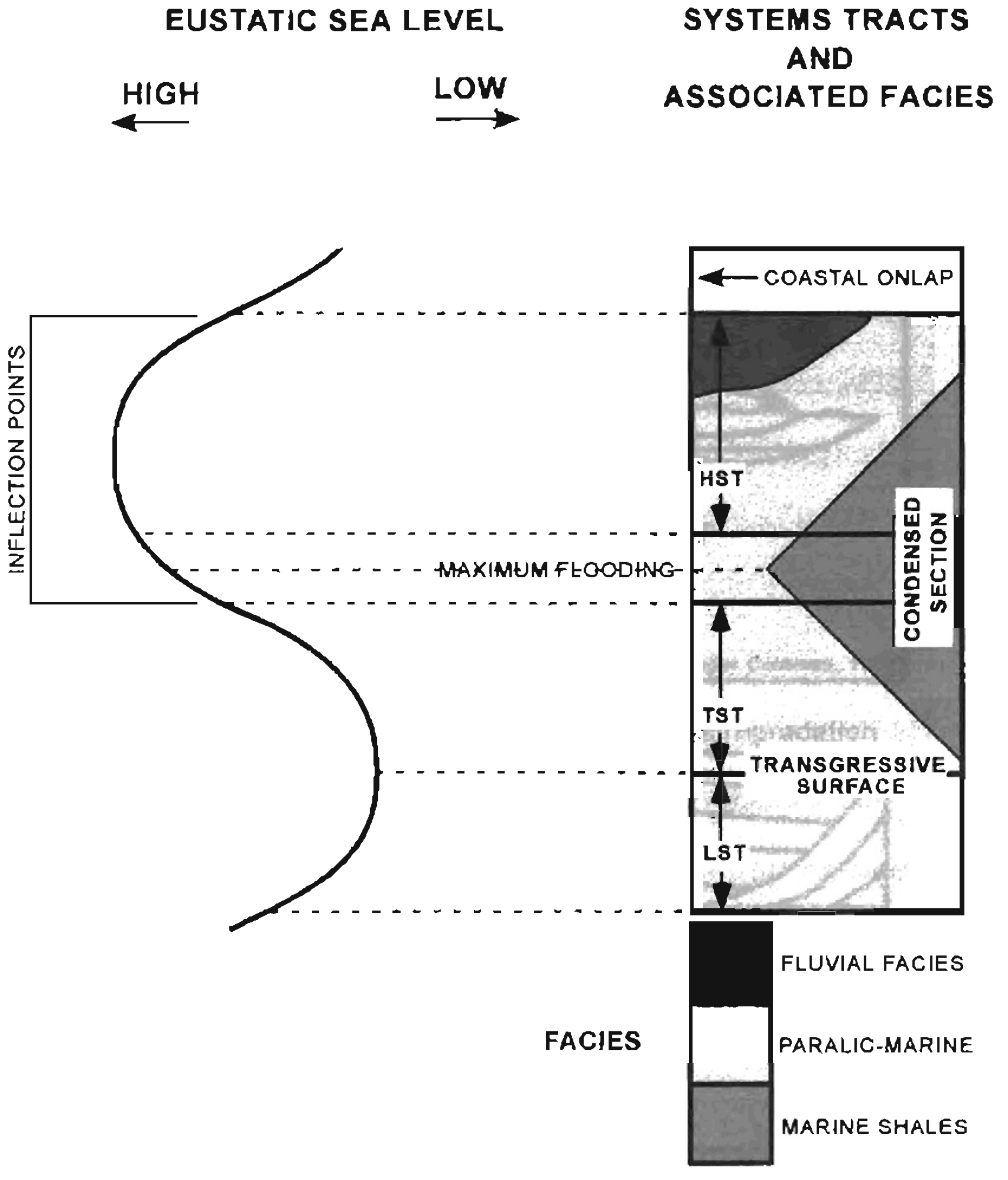
Since the introduction of sequence stratigraphy, certain terminology has been used to characterize and categorize the concepts utilized. This terminology has been adopted over the years and now is well defined in each of their meanings. Within this study, certain concepts were used in the interpretation of the TCB field study area. These concepts and their associated terminology are defined here.

Eustatic Sea Level

The measure of water the column between sea-surface and a fixed datum, usually the center of the Earth is eustatic sea level. Eustasy varies by changing ocean-basin volume or by varying ocean-water volume. It is modeled as a sinusoidal function that can be derived into a coastal onlap curve. This curve can be used to predict the pattern and distribution of depositional systems tracts (Figure 26).

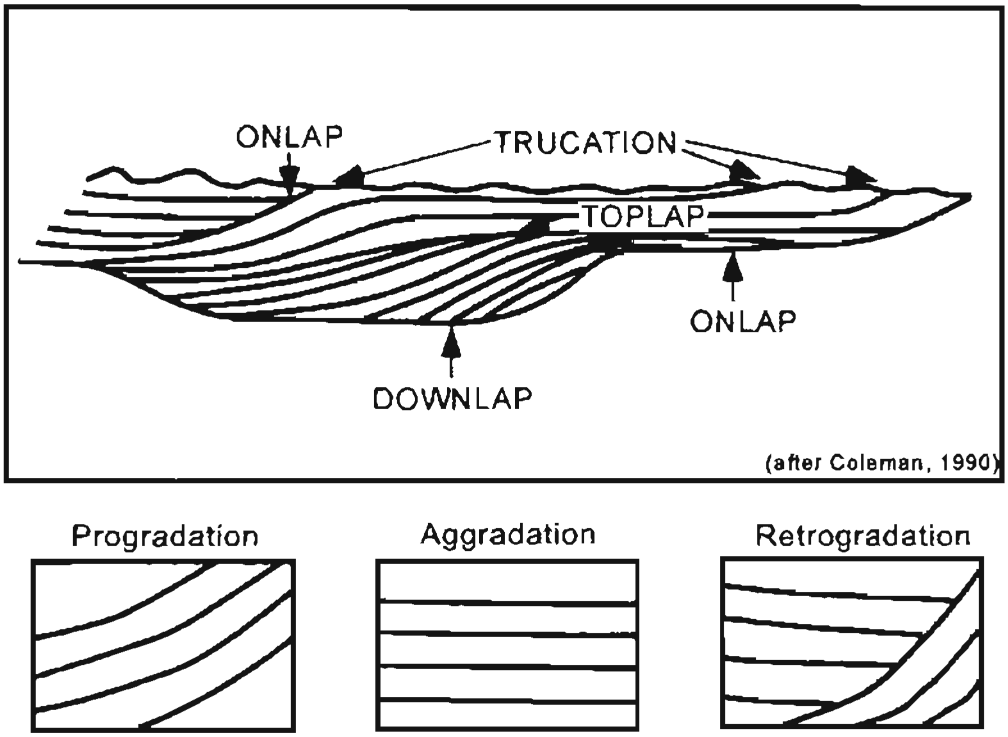
Seismic Sequence Stratigraphy

This is the analysis of subdividing a seismic section into packages of reflectors in continuity separated by reflectors of discontinuity (Figure 27). These individual packages are interpreted as distinct depositional events (Coleman, 1990). The reflector



(after Posamentier et al., 1988)

Figure 26. Sinusoidal eustatic sea level curve with derived depositional systems tracts, sequence stratigraphic surfaces and their associated facies.



(after Coleman, 1990)

Progradation

Aggradation

Retrogradation

(shingled reflectors)

(concordant reflectors)

(onlapping reflectors)

Figure 27. Seismic sequence stratigraphic reflector characteristics

packages are categorized by their geometric terminations into other reflectors as truncation, onlap, downlap or toplap (Mitchum, 1977).

Truncation. A reflector has once extended farther but has now been eroded or truncated by a fault plane (Mitchum, 1977).

Onlap. The termination of low angle reflectors against steeper reflectors, results from filling the of accommodation space with sediment (Mitchum, 1977).

Downlap. The termination of high angle reflectors against less steep reflectors, results from the progradation of sediments on to preexisting strata (Mitchum, 1977).

Toplap. The termination of reflectors against an overlying lower angle reflector, this surface is an unconformity (Mitchum, 1977).

Depositional Sequence

This term refers to a relatively conformable succession of genetically related strata bounded by unconformities. In vertical succession, all depositional sequences are composed of the following elements: bottom sequence boundary, lowstand systems tract, transgressive surface, transgressive systems tract, maximum flooding surface, highstand systems tract and top sequence boundary (Van Wagoner et al., 1990).

Parasequence

These cycles of deposition consist of a relatively conformable succession of genetically related beds bounded by marine flooding surfaces and their correlative boundaries. These can be stacked into parasequence sets that display trends in thickness and facies composition categorized as progradational, aggradational or retrogradational (Van Wagoner et al., 1990).

Progradational Parasequence Set Each parasequence advances farther seaward than that of the preceding parasequence, depositing a shallower set of facies than before. This results from the long-term rate of sedimentation exceeding that of accommodation space (Van Wagoner et al., 1990).

Aggradational Parasequence Set Each parasequence progrades to roughly the same position as the previous parasequence. This results in essentially a repeated set of facies from one parasequence to the next. This stacking pattern results when the long-term rate of accommodation closely matches the long-term rate of sedimentation (Van Wagoner et al., 1990).

Retrogradational Parasequence Set Each parasequence progrades basinward less than the preceding parasequence. This results in deposition of a deeper set of facies with each newly deposited parasequence. This stacking pattern results when the long-term rate of accommodation exceeds the long-term rate of sedimentation (Van Wagoner et al., 1990).

Sequence Boundary

This boundary is defined as unconformity updip and a correlative conformity downdip that is generated by a relative fall in sea level. It is subdivided into two classes: Type 1 and Type 2 sequence boundaries (Van Wagoner et al., 1990).

Type 1 Sequence Boundary Forms when the rate of eustatic sea level fall is greater than that of subsidence creating a subaerial exposure, a stream rejuvenation or a seaward shift of paralic facies and downward shift in coastal onlap (Coleman, 1990).

Type 2 Sequence Boundary Forms when the rate of eustatic sea level fall is less than basin subsidence creating no relative sea level fall and no basinward shift in facies. (Coleman, 1990)

Systems Tract

This feature is composed of three-dimensional assemblages of lithofacies that are defined by their position within the depositional sequence and by their parasequence stacking pattern. Each sequence consists of three systems tracts in this vertical succession, the lowstand, transgressive and highstand systems tracts (Van Wagoner et al., 1990).

Lowstand Systems Tract Is characterized as overlying a Type 1 sequence boundary, capped by a transgressive surface, and is composed of progradational and / or aggradational parasequence sets (Van Wagoner et al., 1990).

Transgressive Systems Tract Is characterized as overlying a transgressive surface, capped by a maximum flooding surface, and is composed of retrogradational parasequence sets (Van Wagoner et al., 1990).

Highstand System Tract Is characterized as overlying a maximum flooding surface, capped by a sequence boundary, and is composed of aggradational and / or progradational parasequence sets (Van Wagoner et al., 1990).

Transgressive Surface

The lowstand systems tract is capped by a prominent flooding surface referred to as the transgressive surface. It represents the first major flooding surface to follow the sequence boundary and is distinct from other minor flooding events before in that it will transgress the existing basin.

Maximum Flooding Surface

The transgressive systems tract is capped by this surface. It marks the turnaround from the retrogradational parasequence stacking found in the transgressive systems tract to the aggradational or progradational parasequence stacking found in the early highstand systems tract. This flooding surface represents the last of the significant flooding surfaces found in the transgressive systems tract and has the widest landward extent forming a condensed section of marine sediments. These deep marine shales accumulate slowly and are commonly radiogenic or "hot" and display a strong positive response on gamma ray logs (Emery and Myers, 1996). This surface is seismically resolved as a toplapping unconformity.

Sequence Stratigraphic Model of a Growth Faulted Margin

The geologic setting of the TCB field Vicksburg formation is that of a growth faulted passive-margin setting (Taylor and Al-Shaieb, 1986). This type of setting needs the application of a different sequence stratigraphic model than that of the typical shelf-slope depositional setting. Within these extensional growth faulted and folded mature passive margin settings, depositional patterns are strongly affected by syndepositional movement and sediment creep. The interaction of syndepositional movement with varying rates of sedimentation and relative sea level change introduces further complexity in the use of sequence stratigraphic models. Conventional sequence stratigraphic models can be modified to include a fourfold history in relating growth fault development to the relative sea level cycle in the Cenozoic Gulf of Mexico strata (Emery and Myers, 1996).

In the Gulf of Mexico's growth faulted margins, Stage 1 is represented by the earliest development of lowstand units with the deposition very thick lowstand basin floor fans due to the great topographic relief between the hanging-wall and footwall of the fault. Stage 2 is a second phase of fault movement that is characterized by slow fault movement that reflects a contractional toe in the hanging wall. This results in a depositional phase of lowstand prograding complexes found within each parasequence. These parasequences will display an overall trend that is progradational becoming aggradational in their stacking patterns. Stage 3 is a phase of no differential fault growth that is characterized by the filling of the remaining topography between the hanging-wall and footwall. This filling results in a retrogradational stacking of parasequences. Stage 4 begins as the complete filling and lack of relief between the footwall and hanging-wall areas result in a continuity of progradation across the fault zone (Emery and Myers, 1996).

A model for the interpretation of the sequence stratigraphy along a growth-faulted margin was constructed (Figure 28). This model explains the facies location, stages of fault movement and sequence stratigraphic surface locations found in this depositional system through time (Figure 29). This model was applied to the Vicksburg formation in the TCB field area for the interpretation the sequence stratigraphy in this study.

Application of the Sequence Stratigraphic Model in Interpretation

The sequence stratigraphic interpretation of the Vicksburg formation in the TCB field area of interest is based on the integration of a chronostratigraphic chart, patterns of core based well log lithologies, well log resolved sequence stratigraphic surfaces and seismic sequence stratigraphy. These separate sources of data were assembled and applied to the previously mentioned model (Figure 28 & 29). The criterion set forth in this model fit the TCB field Vicksburg interpretation of surfaces and strata and corresponds to a single depositional sequence by the definition within this chapter. These interpretations are explained herein.

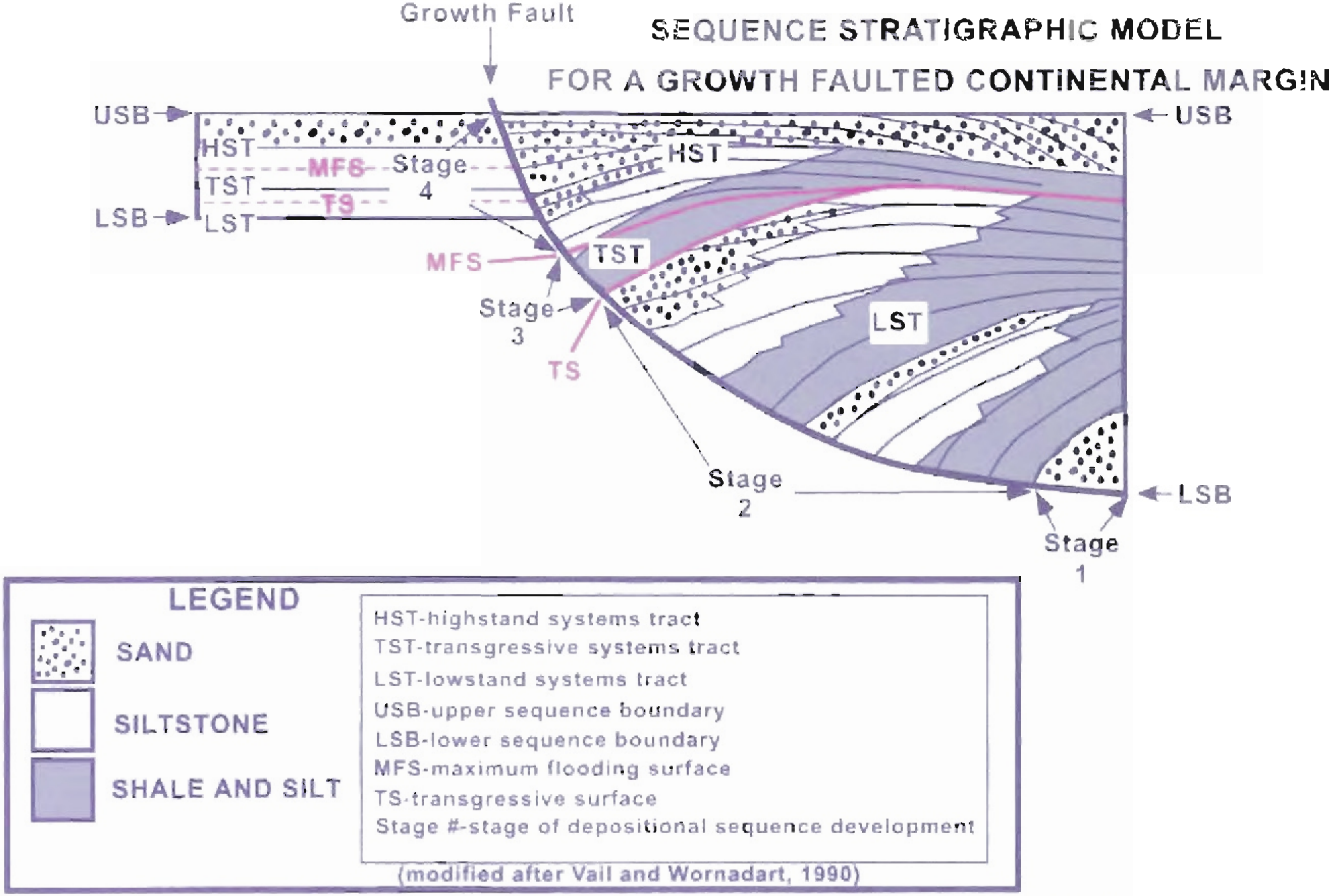


Figure 28 Sequence stratigraphic model for a growth faulted continental margin.

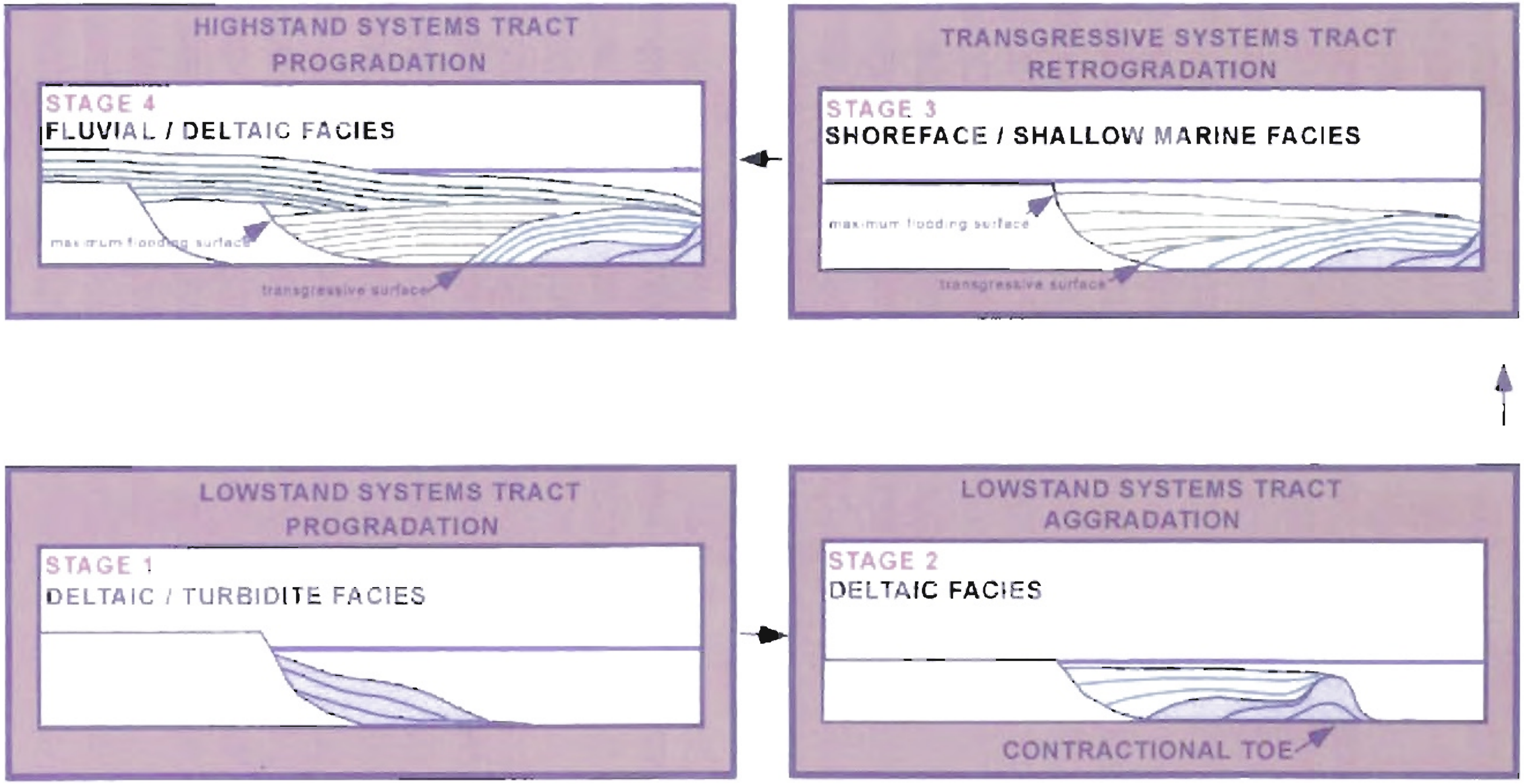


Figure 29 Developmental stages of the sequence stratigraphic model

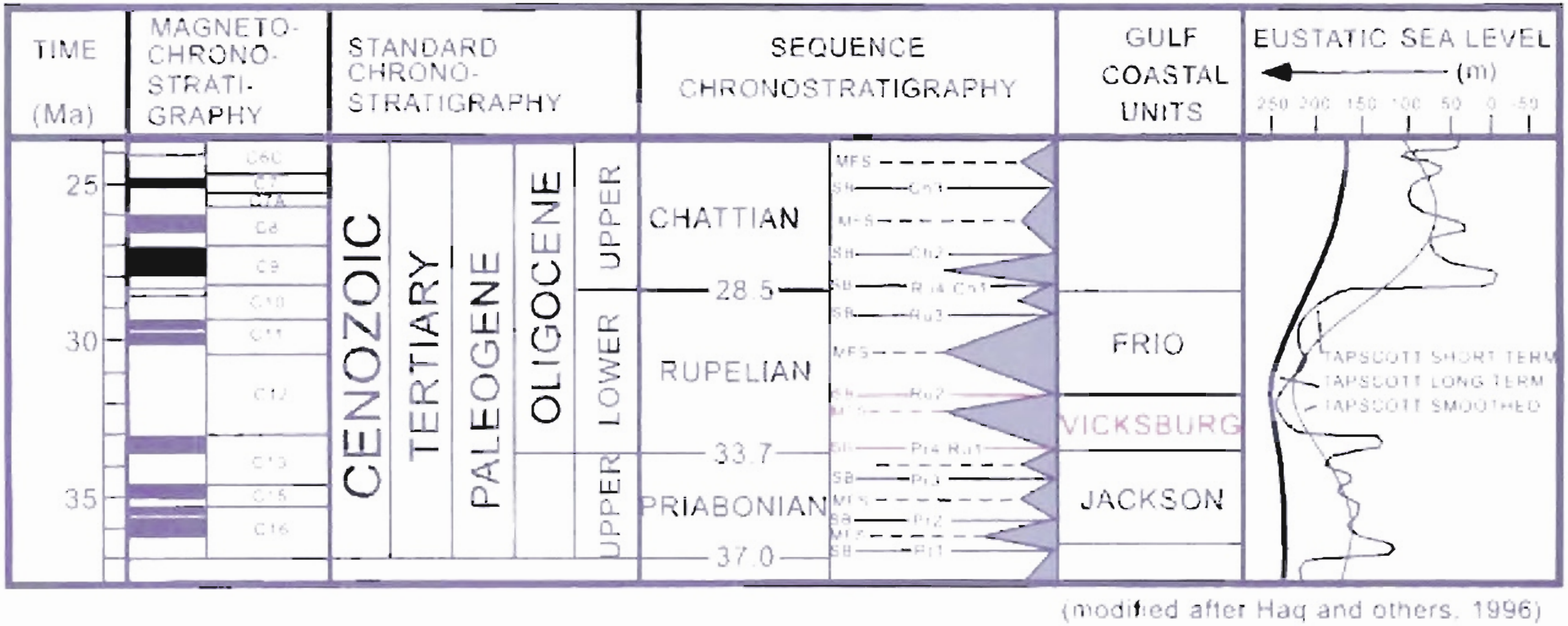
Chronostratigraphic Chart

Sequence stratigraphy involves the interpretation of the relationship between deposition and time. This is accomplished by combining sea level change, degree of coastal onlap, and stratigraphic data with time to build an understanding of nondeposition, erosion, and flooding surface characteristics in the depositional system (Emery and Myers, 1996). The resulting combination of data produces a chart that aids in the interpretation of sequence stratigraphy by ensuring the interpretation makes sense with regards to time and sediment deposition.

A chronostratigraphic chart was constructed for the Gulf Coastal Units found in the TCB field area (Figure 30). The chart illustrates an eustatic sea level rise at the top of the Eocene Jackson formation that produced a coastal incursion of the sea forming a maximum flooding surface. The sea then regressed, thus completing the Oligocene Vicksburg depositional sequence. The sea level again rose in the Lower Oligocene beginning the Frio depositional sequence.

Well Log Lithofacies

The core to well log calibrated lithofacies (Chapter 3) was assembled into a lithofacies-stacking pattern (Van Wagoner et al., 1990). This pattern analysis of well log facies was interpreted according to the trend of spontaneous potential and resistivity



(modified after Haq and others, 1996)

Figure 30. Chronostratigraphic chart illustrating the eustatic sea level relationship to deposition during the Oligocene Vicksburg time.

of the well log and the general facies interpretations for the Upper, Middle and Lower Vicksburg.

The E.G. Canales #18 wire-line log was used to illustrate the interpretation found within the TCB Vicksburg formation (Figure 31). This interpretation demonstrates the repetitive parasequences in the Lower Vicksburg, each being roughly the same thickness and having similar SP and resistivity responses. This is interpreted as being an aggradational stacking pattern in the lowstand systems tract as each parasequence roughly progrades to the same extent in the basin. This corresponds to Stage 2 of the sequence stratigraphic model.

The retrogradational portion of the interpretation exhibits a lack of contrast and a noticeable lessening of the sand / mud ratio with decreasing depth that is correlated to a transgression causing a back stepping of facies from deltaic in the Lower Vicksburg to shoreface / shallow marine in the Middle Vicksburg. This transgressive event begins at the top of the 10250 ft. interval and continues into the 9400 ft. interval. This is the transgressive systems tract and corresponds to Stage 3 of the sequence stratigraphic model.

The progradational phase of the well log lithofacies pattern sequence stratigraphic interpretation begins at the top of the 9400 ft. interval and continues vertically to the top of the Vicksburg; the Wilson sand. This progradation of parasequences corresponds to Stage 4 of the sequence stratigraphic model of the Vicksburg formation, and this log profile is interpreted as the highstand systems tract of the Vicksburg depositional sequence.

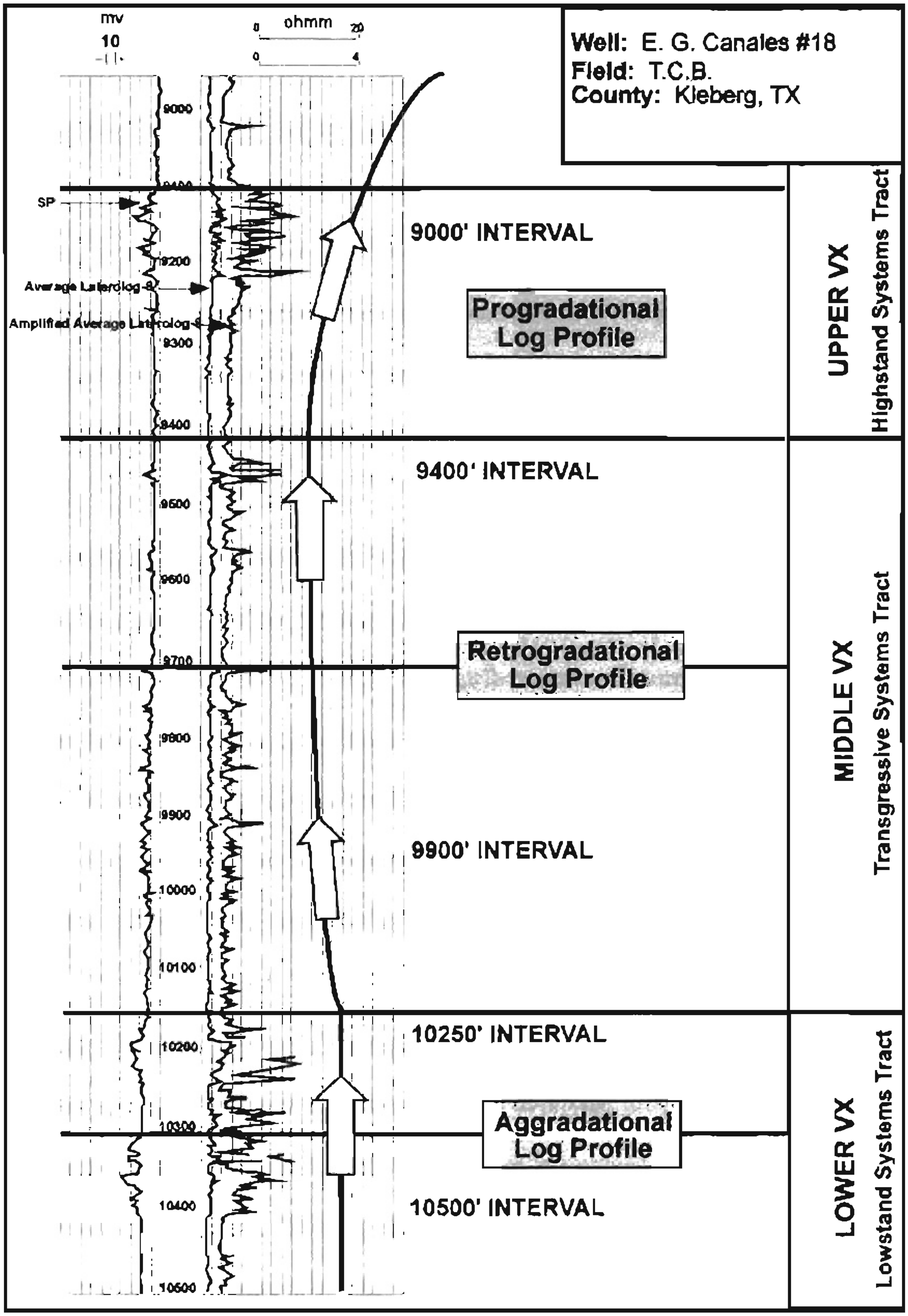


Figure 31. Well log lithofacies interpreted for sequence stratigraphic parasequence stacking patterns and systems tracts.

Well Log Sequence Stratigraphic Surface Identification

Two key stratigraphic surfaces need to be identified on wire-line log data before it can be interpreted into the appropriate component systems tracts. These surfaces are the Transgressive Surface and the Maximum Flooding Surface (MFS). These surfaces were located on well log data in the TCB field and used to separate Vicksburg systems tracts.

Transgressive Surface This surface is expressed on well log data as the surface between a prograding or aggrading parasequence set and an overlying retrograding parasequence set (Emery and Myers, 1996). This surface marks the turn-around point between progradation and retreat in the basin, and it is located at the top of the 10250 ft. interval in the TCB field stratigraphy of the Vicksburg formation (Figure 32). The transgressive surface lies at the boundary between the lowstand systems tract and the transgressive systems tract in the sequence stratigraphic model employed in this study.

Maximum Flooding Surface This surface is located on well log data as the surface between a retrograding parasequence set and an overlying prograding parasequence set (Emery and Myers, 1996). This surface is resolved on gamma ray log data as a gamma maximum peak. This log feature is found within the 9400 ft. interval in the TCB field stratigraphy (Figure 33). The maximum flooding surface lies at the

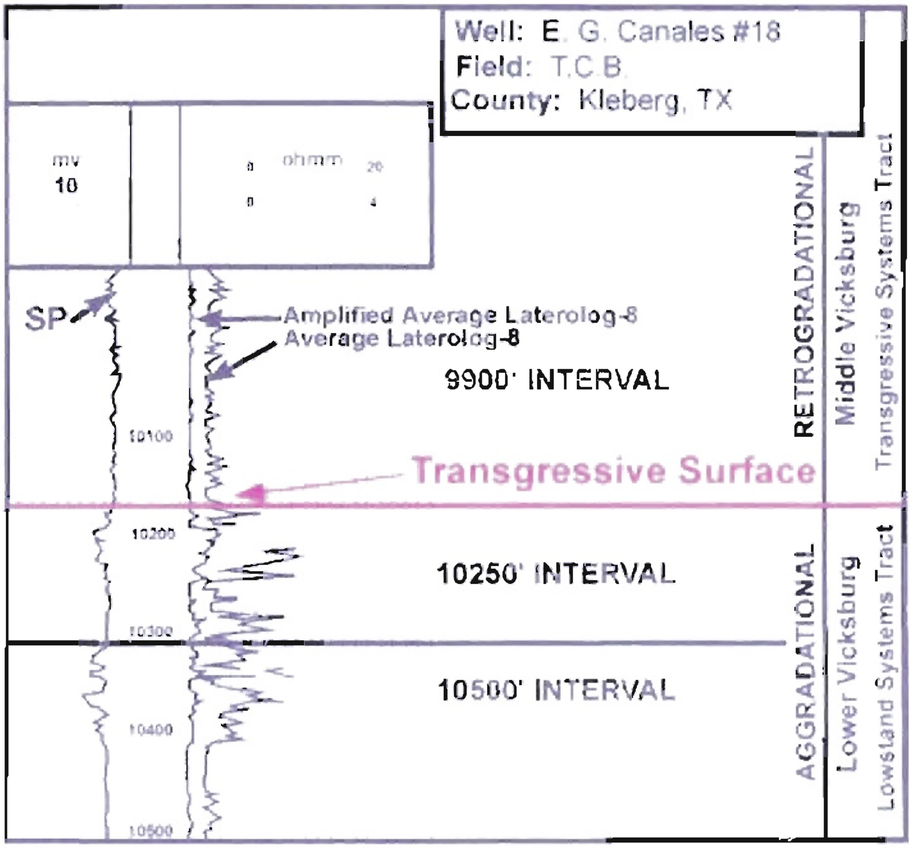


Figure 32 Well log response of the Transgressive Surface separating the Lowstand Systems Tract from the Transgressive Systems Tract

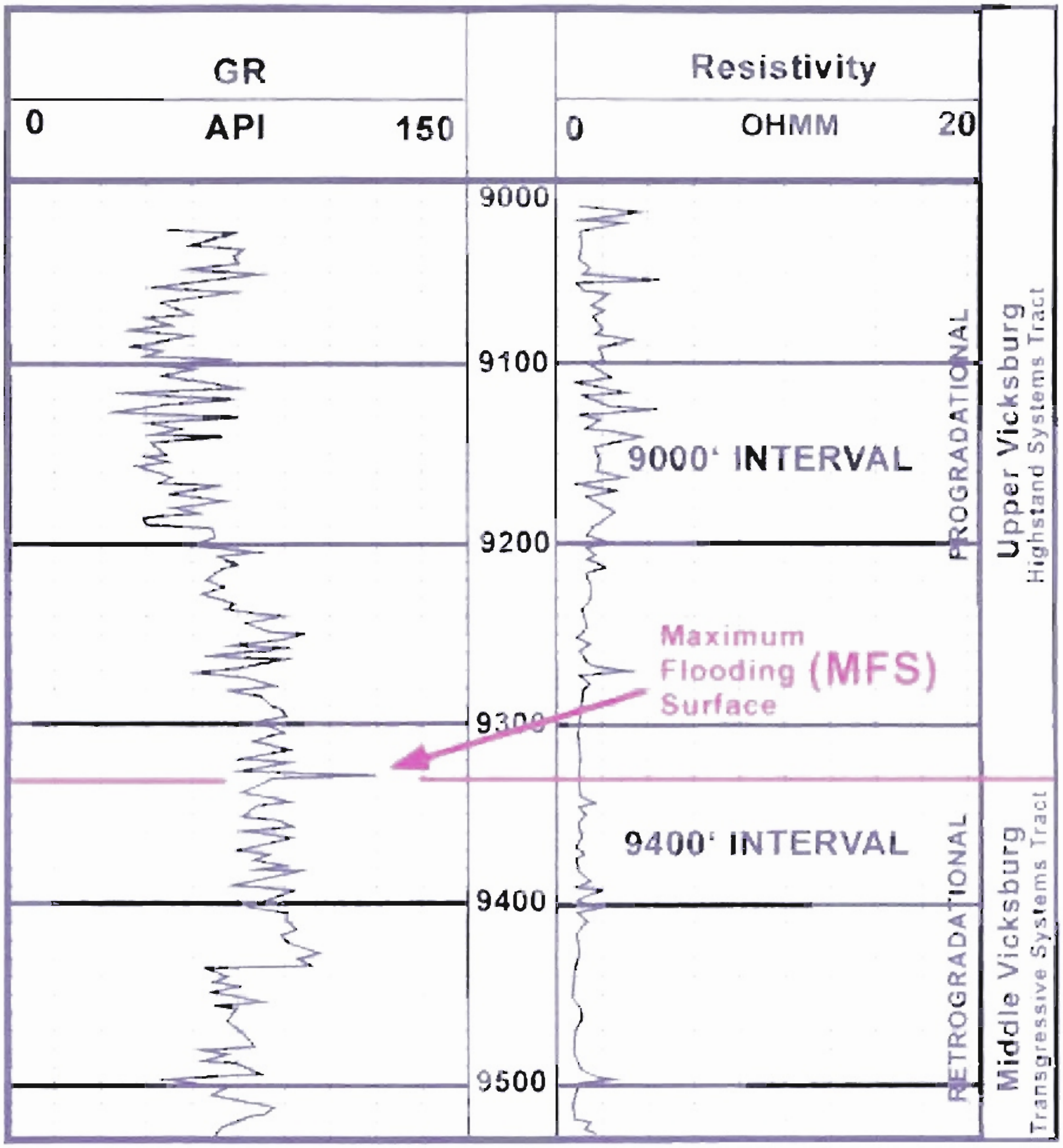


Figure 33. A. T. Canales #81 well log showing characteristic gamma-ray response of the Maximum Flooding Surface (MFS) found within the 9400 ft. interval

boundary between the transgressive systems tract and the highstand system tract in the Vicksburg sequence stratigraphic model.

Seismic Sequence Stratigraphy of the Vicksburg

The first step of seismic based sequence stratigraphic analysis is to divide the seismic data into natural stratigraphic packages of reflectors that make up the section. All reflectors do not go forever, but terminate against another reflector. Where reflections terminate in a consistent manner they define a seismic surface. Separating these surfaces of reflection terminations result in the division of the seismic data into a number of depositional packages containing relatively conformable reflections that are bounded by reflectors of a different geometry that represents a different depositional history.

The dip oriented seismic section Inline 329 (Plate I & II) across TCB field was interpreted for reflection characteristics that correspond to sequence stratigraphic surfaces and packages in order to determine the Vicksburg formation's depositional history. The interpretation of the Vicksburg strata within TCB field is located on Plate III. The sequence stratigraphic model was applied in the interpretation of the Vicksburg formation (Figure 28 & 29). For the Vicksburg to be considered a depositional sequence it must contain a seismically resolved lower sequence boundary, lowstand systems tract, transgressive surface, transgressive systems tract, maximum flooding surface, highstand systems tract and an upper sequence boundary. Following are descriptions of the seismic reflection characteristics of the above depositional sequence (Plate III).

Lower Sequence Boundary (LSB). This is represented seismically as a reflector that can be followed across the section. This horizon is the detachment surface located between the underlying Jackson strata and overlying Vicksburg strata. This surface is a Type 1 sequence boundary, as there was a basinward shift of paralic facies with the increase in eustatic sea level at the end of Eocene and the beginning of the Oligocene (Figure 30) (Coleman, 1990). The swells along the detachment surface are interpreted as being pieces of the Jackson shale that Vicksburg sediments slide upon during the detachment process (Figure 5) (Plate III).

Lowstand Systems Tract (LST). This package of reflectors is identified by their aggradational stacking pattern (Figure 27). This interpretation is attributed to the relative conformable thickness and orientation of each seismic reflection between the 11800 ft. sand and the 10250 ft. sand, which collectively are called the Lower Vicksburg. This corresponds to Stage 2 of the sequence stratigraphic model (Figure 28 & 29). Stage 1 of the depositional sequence occurs further basinward off of the Canales area of interest (Plate III).

Transgressive Surface. This surface is seismically imaged as the 10250 ft. sand reflector. This surface marks the top of the lowstand systems tract or end of lowstand aggradation and the base of the transgressive systems tract of the depositional system as is illustrate in the sequence stratigraphic model (Figure 28 & 29). The seismic reflector patterns change from conformable, aggradational below this surface to that of an onlapping, retrogradational set of reflectors above this surface (Figure 27) (Plate III).

Transgressive Systems Tract. This set of reflectors is identified by their onlapping nature of retrograding parasequences (Figure 27). This systems tract, which corresponds to the Middle Vicksburg, begins at the top of the 10250 ft. sand reflector and ends at the 9400 ft. sand reflector. This package of reflectors corresponds with Stage 3 of the sequence stratigraphic model used in this study (Figure 27) (Plate III).

Maximum Flooding Surface. This surface is seismically resolved as a toplapping reflector that can be carried across the TCB field (Figure 27). The maximum flooding surface marks the end of retrogradation or the transgressive systems tract and the beginning of highstand progradation. This surface is found at the 9400 ft. sand reflector and is toplapping unconformably onto underlying seismic surfaces as is illustrated in the sequence stratigraphic model (Figure 28 & 29) (Plate III).

Highstand Systems Tract. This prograding systems tract is seismically imaged as packages of shingled downlapping reflectors (Figure 27). The highstand systems tract begins at the top of the 9400 ft. sand reflector and ends at the top of the Vicksburg formation Wilson sand reflector. This interval of strata is known as the Upper Vicksburg. The final stage of the depositional sequence development or Stage 4 of the sequence stratigraphic model corresponds to this set of prograding highstand reflectors (Figure 28 & 29) (Plate III).

Upper Sequence Boundary. This surface corresponds to the Wilson sand reflector. The upper sequence boundary completes the Vicksburg depositional sequence, and Coleman (1990) interpreted this boundary as a Type 2 sequence boundary because the overlying Oligocene Frio formation was deposited conformably onto the Oligocene Vicksburg strata. A minor drop in eustatic sea level caused the Vicksburg / Frio contact to shift from progradational to aggradational in parasequence stacking (Figure 30) (Plate III).

Extent of the Systems Tracts

The Vicksburg depositional sequence was broken into the three appropriate Lowstand, Transgressive and Highstand Systems Tracts based on the seismic surfaces and sequence stratigraphic interpretations of reflector patterns. The thickness for each systems tract was mapped in time (milliseconds), but can be converted using the general time-depth conversion of 5 feet of thickness for every millisecond or by using Figure 20 for greater precision. These maps illustrate the extent, thickness, and structural timing of each systems tract across the TCB area of interest (Plate III).

Lowstand Isochron (Plate III)

This map portrays the evolution of this particular systems tract. The lowstand systems tract was deposited in a small region as it prograded and slide along the detachment surface creating a topographic relief between the hanging-wall and footwall of the TCB fault (Diegel and others, 1995) (Figure 5). This feature corresponds to Stage 1 and Stage 2 of the sequence stratigraphic model. The thickening of sediments into the listric growth fault is indicated by the color bar, reds are the sediment thicks and blues are the sediment thins. Fault contacts are given on the map with the triangles; upward points are footwalls and downward points are the hanging-walls of the antithetic and synthetic faults associated with the structural style.

Transgressive Isochron (Plate 3)

This map of the Transgressive Systems Tract demonstrates the same trend as the previous tract, except this depositional set of parasequences is infilling the accommodation space left by the movement along the detachment of the lowstand systems tract (Stage 2) forming a noticeable thickening into the TCB fault zone and then the systems tract is thinning on to the crest of the rollover anticline structure beneath until nondeposition occurs, known as toplapping. This trend corresponds to Stage 3 of the sequence stratigraphic model (Figure 5). The sediment thickness color scheme and fault contact symbols remain the same as before.

Highstand Isochron (Plate III)

This map displays the wide area the Upper Vicksburg is deposited in as this highstand systems tract progrades out into the basin with the eventual complete filling and lack of relief along the fault trend. Noticeable thickening is not evident in the region of the TCB growth fault zone as the deltaic sediments prograded over the fault and extension along this detachment zone is complete. This trend of deposition corresponds to Stage 4 of the sequence stratigraphic model. Faulting by both the synthetic and antithetic types still are affecting this interval as some movement is still taking place, however this movement is not affecting deposition in the TCB field.

Conclusion

The Vicksburg Depositional Sequence is a complex interaction of eustatic sea level change, coastal onlap, and growth fault movement. The results of this interaction are the generation of systems tracts containing distinct distributions of facies. This entire system of intermingling influences can be modeled into four stages of development (Figure 34). The model can be applied to other growth faulted continental margins to predict the sequence stratigraphy and depositional facies of the system.

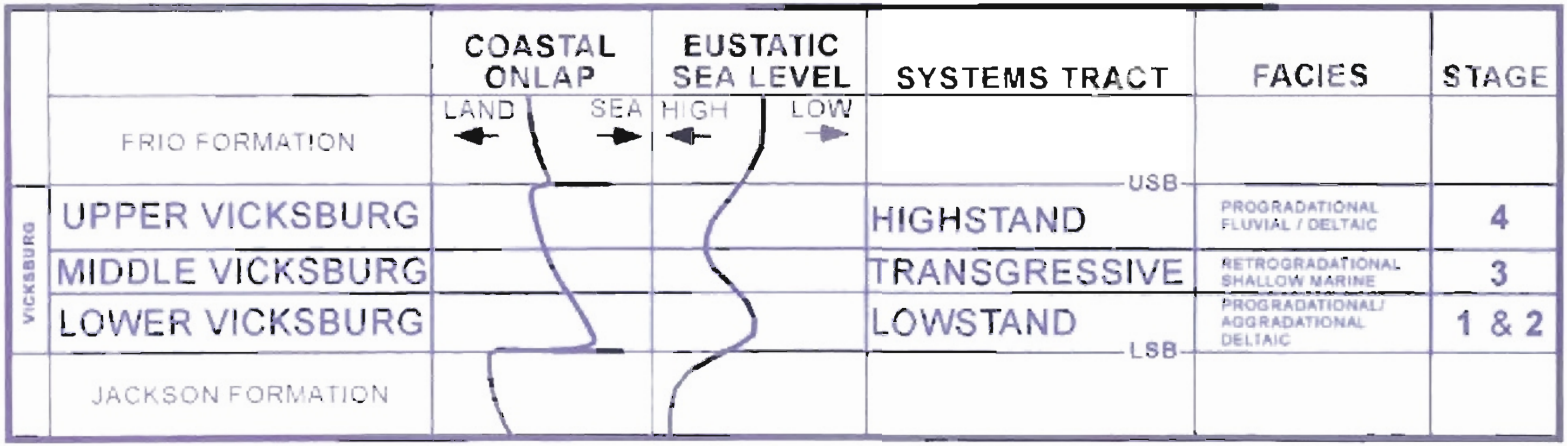


Figure 34. The Vicksburg Depositional Sequence

Chapter 6

CONCLUSIONS

The principal conclusions of this study are as follows:

1. The Vicksburg formation was deposited in a high accommodation depositional setting that was directly related to the variable rate of syndepositional listric normal fault movement and eustatic sea level change.

2. This depositional style influenced the type of facies deposited in the Vicksburg.

3. The Vicksburg formation in the South Texas TCB field forms a complete depositional sequence. This sequence contains a lower sequence boundary, lowstand system tract, transgressive surface, transgressive system tract, maximum flooding surface, highstand systems tract and an upper sequence boundary.

4. The lower sequence boundary of the Vicksburg depositional sequence is a Type 1 boundary formed at the base of the Oligocene Vicksburg formation and top of the Eocene Jackson Group.

5. The lowstand systems tract in the Vicksburg depositional sequence corresponds with the Lower Vicksburg. This systems tract is composed of repetitive aggradational

parasequences that are deltaic in origin and resolved both seismically and with wire-line well log data.

6. The transgressive surface in the Vicksburg depositional sequence is resolved both seismically and by wire-line well log data as the top of the 10250 ft. sand interval.

7. The transgressive systems tract in the Vicksburg depositional sequence corresponds with the Middle Vicksburg. This systems tract is composed of retrogradational parasequences that are shallow marine / shoreface in origin and resolved both seismically and with wire-line well log data.

8. The maximum flooding surface of the Vicksburg depositional system is resolved both seismically and by wire-line well log data as the 9400 ft. sand interval.

9. The highstand systems tract of the Vicksburg depositional system corresponds with the Upper Vicksburg. This system tract is composed of prograding parasequences that are fluvial / deltaic in origin and resolved both seismically and with wire-line well log data.

10. The upper sequence boundary of the Vicksburg depositional sequence is a Type 2 boundary formed at the top of the Vicksburg Wilson sand interval and base of the overlying Oligocene Frio formation.

11. The Vicksburg sequence can be modeled in four stages of development. These four stages are related to both growth fault movement and eustatic sea level change.

REFERENCES

Coleman, J. Combes, and Galloway, W. E., Petroleum geology of the Vicksburg Formation, Texas: Gulf Coast Association of Geological Societies Transactions, v. 40, 1990, p. 119-130.

Coleman, J. M., and Prior, D. B., Deltaic environments of deposition, in Sholle, P. A., and Spearing, D. R., eds., Sandstone depositional environments: American Association of Petroleum Geologists Memoir 31, 1982, p. 139-178.

Coleman, J. M. C., Depositional systems and tectonic / eustatic history of the Oligocene Vicksburg episode of the Northern Gulf Coast, The University of Texas at Austin, Ph.D. dissertation, 1990.

Combes, J. M., "The Vicksburg Formation of Texas: Depositional systems Distribution, Sequence Stratigraphy, and Petroleum Geology", American Association of Petroleum Geologists Bulletin, v. 77, no. 11, 1993.

Diegel, F. A., Karlo, J. F., Schuster, D. C., Shoup, R. C., and Tauvers, P. R., 1995, Cenozoic Structural Evolution and Tectono-Stratigraphic Framework of the Northern Gulf Coast Continental Margin. In: American Association of Petroleum Geologists Memoir No. 65: Salt Tectonics: A Global Perspective, Chapter 6. p. 109-151.

Emery, D., and Myers, K., 1996, Sequence Stratigraphy. Blackwell Science, London, 297 p.

Galloway, W. E., 1989, Genetic Stratigraphic Sequences in Basin Analysis II: Application to Northwest Gulf of Mexico Cenozoic Basin. American Association of Petroleum Geology Bulletin, v. 73, No. 2, p. 143-154.

Han, J. H., 1981, Genetic stratigraphy and associated structures of the Vicksburg Formation, South Texas: The University of Texas at Austin, Ph.D. dissertation, 162 p.

International Oil Scouts Association, International Oil and Gas Development Yearbook, Review of 1995 Production, v. 66, 1997, 1071p.

Langford, R. P., and Combes, J. M., 1994, Depositional Environments of Unstable Shelf-

Margin Deltas of the Oligocene Vicksburg Formation, McAllen Ranch Field, South Texas. The University of Texas at Austin, Bureau of Economic Geology Report No. 219, 60 p.

McQuillin, R., Bacon, M. & Barclay, W., 1984, An Introduction to Seismic Interpretation. Graham and Trotman, London, 287 p.

Mitchum, R. M., Jr., Sangree, J. B., Vail, P. R. & Wornardt, W. W.,1990, Sequence stratigraphy in Late Cenozoic expanded sections, Gulf of Mexico, In: Sequence Stratigraphy as an Exploration Tool: Concepts and practices from the Gulf Coast. Eleventh Annual Research Conference, Gulf Coast Section, Society of Economic Paleontologists and Mineralogists, p. 237-256.

Mitchum, R. M., Jr. and Vail, P. R., 1977, Seismic stratigraphy and global changes of sea level, part 7: stratigraphic interpretation of seismic reflection patterns in depositional sequences. In: Seismic Stratigraphy-Applications to Hydrocarbon Exploration. American Association of Petroleum Geologists Memoir 26, p. 135-144.

Petroleum Information / Dwight's, Natural Gas Well Production Histories, 1999.

Posamentier, H. W. & Allen, G. P., 1993, Siliciclastic sequence stratigraphic patterns in foreland ramp type basins. Geology, 21, 455-458.

Rahmanian, V. D., Thering, M. L., and Ely, P. B., 1996, Sequence Stratigraphic Controls on Reservoir Compartmentalization, Hydrocarbon Distribution and Optimization of Field Development Process: Vicksburg Trend, South Texas, U.S.A.: Abstract. American Association of Petroleum Geologists. V. 80 p. A117.

Shelton, J. W., 1984, Listric Normal Faults: An Illustrated Summary. American Association of Petroleum Geologists. V. 68, No. 7, p. 801-815.

Taylor, D. A., and Z. Al-Shaieb, "Oligocene Vicksburg sandstones of the Tijerinia-Canales- Blucher field: a south Texas jambalaya", Gulf Coast Association of Geological Societies Transactions, v. 36, 1986, p. 315-339.

Van Wagoner, J.C., Mitchum, R. M., Jr., Campion, K. M. & Rahmanian, V. D., 1990, Siliciclastic Sequence Stratigraphy in Well Logs, Cores and Outcrop: Concepts for High Resolution Correlation of Time and Facies. American Association of Petroleum Geologists Methods in Exploration Series, Tulsa, 7, 55 p.

Winker, C. D., and Edwards, M. B., 1983, Unstable progradational clastic shelf margins: Society of Economic Paleontologists and Mineralogists Special Publication No. 33, p. 139-157.

Plates 1, 2, and 3

PLATE I


WEST
INLINE 329
EAST
UNINTERPRETED DIP LINE
TRC 634 630
CDP 634
620
610
600
600
590
580
570
560
550
550
540
530
520
510
500
500
490
480
470
460
450
450
440
430
420
410
400
400
390
380
370
360
350
350
340
330
320
310
300
300
290
280
270
260
250
250
240
230
220
210
197 TRC
197 CDP
0.364
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.584
ey001
migration
ILN 329
Time

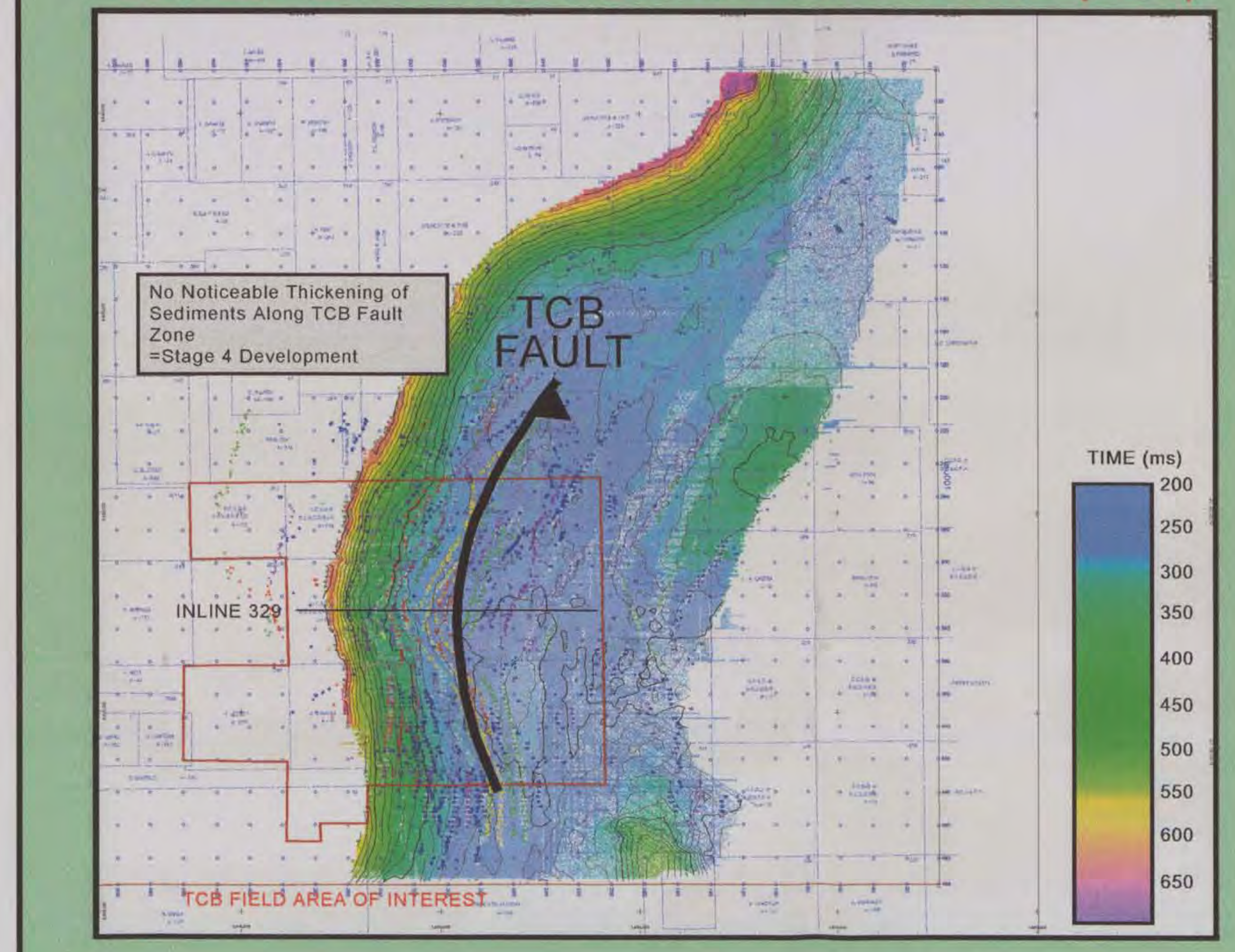
PLATE II


WEST
INLINE 329
EAST
OLIGOCENE FRIO
OLIGOCENE VICKSBURG
EOCENE JACKSON
DETACHMENT SURFACE
0.364
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.564
TCB Stratigraphy
Wilson(TPVX)
8800' sand
9000' sand
9400' sand
9900' sand
10250' sand
10500' sand
10600' sand
11000' sand
11800' sand

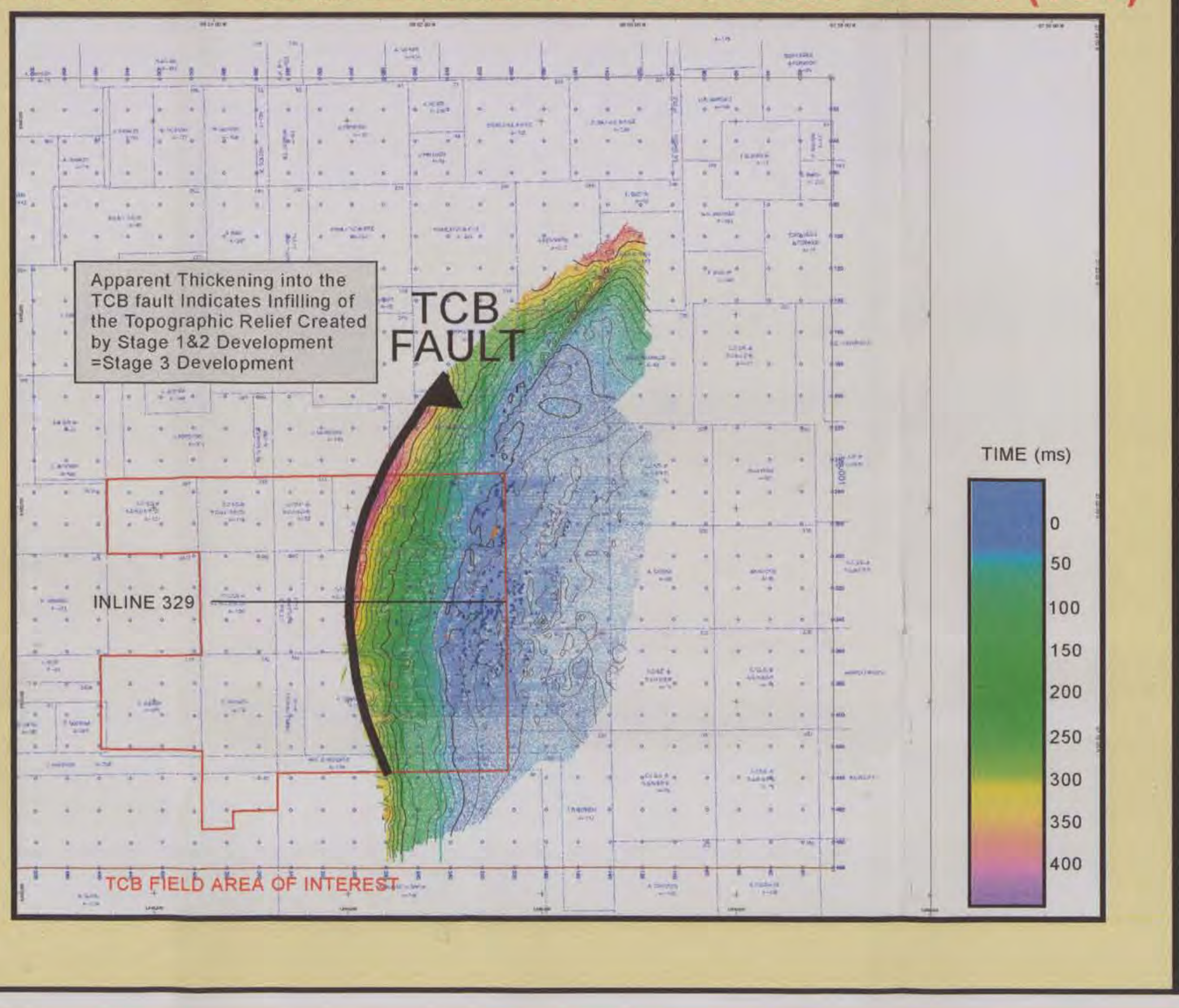
SEQUENCE STRATIGRAPHY OF THE TCB FIELD AREA

PLATE III

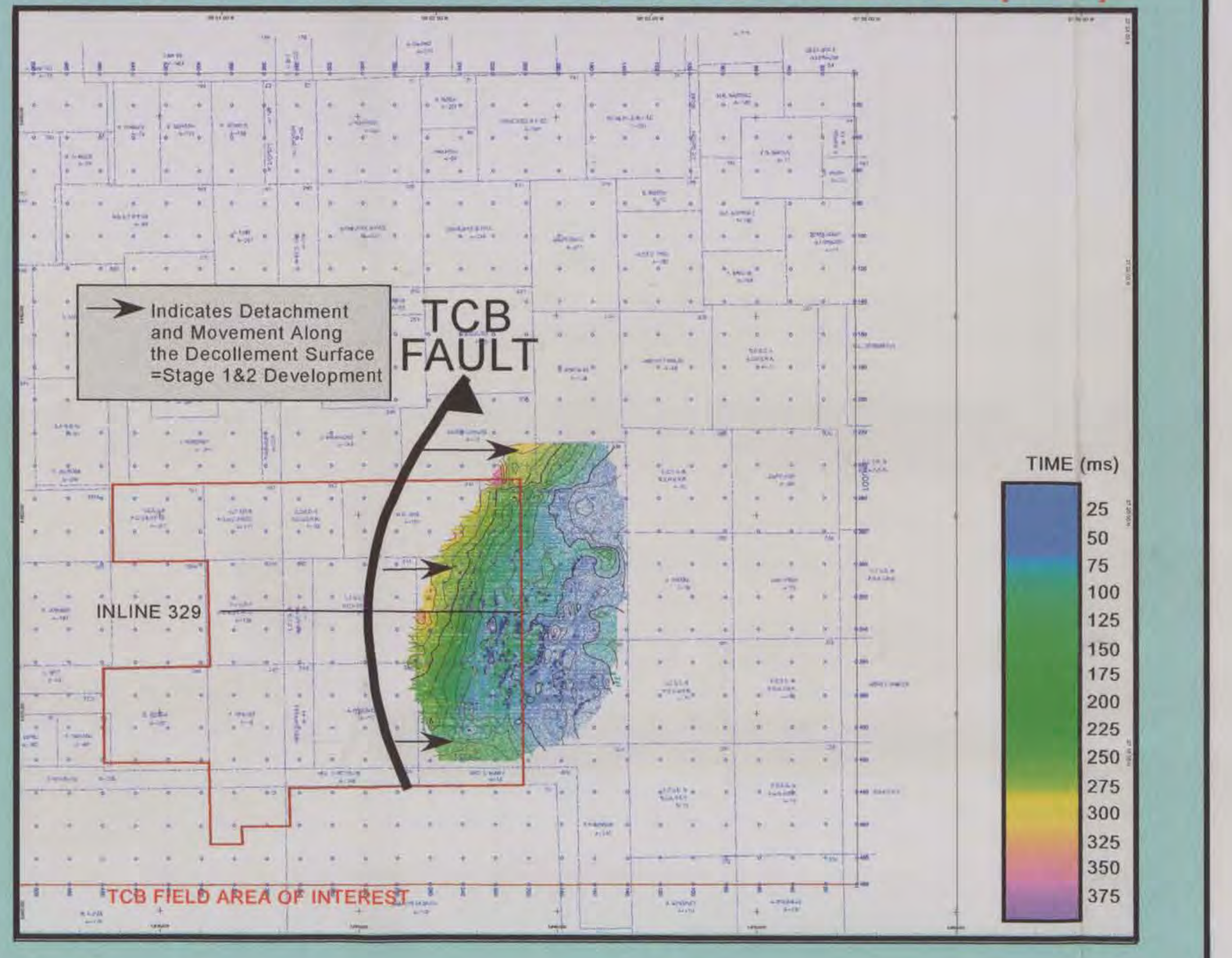
EXTENT OF HIGHSTAND SYSTEMS TRACT (HST)

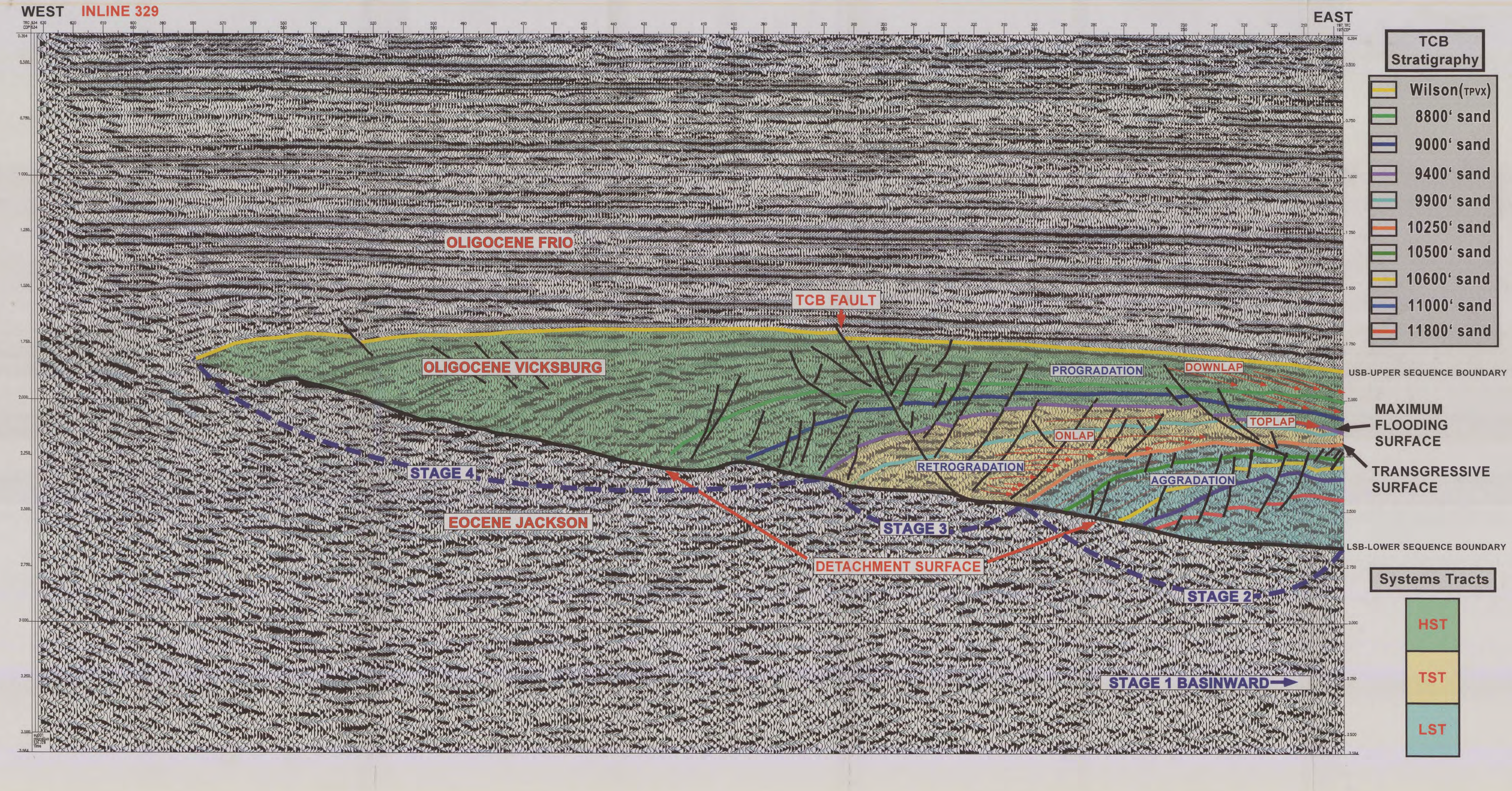


EXTENT OF TRANSGRESSIVE SYSTEMS TRACT (TST)



EXTENT OF LOWSTAND SYSTEMS TRACT (LST)





VITA

Ryan Edward Birkenfeld

Candidate for the Degree of

Master of Science

Thesis: SEQUENCE STRATIGRAPHY AS A CONTROL OF DEPOSITIONAL FACIES IN THE OLIGOCENE VICKSBURG FORMATION, TCB FIELD, KLEBERG COUNTY, TEXAS

Major Field: Geology

Biographical:

Personal Data: Born in Pryor, Oklahoma on September 27, 1976, the son of Ralph and Patty Birkenfeld.

Education: Graduated from Pryor High School, Pryor, Oklahoma in May 1995; received Bachelor of Science degree in Geology from Oklahoma State University, Stillwater, Oklahoma in December 1998. Completed the requirements for the Master of Science degree with a major in Geology at Oklahoma State University in December 2000, with degree granted in May 2001.

Experience: Research Assistant for Dr. Al-Shaieb, 2000. Employed by Exxon Exploration Company, West African Regional (WAR) Group as an intern, 1999.