Report Title

"T-R Cycle Characterization and Imaging: Advanced Diagnostic Methodology for Petroleum Reservoir and Trap Detection and Delineation"

Type of Report

Fourth Quarterly Progress Report for Year 2

Reporting Period Start Date

06/01/05

Reporting Period End Date

08/31/05

Principal Author

Ernest A. Mancini (205/348-4319)
Department of Geological Sciences
Box 870338
202 Bevill Building
University of Alabama
Tuscaloosa, AL 35487-0338

Date Report was Issued

09/19/05

DOE Award Number

DE-FC26-03NT15409

Name and Address of Participants

Ernest A. Mancini	William C. Parcell	Bruce S. Hart
Dept. of Geological Sciences	Department of Geology	Earth & Planetary Sciences
Box 870338	Wichita State University	McGill University
Tuscaloosa, AL 35487-0338	Wichita, KS 67260	Montreal, CANADA

Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Abstract

The principal research effort for Year 2 of the project is on stratigraphic model assessment and development. The research focus for the first six (6) months of Year 2 is on T-R cycle model development. The emphasis for the remainder of the year is on assessing the depositional model and developing and testing a sequence stratigraphy model. The development and testing of the sequence stratigraphy model has been accomplished through integrated outcrop, well log and seismic studies of Mesozoic strata in the Gulf of Mexico, North Atlantic and Rocky Mountain areas.

TABLE OF CONTENTS

"T-R Cycle Characterization and Imaging: Advanced Diagnostic Methodology for Petroleum Reservoir and Trap Detection and Delineation"

Fourth Quarter Report for Year 2
June 1, 2005 – August 31, 2005

Introduction

The University of Alabama, Wichita State University and McGill University have undertaken a cooperative 3-year research project involving the characterization and modeling of transgressive-regressive (T-R) cycles to facilitate exploration for underdeveloped and undiscovered petroleum resources associated with stratigraphic traps and with specific facies in continental and coastal geologic systems that have reservoir potential.

Executive Summary

The principal research effort for Year 2 of the project is on stratigraphic model assessment and development. The research focus for the first six (6) months of Year 2 is on T-R cycle model development. The emphasis for the remainder of the year is on assessing the depositional model and developing and testing a sequence stratigraphy model. The development and testing of the sequence stratigraphy model was accomplished by studies by Wichita State University, McGill University and the University of Alabama. This work was achieved through integrated outcrop, well log, and seismic studies of Mesozoic strata in the onshore and offshore Gulf of Mexico, offshore North Atlantic, and onshore Rocky Mountain areas.

Project Objectives

The objectives of the project are to develop through T-R cycle characterization and modeling a sequence stratigraphic predictive model that can be used for improved petroleum trap and reservoir imaging, detection and delineation by using the characteristics and geometries of T-R cycle units and their associated bounding surfaces to provide a reliable and advanced approach for targeting stratigraphic traps and specific reservoir facies associated with continental and coastal plain geologic systems and to demonstrate the importance of using the concept of T-R cycles in the formulation of advanced exploration strategies in the search for underdeveloped and undiscovered petroleum resources associated with subtle stratigraphic traps and with specific continental and coastal plain reservoir facies.

Experimental

<u>Work Accomplished</u>

Sequence Stratigraphy Model—A sequence stratigraphy model based on the T-R model and depositional sequence model is being developed and tested through integrated outcrop, well log, and seismic studies in the onshore and offshore Gulf of Mexico, offshore North Atlantic, and onshore Rocky Mountain areas. William Parcell at Wichita State University has mainly studied

Mesozoic T-R cycles and depositional sequences as observed from outcrops in the Rocky Mountains, Wyoming and Montana. Bruce Hart at McGill University has primarily studied Mesozoic T-R cycles and depositional sequences as observed in seismic sections from the Gulf coast, North Atlantic and Rocky Mountains, Canada and New Mexico. Kaiyu Liu and Jamal Obid have studied Mesozoic T-R cycles and depositional sequences as observed in well logs and seismic sections from the Gulf of Mexico.

A. Wichita State University Studies—the following is a report from William Parcell

1. Introduction

Wichita State University (WSU) has applied T-R cycle models to describe Middle Jurassic continental and marginal marine units in Wyoming and Montana. This study has encompassed detailed description of Middle Jurassic outcrops in the Bighorn Basin of Wyoming and Montana and has developed a T-R cycle model to characterize stratal architecture and the nature of bounding surfaces of these units.

Initial assessment of outcrops during Year 1 indicated widespread, continuous outcrop belts along the margins of the Bighorn Basin that could be used to examine continuity of bounding surfaces and lateral variation in lithofacies and stratal geometries (Fig. 1). Additionally, well log data was collected to further expand the examination of T-R cycles into the subsurface of Bighorn Basin; thereby connecting outcrops on the east and west sides of the Basin. Year 1 also saw the initiation of detailed outcrop descriptions in Wyoming, definition of major lithofacies and their correlation into the subsurface. This work was continued into Year 2 with expansion of outcrop descriptions into southern Montana. With a large and widespread dataset, Year 2 saw the commencement of the interpretation of T-R cycles and the correlation of bounding surfaces into the subsurface.

2. Descriptions of Project Objectives

The goals of the study were to integrate outcrop and well log analyses of Middle Jurassic strata in Wyoming and Montana and to view the lateral extent, vertical changes, geometries, and nature of the physical bounding surfaces of the T-R cycles in the field. The purpose of such an undertaking was to support the development of a sequence stratigraphic predictive model for continental and marginal-marine geologic systems.

In order to complete the objectives for Years 1 and 2, WSU was to assess outcrop exposure, accessibility, and completeness, and collect subsurface well log data. Then, detailed outcrop measurements were to be initiated. With outcrop assessment and measurement completed, T-R cycles were to be defined and outcrop measurements to be integrated with well log data through correlation of physical bounding surfaces. All of the objectives for Years 1 and 2 were met. The results of this work are described below.

3. Work Accomplished and Results

a. Outcrop and Well Log Assessment (Years 1 and 2)

The first phase of the project was to assess outcrop exposure, accessibility and stratigraphic completeness. Twenty-four outcrops were chosen (Fig. 1) to best represent the variation in lithology while providing as even a distribution of measurement points.

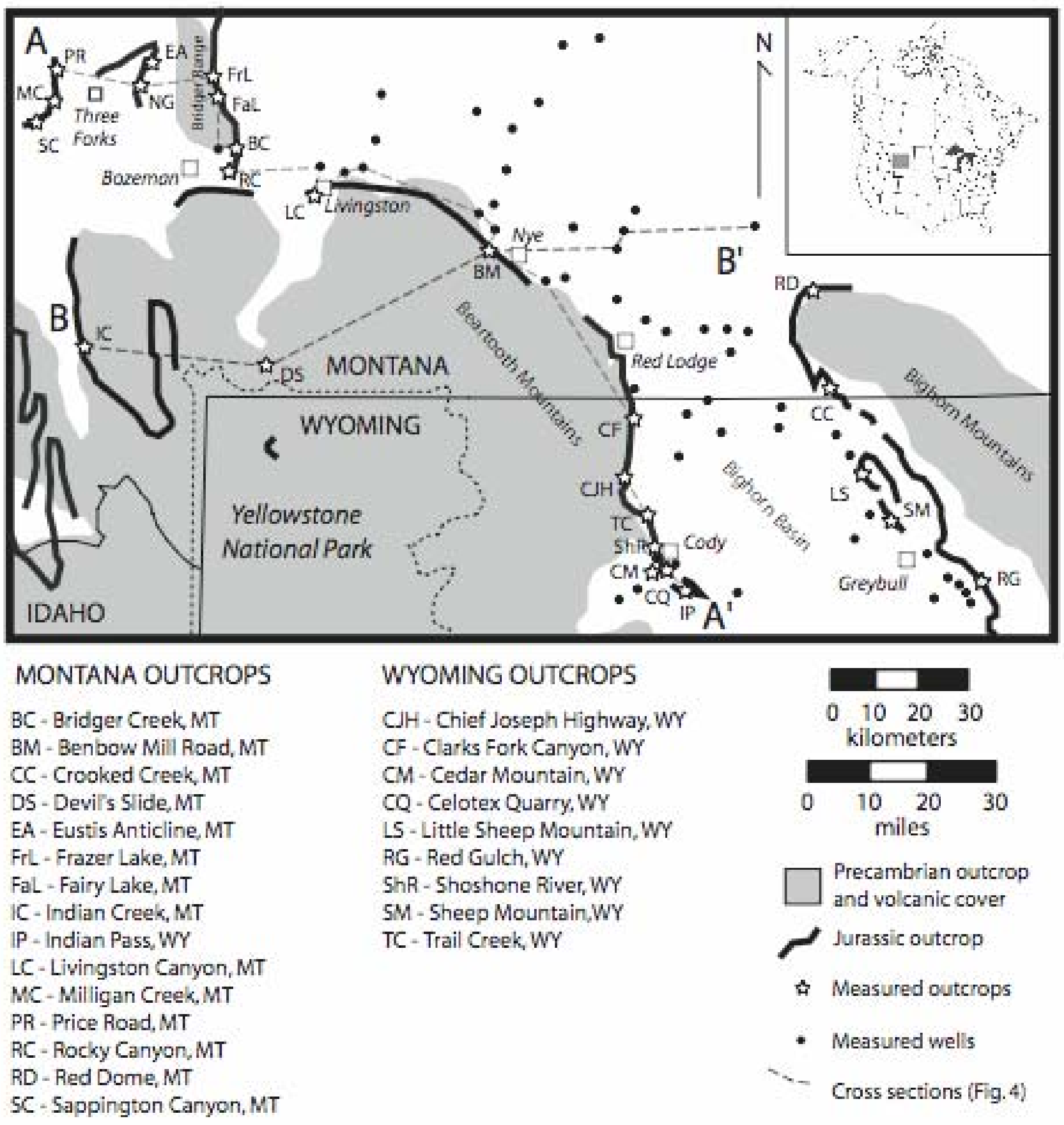


Figure 1. Map of study area showing outcrop and well locations referred to in text. Cross sections A-A' and B-B' are displayed in Figure 4.

Eight outcrops were examined in northern Wyoming and 16 outcrops were studied in southern Montana. In northern Wyoming, the outcrops are, (1) Clark's Fork Canyon, State Route 294, (2) Indian Pass, Cody, (3) Chief Joseph Highway, State Route 296, (4) Shoshone River, Cody (Imlay 1956), (5) Trail Creek, Cody, (6) Little Sheep Mountain, Lovell, (7) Sheep Mountain, Greybull, and (8) Red Gulch, Shell. In southern and southwestern Montana, outcrops include, (1) Benbow Mill Road, Limestone, (2) Bridger Creek, Bozeman (Gardner et al. 1946), (3) Crooked Creek, (4) Devil's Slide, Gardiner, (5) Eustis anticline, Manhattan, (6) Fairy Lake, Bridger Mountains, Bozeman, (7) Fraser Lake, Bridger Mountains, Bozeman, (8) Indian Creek, Madison County (Gardner et al. 1946), (9) Livingston Canyon, Park County, (10) Milligan Canyon, Three Forks, (11) Nixon Gulch, Manhattan, (12) Price Road, Three Forks, (13) Red Dome, (14) Rocky Canyon, Bozeman, (15) Sappington Canyon, Three Forks, and (16) Crooked Creek.

b. General Formation Description (Year 1)

These twenty-four outcrops, supplemented with well logs, provided an opportunity to view the lateral extent, vertical changes, geometries, and nature of the physical bounding surfaces in the field; elements critical to the formulation and application of a T-R cycle model.

The Sawtooth, Piper, and Gypsum Spring Formations represent the Bajocian and Bathonian section (Fig. 2) in Wyoming and Montana. The Sawtooth Formation in western Montana varies between limestone, dolomite, shale, siltstone, and sandstone. The Sawtooth Formation is divided into three units: (1) a basal sandstone/siltstone unit, (2) a middle limestone/shale unit, and (3) an upper shale/siltstone unit (Cobban 1945). Imlay et al. (1948) defined the Piper Formation from exposures near Lewiston, Montana because lithologies in southern and eastern Montana are dominated by carbonates and evaporites. The Piper is likewise divided into three formal members: (1) Tampico Shale Member, (2) Firemoon Limestone Member, and (3) Bowes Member (Nordquist, 1955). Equivalent units in northern Wyoming are called Gypsum Spring Formation. It is also informally divided into three major lithologic units based on lithology and regional continuity of strata. The basal unit contains predominantly white, massive gypsum or anhydrite with interbedded noncalcareous red shale and siltstone. The middle unit contains interbedded green-gray to varicolored shales and gray, black, and brown limestones. The informal upper unit contains primarily red to gray shale and siltstone. The wide variety of member and subunit names in the Sawtooth, Piper, and Gypsum Spring formation is quite confusing and has led to miscorrelations of the Jurassic section. Therefore, for simplicity of discussion, the following informal terms are used for this project: 1) Lower Unit (includes basal unit of Sawtooth Formation, Tampico Member of Piper Formation, and lower unit of Gypsum Spring Formation), 2) Middle Unit (includes middle limestone/shale unit of Sawtooth Formation, Firemoon Member of Piper Formation, and upper limestone and shale member of Gypsum Spring Formation), and 3) Upper Unit (includes upper shale/siltstone unit of Sawtooth Formation, Bowes Member of Piper Formation in Montana, the Piper Formation as commonly denoted in Wyoming, and the informal upper member of the Gypsum Spring Formation).

The Sawtooth, Piper and Gypsum Spring formations are overlain by the Bathonian to Callovian Sundance and Rierdon formations (Fig. 2). The "Lower Sundance" Formation of Wyoming and equivalent Rierdon Formation of Montana consist interbedded gray-green shale, limestone, and sandstone with some green, slightly glauconitic, ripple-marked siltstone near the top.

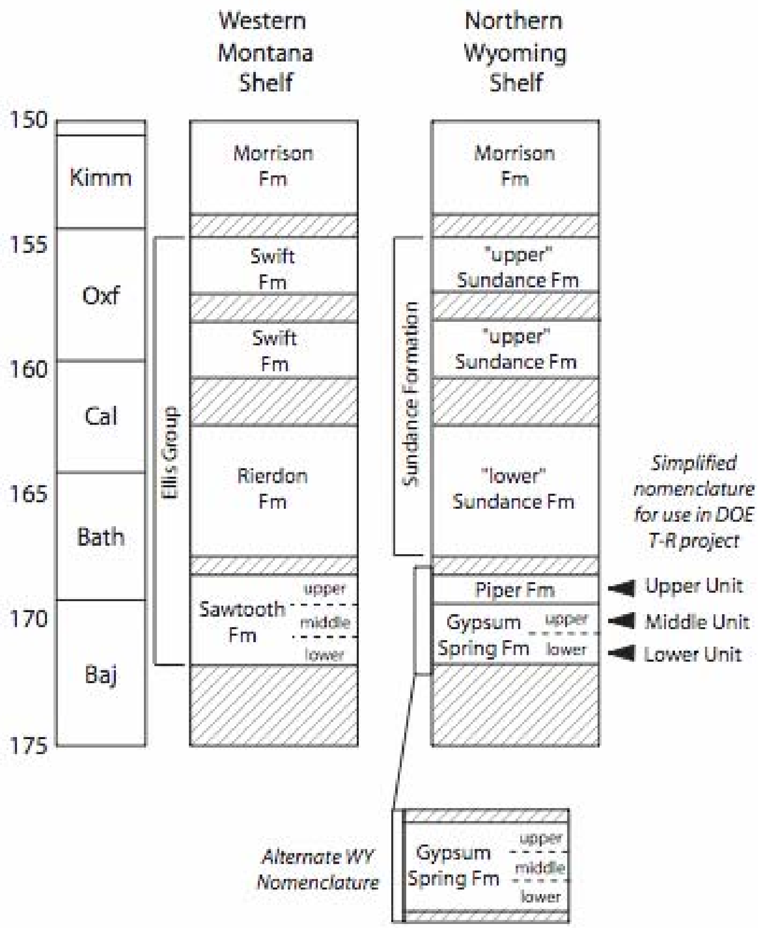


Figure 2. Stratigraphy of the Middle Jurassic section across western Montana and northern Wyoming. The Sawtooth, Piper, and Gypsum Spring formations represent mixed siliciclastic-carbonate-continental deposition.

Siliciclastics occur throughout the “lower” Sundance but increase frequently towards the top of the formation. They are usually light gray to white or buff, well sorted, dominantly fine-grained sandstones, and occasionally oolitic or glauconitic (Mills 1956). White, gray, and tan argillaceous limestone beds occur throughout the section. Shale predominates over limestone except in a few areas (Imlay 1980). Shale beds are usually gray-green, but some red to maroon, papery, soft varicolored units are present.

c. Outcrop Lithofacies Description (Year 1 and 2)

Descriptions of the twenty-four outcrops included the notation of lithology, grain or fossil-fragment size/sorting, mineralogy, nature of physical bounding surfaces, sedimentary structures, macrofossils, and bioturbation. Thin sections were prepared, point-counted, and described; hand samples were analyzed; and macro-, micro-, and trace fossils were noted. In areas where outcrops did not exist, well logs were tied-in to establish 3-D lithofacies and stratigraphic geometries.

Outcrop and subsurface measurements of the Middle Jurassic section in northern Wyoming and southern Montana have resulted in the classification of ten primary lithofacies including: gypsum, varicolored shales, limestones, microbial laminates, dolomites, siltstones, and chert. These ten lithofacies are recognized by outcrop, hand sample, and thin section descriptions of sedimentary texture and structure, mineralogy, and fossil assemblage. Outcrop photographs showing representative examples of T-R cycle bounding surfaces and lithofacies are shown in Figure 3.

<u>Lithofacies I (LF I) – gypsum</u>

Massively bedded, cliff-forming, white gypsum or anhydrite can dominate the base of the Middle Jurassic section in southern and eastern Montana and northern Wyoming. Individual beds average 2.0 m but some thicker beds (up to ~ 10 m) are present in various locations. At some sites, the basal gypsum can thin to zero in less than a kilometer with chert and gypsum nodules, dolomite, or a siliceous limestone breccia occurring in its place. Thin beds of various lithologies can often be found interbedded with the gypsum / anhydrite. These units are most commonly composed of moderate brown, noncalcareous shale. Gypsum nodules or thin layers or lenses of gypsum are often interbedded with or intergrown with the shale sediments.

<u>Lithofacies II – reddish brown shale</u>

Moderate brown shales dominate the Lower and Upper Units of the Middle Jurassic section. These reddish-brown shales are generally noncalcareous and laterally continuous. Thin units of gypsum or gypsum nodules (usually < 0.5 m, but may be up to 1.5 m) are frequently found interbedded with the shales throughout each section.

<u>Lithofacies III – gray-green shale</u>

Greenish-gray, typically calcareous, shales occur in the Middle Jurassic section. Most beds are continuous over the study area. Argillaceous limestones, varicolored shales and occasional gypsum nodule lenses are often interbedded with the green-gray shales. The oyster, *Gryphaea*

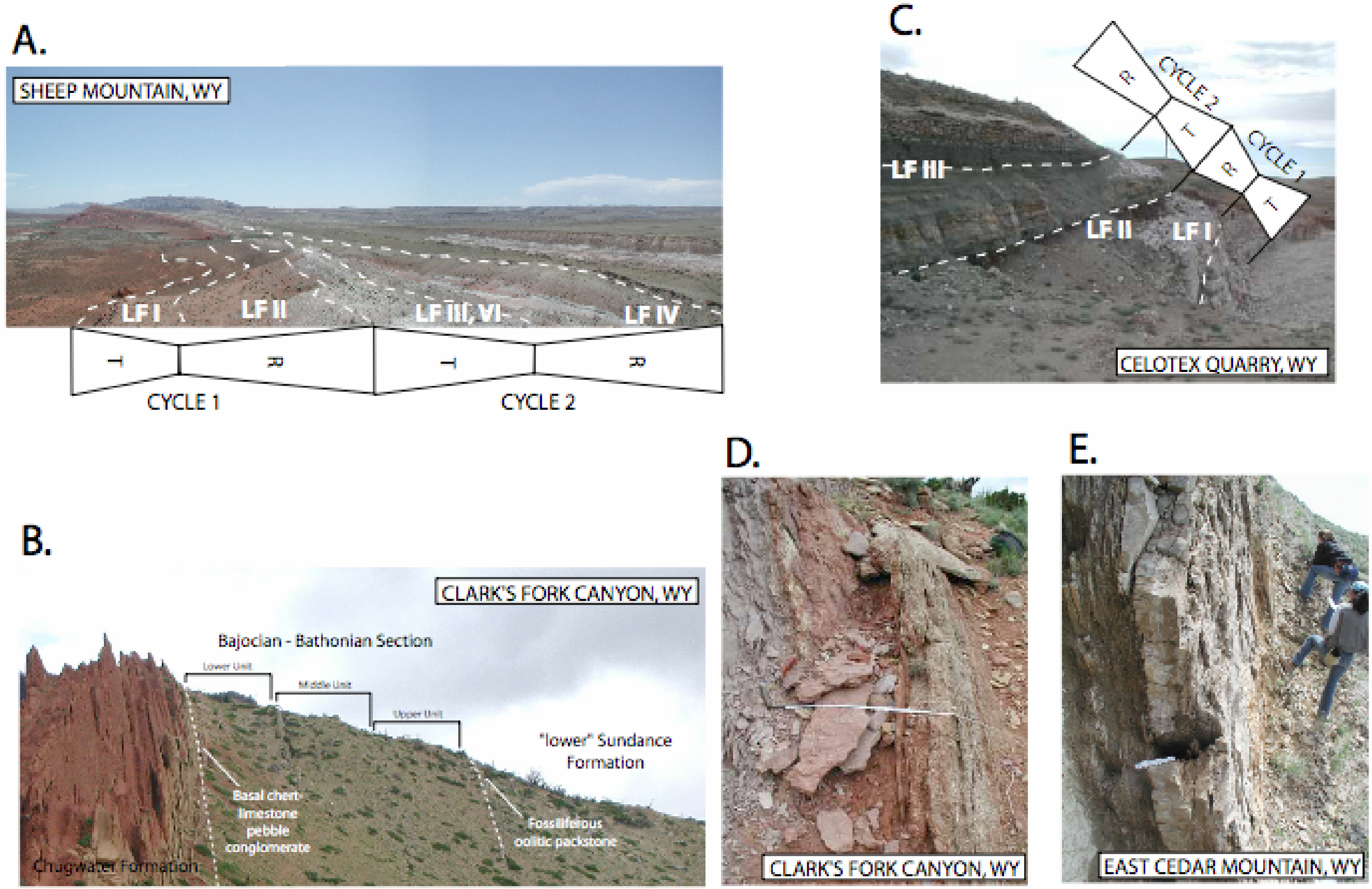


Figure 3. Outcrop photographs of significant lithofacies, bounding surfaces and T-R cycles in the Bajocian to Bathonian section in Bighorn Basin, Wyoming. Outcrops surrounding Sheep Mountain in the eastern Bighorn Basin (A), exposures at Clarks Fork Canyon (B), and near Cody, Wyoming (C) provide complete sections to describe T-R cycles. The base of the Jurassic section is often characterized by a chert-limestone conglomerate (D) marking the beginning of the transgressive phase or T-R cycle 1. The surface of maximum sediment starvation of T-R cycle 2 is marked by a hardground, recognized by fossil concentrations and development of microbial buildups (E).

calceola var. *nebrascensis*, the crinoid, *Pentacrinus* sp., and the coral, *Coenastraea hyatti* Wells are typical biota characteristic of this facies.

Lithofacies IV – varicolored shale

Varicolored calcareous and noncalcareous shales are found primarily in the Middle Unit across Wyoming and Montana. Contacts between the varicolored shales and the surrounding varicolored, greenish-gray, or reddish-brown shales are gradational. Many of these shales contain gypsum nodules or lenses and some chalcedony may be present locally.

Lithofacies V – siltstone

Few thin siliclastic beds are found in the southern Montana and northern Wyoming, but are pervasive in northern Montana. Greenish-gray to yellowish-brown units contain subangular to subrounded quartz crystals and are usually calcareously cemented. At some locations, the siltstone is rippled and contains minor pelecypod fragments. Where sandy limestone-chert breccias replace the lower member gypsum, rounded quartz grains are often present as inclusions in the matrix.

Lithofacies VI – chert

Chert in the Middle Jurassic section occurs in two forms: (1) mixed chert-limestone pebble conglomerate or breccia and (2) beds of dark laminated chert. The brecciated chert is found at the base of the Piper and Sawtooth Formations and is mixed with limestone fragments (e.g. the base of section at Clark's Fork Canyon). Laminated chert layers have been reported at multiple stratigraphic intervals in the Middle Jurassic section in the Bighorn Basin (Kvale et al., 2001). Chert horizons have been described in the Gypsum Spring Formation (Imlay, 1956), at the base of the Sundance Formation (Imlay, 1956), and within the Sundance Formation (Imlay, 1956; Kvale et al., 2001).

Lithofacies VII – carbonates

Limestones and microbialites in the study area are found predominantly in the Middle Unit of the Sawtooth, Piper and Gypsum formations and in the "lower" Sundance Formation.

Lithofacies VIIm – mudstone, microbial laminate (VIIml), dolomite (VIId)

Mudstones (LF VIIm) are typically gray to yellow-gray with laminated to thin, wavy/hummocky bedding. Some locations contain minor interbedded gypsum, reddish-brown or gray-green shale, or, rarely, subangular to rounded quartz grains. Outcrop mudstones contain minor pelecypod fragments, occasional small algal heads, minor oncoids, peloids, and burrows. Many locations show signs of bioturbation.

Lithofacies VIIw – wackestone

Wackestones in the study area are laminated to thin, wavy bedded units (< 10 cm) with pelecypods, crinoids, gastropods, foraminifera, oolites, peloids, and mudclasts. These allochems are often found as nuclei for ooids and peloids but some are uncoated grains within the matrix. In addition to fossil nuclei, some subangular to rounded quartz grains are used for nucleation also. Some locations show burrows and bioturbation, and minor amounts of iron are concentrated locally along algal laminations. The matrix is typically calcitic with traces of gypsum.

Lithofacies VIIpg – packstone and grainstone

Packstones and grainstones occur in the Middle and Upper Units and "lower" Sundance Formation. Most of these limestones vary from olive-gray to yellowish gray. Some rippled and cross-bedded units were found but most are typically thin bedded (< 10 cm) to medium bedded (up to 20 cm) with some bioturbation. Peloids and ooids, with fossil fragments or quartz grains for nuclei, make up the majority of the allochems found in these limestones. Fossils, either as nuclei or as uncoated grains, include pelecypods, foraminifera, brachiopods, gastropods, echinoderm fragments, and crinoids, including *Pentacrinus* sp. Other allochems include algal and micrite clasts, chert clasts, minor mud clasts, minor gypsum, and angular to subrounded quartz grains. Many fragments contain micrite envelopes. Fossils and other allochems are often aligned parallel to bedding. Matrix is typically recrystallized calcite with some trace gypsum in several locations.

Lithofacies VIIt – thrombolite

Thrombolites are cryptalgal structures that resemble stromatolites but lack distinct laminations and are characterized by macroscopic clotted fabric. These buildups may have formed through entrapment of detrital grains without layering or organization. In the Middle Jurassic section in the northern Bighorn Basin of Wyoming, thrombolites occur as isolated buildups. The East of Cedar Mountain outcrop, near Cody, WY, contained several thrombolite patches resting on and slightly grown down into a rippled, fossiliferous, oolitic, pelloidal packstone to grainstone. The underlying limestone is medium bedded (~ 10 cm) in the lower part and thins upward. Allochems include pelecypod hash, crinoids, echinoderms, some gastropods, and rounded, elongate micritic fragments.

d. Data Integration and T-R Cycle Characterization (Year 2)

Outcrop descriptions and measurements were correlated to well logs in the Bighorn Basin and southern Montana during Year 2. This provided a regional picture of the nature of stratigraphic geometries and resulting lithofacies distribution. Stratigraphic cross sections combining outcrop and well data are represented in Figure 4.

Stratigraphic relationships within the Bajocian to Bathonian section were interpreted from characteristic bounding surfaces, stacking patterns, and lateral facies relationships. Six regionally significant surfaces are recognized in outcrop and wells: (1) a regional unconformity at the base of the Middle Jurassic section, (2) a gradational boundary between the basal gypsum beds and redbeds of the Lower Unit, (3) a gradational to sharp (and locally unconformable) contact at the base of the Middle Unit, (4) a horizon within the Middle Unit marked by the coral, *Coenastraea hyatti* Wells, thrombolite buildups (LF VIIt), and the *Pleuromya compressa* bivalve assemblage, (5) a gradational boundary between the Middle Unit and Upper Unit, and (6) an abrupt (and locally unconformable) contact between the Upper Unit and the "lower" Sundance Formation. These surfaces separate genetically related strata of two T-R cycles in the Middle Jurassic section (Fig. 5). The Lower Unit records the first T-R cycle. This cycle is underlain by a major regional unconformity that separates the Middle Jurassic from Triassic and Paleozoic units below. The first cycle represents deposition dominated by restricted marine and sabhka conditions. The subaqueously deposited lower gypsum beds of the Piper and Gypsum Spring formations correspond to the transgressive phase and the lower redbeds represent the regressive phase of the first cycle. A sharp to gradational contact at the base of the Middle Unit

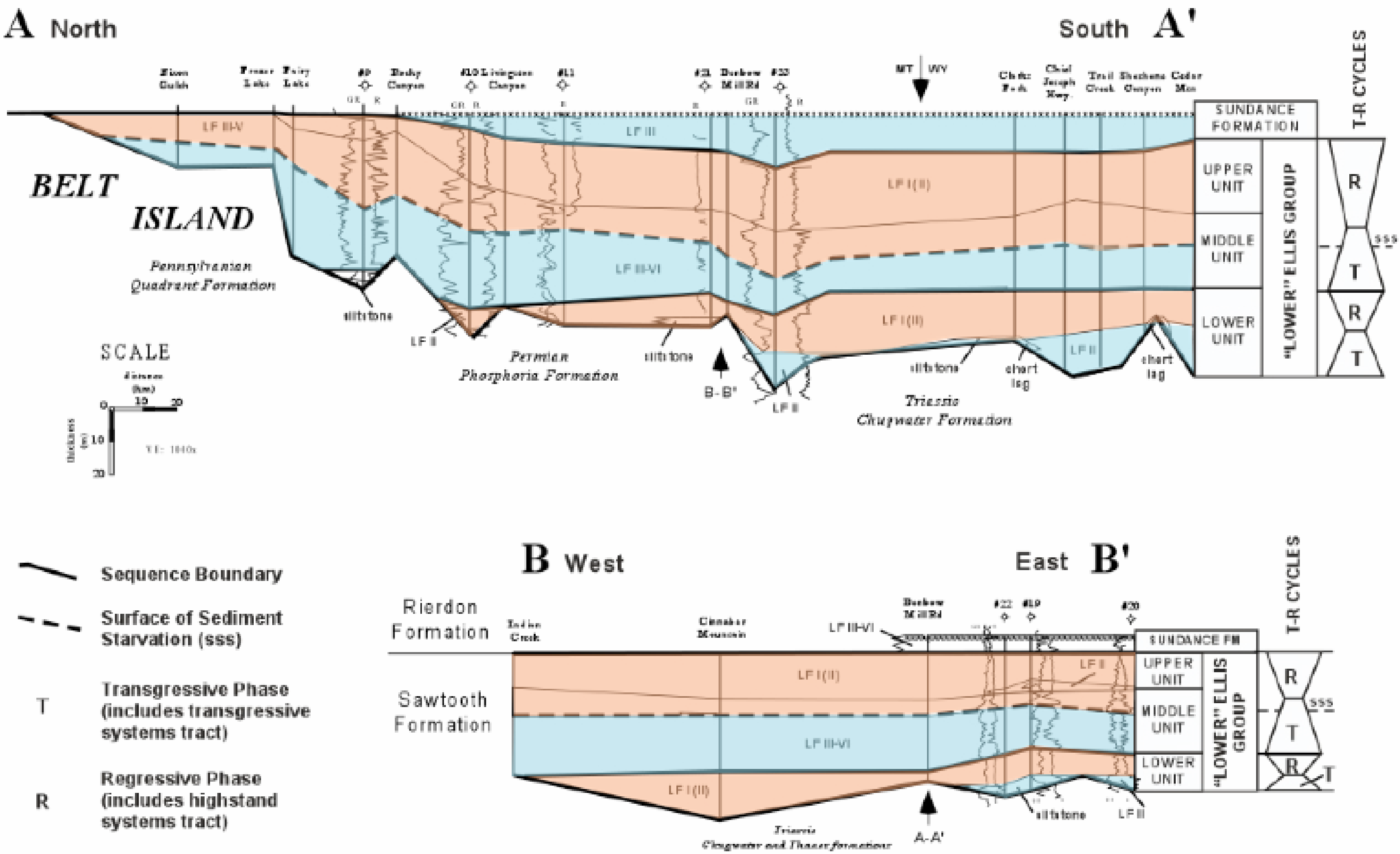


Figure 4. Stratigraphic cross sections representing T-R cycles along a dip profile (A-A') and depositional strike (B-B'). See Figure 1 for locations of cross sections.

defines the boundary between the first and second T-R cycles. This contact is also unconformable when associated with local paleohighs such as the Sheridan Arch in north-central Wyoming and Belt Island in central Montana. Evidence for unconformable relationships includes dessication cracks and dinosaur tracks (Kvale et al., 2001). However, there is no such evidence of exposure or erosion at this contact in locations off-structure. The Lower Unit varies in thickness related to pre-Jurassic topography. The Lower Unit pinches out against Belt Island and thickens dramatically in subbasins in northern Wyoming.

The second T-R cycle is recorded in the Middle and Upper Units. This cycle represents a wider range of depositional environments ranging from more open marine to sabkha settings. The Middle Unit corresponds to the transgressive and the early regressive phase, while the upper portion of the Upper Unit represents the late infilling regressive episode. A regionally significant horizon marked by the coral, *Coenastraea hyatti* Wells, thrombolite buildups (LF VIIt), and the *Pleuromya compressa* bivalve assemblage occurs within the Middle Unit and marks the sediment starvation surface of the second cycle. The early regressive phase of second cycle is characterized by dark green-black, shaly to silty carbonate mudstones of LF VIIm and is recognized in well logs by gradual gamma-ray increase in the upper portions of the Middle Unit. The aggradational phase of the second T-R cycle is also recognized by increased upsection winnowing from LF VIIw to VIIpg facies. The Middle Unit maintains a fairly consistent thickness across the study area but gradually thickens along the margins of Belt Island and the Sheridan Arch.

The Upper Unit represents deposition during the infilling regressive phase of the second T-R cycle. The lower contact of the regressional phase is gradational from the transgressive units below. The upper contact of the regressive phase is sharp against the overlying oolitic packstones and grainstone (LF VIIpg) of the Rierdon and “lower” Sundance formations. The thickness of the Upper Unit also varies in relation to local structures. The Upper Unit thins along the margin of the Sheridan Arch in north central Wyoming and along the southern margin of Belt Island in central Montana.

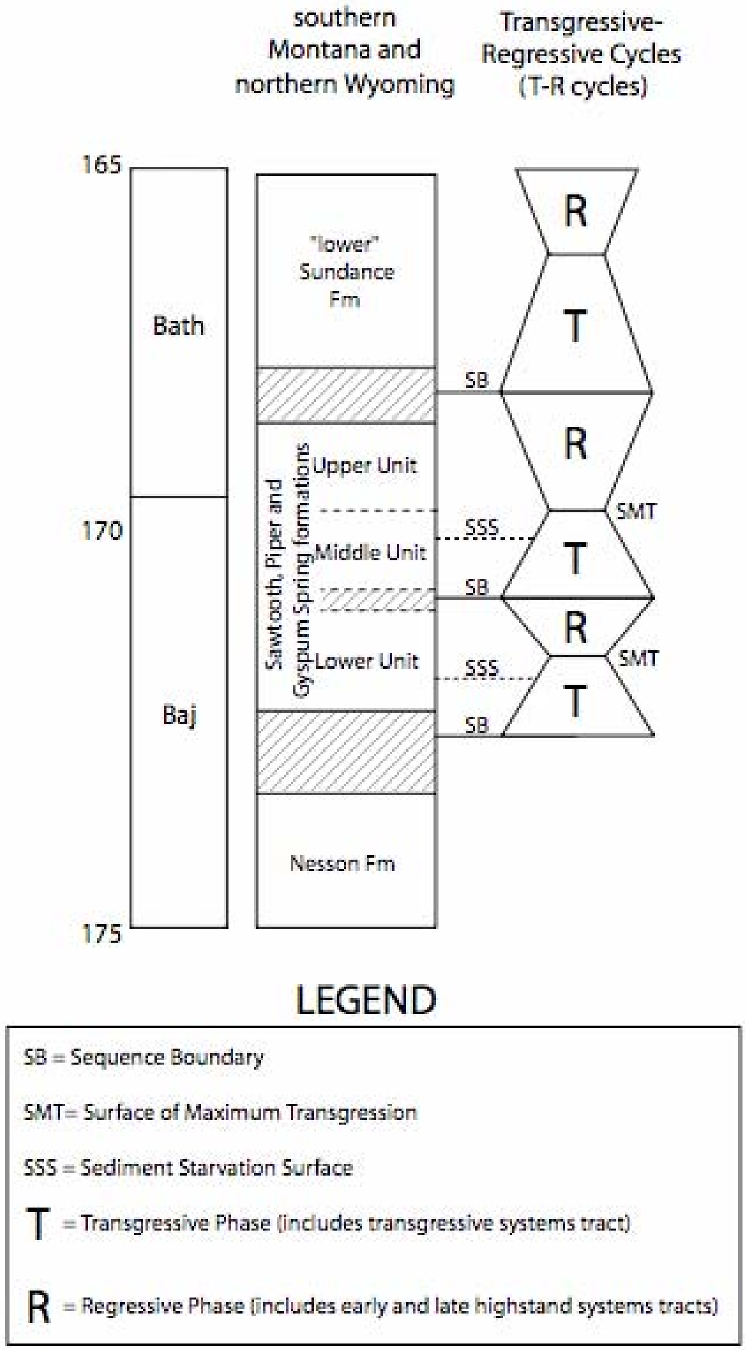


Figure 5. Interpreted T-R cycles for Bajocian to Bathonian section of Wyoming and Montana.

B. McGill University Studies—the following is a report from Bruce Hart

1. Seismic Analyses

Seismic analyses undertaken in Year 1 established the reflection character of T-R cycles using data from the Gulf of Mexico (Location 1 on Fig. 6). In Year 2 additional seismic datasets were included to: a) help define the controls (i.e., bed thickness and rock velocity) on recognition of key reflection configurations used to develop seismic stratigraphic models, b) make the T-R cycle model more general by including data from different areas (North American foreland basins and other passive margins), and c) examine the seismic expression of key surfaces using 3-D surveys such as those that are commonly available to small independent producers. Lower and Upper Cretaceous marginal marine clastics are the target intervals for this new work. Key to this work is the inclusion of geologic "ground truth" in the form of measured outcrop or core sections from the intervals of interest.

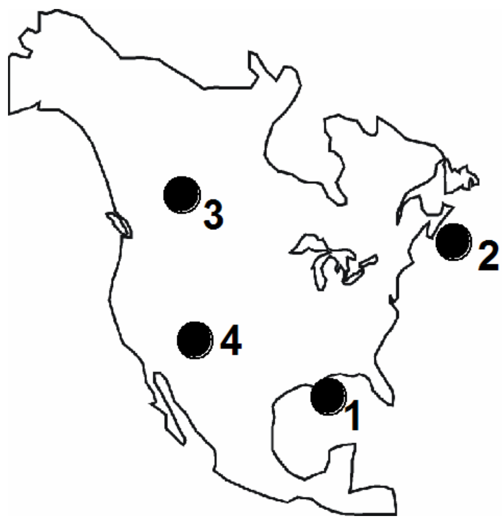


Figure 6. Location of seismic study areas: 1) Gulf Coast, 2) Scotian Shelf, 3) Deep Basin and 4) San Juan Basin.

2. Database

The new seismic database consists of three 3-D seismic surveys and associated well and other data. Two of the 3-D seismic surveys are from the Atlantic margin of North America (Scotian Shelf; Location 2 on Fig. 6). They cover areas of approximately 340 km^2 (~130 square miles) and 96 km^2 (~ 38 square miles). Like some Gulf Coast counterparts, wells in this area penetrated Tertiary and Cretaceous clastics on their way to Cretaceous (clastic) and Jurassic (carbonate) targets. No cores are available from the larger survey area, and so lithologic control is derived using logs and ties to the smaller 3-D survey area located to the northeast (Cummings et al., submitted). The surveys image the Lower Cretaceous shelf (smaller survey) and shelf margin (larger survey), making them an ideal dataset for studying how stratigraphic surfaces formed on the shelf make their way into deeper water.

The third survey is from the Deep Basin of Alberta (Location 3 on Fig. 6). This 3-D dataset covers an area of approximately 460 km^2 (180 square miles) has a 30 x 40 m (98 x 131 ft) bin size and a 2 ms sampling rate. The database includes measured core, wireline logs, and production data. Core sections were measured to provide lithologic control for the seismic interpretation. Like productive, time-equivalent rocks of the Rocky Mountain area to the south, the Cretaceous clastics analyzed in this study were deposited along the western margin of the Western Interior Seaway, with T-R cycles developing in response to interactions between subsidence, sediment supply and eustatic sea-level change.

We are also negotiating the release of long, 2-D seismic lines from the San Juan Basin (Location 4 on Fig. 6). This area produces gas from Upper Cretaceous T-R cycles, primarily from unconventional reservoirs in the Dakota Formation and Mesaverde Group (both "tight-gas" reservoirs) and the Fruitland Formation (coalbed methane). The long seismic lines we seek will show dip sections that are longer to view than can be seen in 3-D data. As such, they will help us to examine large-scale stratigraphic geometries that cannot be imaged in even large 3-D surveys like those employed in this study. Outcrop sections were measured in the San Juan Basin in order to provide lithologic control for the seismic interpretation.

3. Results

We discuss each new study area separately.

a. Atlantic Shelf Dataset

This area shares many similarities with the U.S. Gulf Coast. Jurassic carbonates and overlying Cretaceous and Tertiary clastics are drilling targets. Lower Cretaceous (Berriasian to Cenomanian) marine, marginal marine, and continental clastics of the Missisauga and Logan Canyon formations are imaged in the two 3-D seismic data volumes from the Scotian Shelf. The general stratigraphy of this area was established by Wade and MacLean (1990). Cummings et al. (in review) examined the stratigraphy of the "Upper Member" of the Missisauga, and the overlying Naskapi and Cree members of the Logan Canyon Formation using 3-D seismic data, logs and core from an area that was situated on the paleoshelf. A strike-oriented section through their dataset (Fig. 7) shows incision that is easily recognized being caused by fluvial incision during lowstand. In fact, two such sequence boundaries may be present. Fluvial sands directly overlie the sequence boundary and marginal-marine deposits (e.g., hummocky cross-stratified sandstones) underlie it. This seismic transect is flattened on the O Marker, a mixed carbonate-siliciclastic unit that generates a strong seismic reflection in proximal parts of the shelf and which separates the Upper Member of the Missisauga Formation from the underlying units.

In Year 2 we extended the seismic-based stratigraphic analyses to a new 3-D seismic data volume located SW of the dataset shown in Figure 7. This volume images the Missisauga and Logan Canyon shelf margin (Fig. 8), and together the two seismic volumes provide a unique opportunity to examine the relationships between shelf incision and continental margin progradation. Two uncored (in the Cretaceous section) wells are located in the new survey

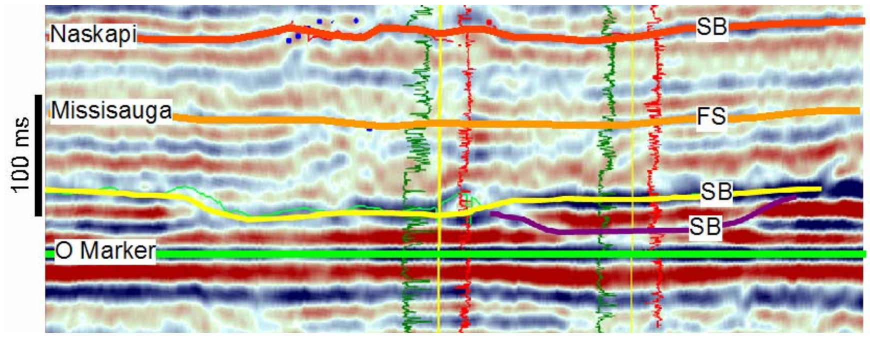


Figure 7. Strike-oriented seismic transect showing seismic expression of a subaerial erosion surface/sequence boundary (yellow) in the Missisauga Formation on the Scotian Shelf (Location 2, Fig. 6). A second sequence boundary (purple) may be present at this level, implying relatively short-lived (e.g., fourth order) sea-level fluctuations superimposed on a longer fall of relative sea level.

area, and the stratigraphy of these wells was established by correlations with wells studied by Cummings et al. (in review). Stratigraphic analyses of this new dataset are currently in progress, but already we have been able to identify one, and possibly two unconformities in the Upper Missisauga that probably correlate to the features identified in Figure 7. In Figure 8 the unconformities can be seen to truncate the O Marker near the shelf margin. Unfortunately shelf-margin clinoforms are not well developed in the Missisauga, possibly because of synsedimentary slumping. A "hot shale" (condensed section) in logs at the top of the Naskapi shale can be correlated basinward to a downlap surface below the Cree Member, and therefore can be recognized as a maximum flooding surface. We anticipate that continued mapping of these horizons, and correlation with the stratigraphy imaged on the shelf (Cummings et al., in review), will help to define the relationships between lowstand incision, coastal plain aggradation, and shelf-margin progradation.

b. Western Interior Seaway

Three different stratigraphic levels have been identified for analysis in the Deep Basin study area. In stratigraphically ascending order, these are: a) the Lower Albian Notikewin Member of the Spirit River Formation, b) the Middle Albian Harmon and Cadotte members, and Upper Albian Paddy members of the Peace River Formation, and c) the Turonian – Coniacian Cardium Formation. These rocks were deposited in a foreland basin setting, where accommodation increased towards the thrust belt.

The Peace River Formation (Harmon, Cadotte and Paddy members) directly overlies the Notikewin Member and had a similar shoreline orientation. For that reason, we studied these units together. We measured core and generated log cross-sections that show the stratigraphic relationships in an approximately N-S orientation that is nearly parallel to depositional dip (Fig. 9). The base of the Notikewin Member is a basin-wide unconformity, with non-marine and marine rocks of the Notikewin overlying non-marine rocks of the Falher Member of the Spirit River Fm (Hayes et al., 1994).

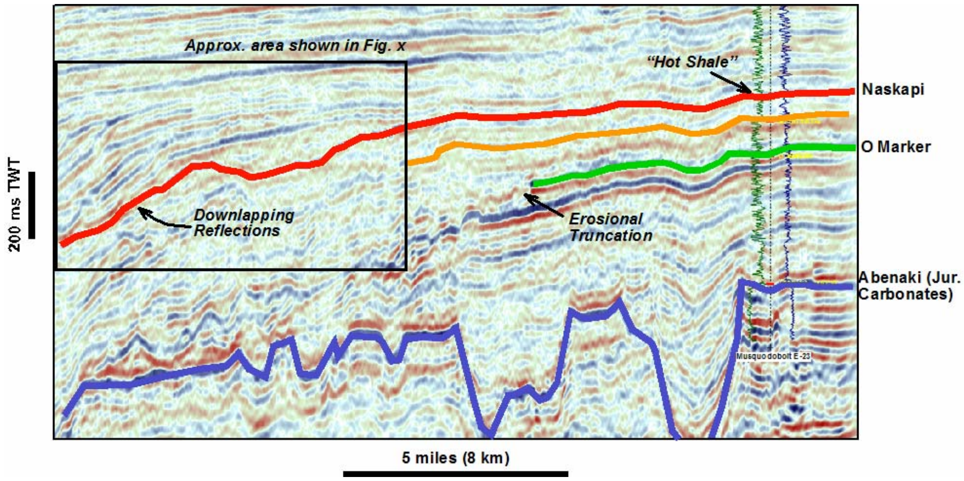


Figure 8. Dip-oriented seismic transect showing stratal geometries at the paleo shelf edge for strata equivalent to those displayed in Figure 7. Lower Cretaceous rocks of interest to this study are those above the O Marker.

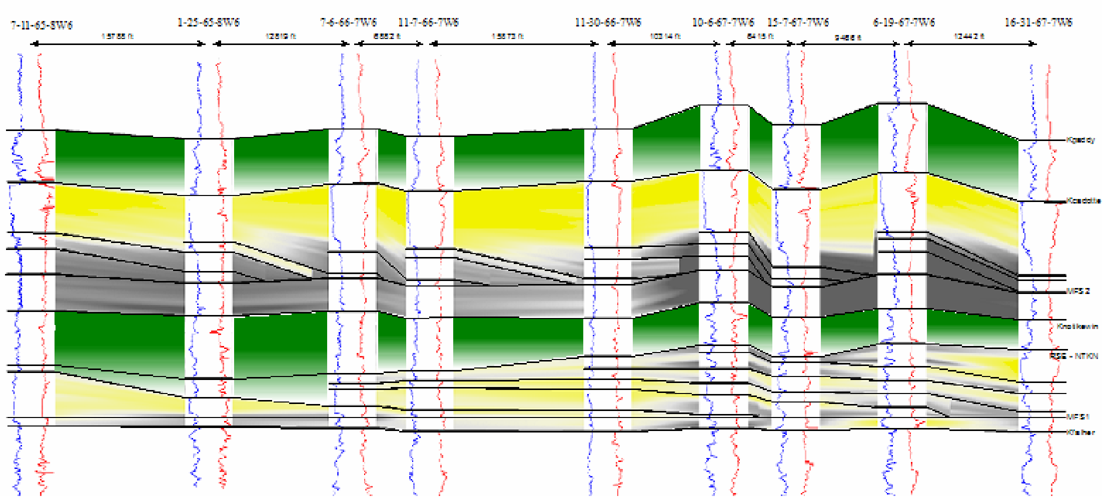


Figure 9. Dip-oriented log cross section showing stratigraphic relationships in the Notikewin to Paddy interval of the Deep Basin (Study area 3, Fig. 6). Grey=marine shale, yellow=shoreface/delta front sands, green=coastal plain deposits. Note the prograding geometries in the Notikewin and Cadotte intervals. Transect ~ 12 miles long.

The juxtaposition of marine rocks (Notikewin) above the Falher indicates the presence of a transgression surface, and Schmidt and Pemberton (2003) showed that a transgressive systems tract, bounded below and above by a transgression surface and a maximum flooding surface respectively, can be mapped using core and logs in an area immediately west of our study area. We identified their stratigraphic units in our data. Above the maximum flooding surface, the Notikewin consists of a series of northward prograding to slightly aggrading parasequences, with interfingering of marine, shoreface and coastal plain deposits. In T-R Cycle terminology, these parasequences form a progradational systems tract. No subaerial unconformity is present within, or at the top of, the Notikewin, at least in our study area.

A transgression surface caps the Notikewin, with marine shales of the Harmon Member overlying that surface. A maximum flooding surface within the Harmon is recognizable based on gamma ray signature ("hot shale") and stratal geometry (downlap surface on log cross-sections; Fig. 9). As such, the lower part of the Harmon can be identified as a transgressive systems tract in T-R Cycle terminology. Above the MFS, the lithostratigraphically defined Harmon and Cadotte members show prograding relationships. Shoreface sandstones of the Cadotte appear to be conformably overlain by non-marine deposits of the Paddy Member. However, regional work has shown that a significant unconformity is present either within the Paddy or at the Paddy/Cadotte contact (Leckie et al., 1994). This unconformity appears to correspond to a Middle to Upper Albian eustatic sea level drop of approximately 50 m (Haq et al., 1987). In our area, the unconformity is difficult to locate because it either separates non-marine from non-marine strata (i.e., it is within the Paddy), or it separates foreshore deposits (Cadotte) from overlying non-marine deposits (Paddy). In either case the contact is easily misidentified as a normal facies transition, and so some operators place the unconformity at the top of the Cadotte whereas others place it at the base of a channelized sandbody in the upper part of the Paddy. To date, palynology data have not been employed, or have not been able, to locate the unconformity in our area. Because of this uncertainty, the top of the progradational systems tract that includes the Cadotte Member is not adequately defined in our study area. Another transgression surface caps the Paddy, separating it from the overlying Shaftsbury Shale.

We now compare the stratal geometries and systems tracts definable using log and core data with the seismic data. To do so, we have generated synthetic seismograms to tie the logs to the seismic data, and we have also used log cross-sections to generate seismic models of this interval. Figure 10 shows a sample synthetic seismogram generated using a range of frequencies that is comparable to those in the 3-D seismic data at the Cadotte/Notikewin level. Figure 11a shows a seismic model of the cross-section shown above and Figure 11b shows a arbitrary transect from the seismic data that goes through all of the wells used to construct the cross-section. From the synthetic seismogram and the seismic model, we make the following observations: A) The flooding surface at the top of the Paddy (Kpaddy) is imaged as a peak. B) The lithologic break at the top of the Cadotte (shoreface/foreshore sands below, coastal plain deposits above; Kcadotte) is imaged as a trough. This could be a surface of maximum regression in T-R terminology. C) The maximum flooding surface in the Harmon Shale (MFS2) is imaged as a relatively low-amplitude peak. D) The flooding surface at the top of the Notikewin (FS – Top Notikewin) is imaged as a high-amplitude trough. This flooding surface generates a strong

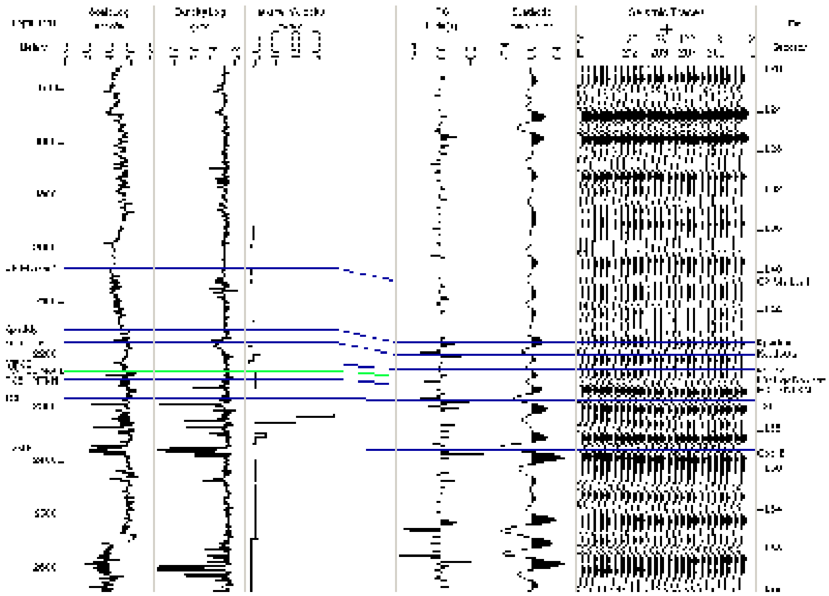


Figure 10. Sample synthetic seismogram showing suggested tie to the seismic data for the Notikewin to Paddy interval.

reflection than the overlying maximum flooding surface (MFS2). E) The "Regressive Surface of Erosion" (as defined by Schmidt and Pemberton, 2003) at the top of the prograding Notikewin shoreline (RSE – NTKN) is imaged as a peak. F) The flooding surface/unconformity at the base of the Notikewin (TSE) is imaged as a peak. The details of the stratigraphic geometries seen in the log cross-section (Fig. 9) are not visible in the seismic model, and only subtle variations in amplitude, somehow related to changes in lithology and stratigraphic geometry, are evident. The seismic data show similar geometries to the seismic model results. It is clear that the seismic data do not image all of the stratigraphic complexity that is mappable using dense well control, and that the unconformity in, or at the base of, the Paddy cannot be imaged.

The stratigraphy of the Cardium Formation in this area was studied by Hart and Plint (1993). The formation is particularly interesting in our study area because of the presence of "sharp-based" shoreface sands that have been interpreted by some authors to indicate shoreline progradation during a fall of relative sea level ("forced regression"). The base of the sharp-based shoreface has been called a "regressive surface of marine erosion" (RSME) and has been identified by some authors with a sequence boundary in EXXON-style sequence stratigraphy. Embry (2002) explained why the RSME is a poor candidate for a sequence boundary.

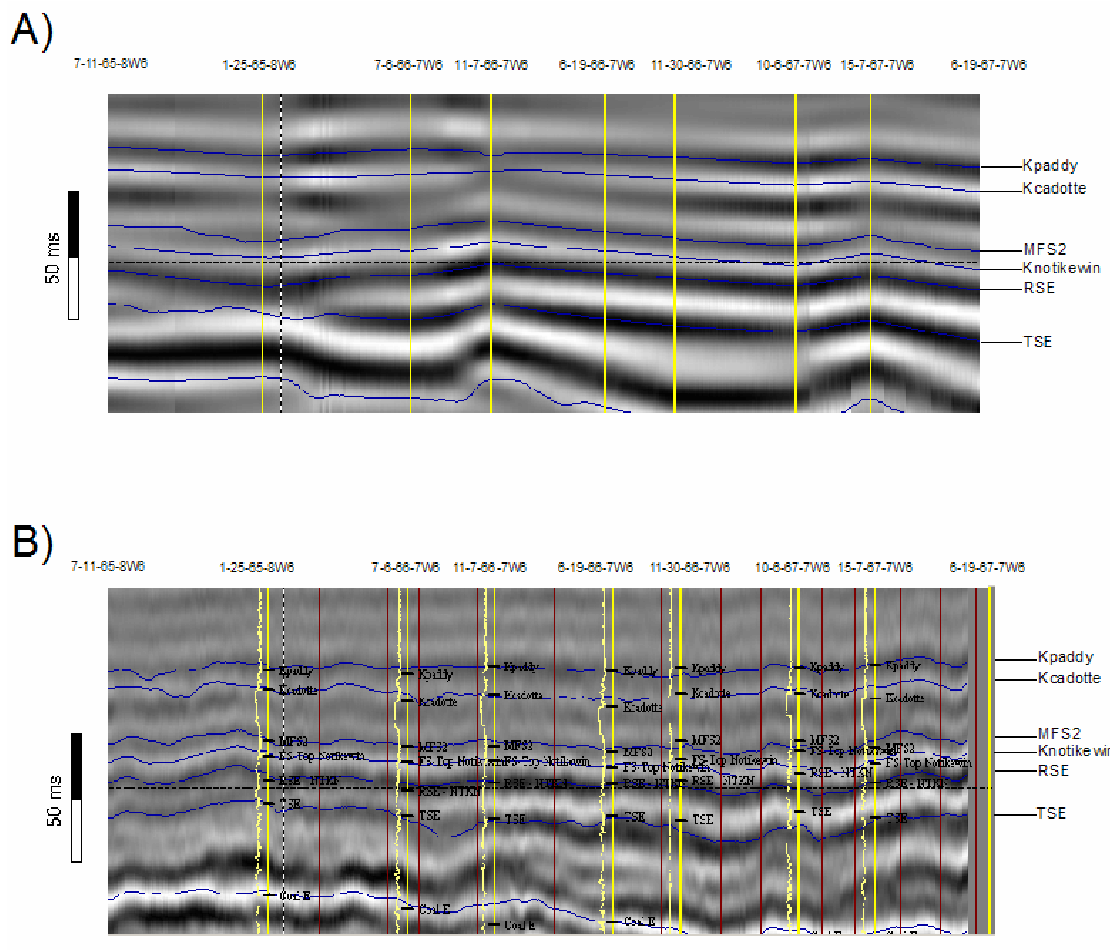


Figure 11. A) 2-D seismic model based on log cross section shown in Figure 10. B) Arbitrary transect through 3-D seismic volume that corresponds to seismic model shown in Part A. Marked horizons correspond to log picks shown in Figure 10. Details are described in the text, but it is clear that the seismic images cannot capture the stratigraphic details evident in the log cross section.

A dip-oriented (SW-NE) log cross-section of the Cardium and stratigraphically adjacent units is presented in Figure 12a. In this area the formation consists of a progradational package of shoreface sandstones that are overlain by non-marine/coastal plain deposits and finally by a succession of thin, dominantly shaley (in this area), marine parasequences (Fig. 12b). Like many other foreland basin deposits, well-developed subaerially formed erosion surfaces (accompanied by major channel incision) developed during lowstands are not present in the Cardium.

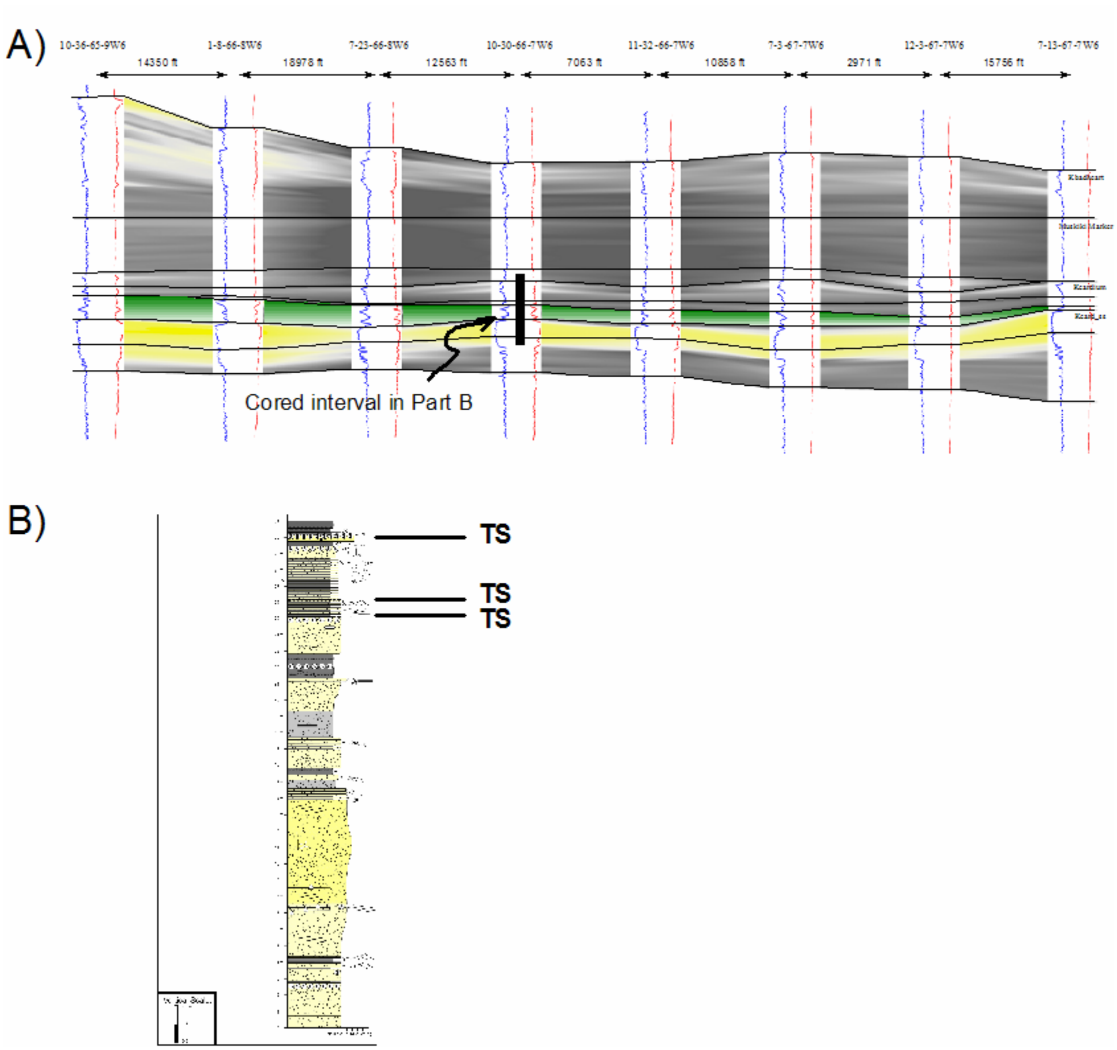


Figure 12. A) Dip-oriented log cross section of the Cardium Formation and stratigraphically adjacent units. A main shoreface sandstone body (yellow) is overlain by coastal plain deposits (green) that are, in turn, overlain by marine parasequences. Stratigraphic surfaces correspond to those defined by Hart and Plint (1993). B) Measured core showing lithologic expression of facies and surfaces identified in Part A. Corresponding logs shown in Part A. TS-Transgression Surface.

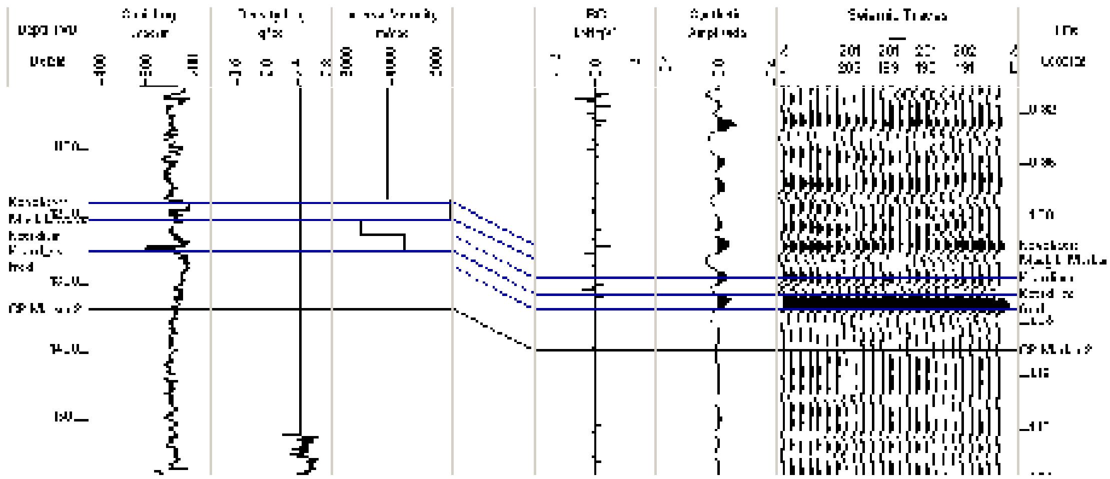


Figure 13. Synthetic seismogram showing predicted seismic response of Cardium Formation and adjacent strata.

A synthetic seismogram from this area is shown in Figure 13, and a seismic model and seismic transect corresponding to the log cross-section of Figure 12a are shown in Figure 14a and 14b respectively. Low-amplitude detachment folds affect the Cardium in this area and so the seismic data have been flattened on an upper horizon. Reverse faults affect the shales below the Cardium, obscuring some of the stratigraphic relationships in the shale in both log cross-sections and seismic data. Additionally this interval is in the upper part of the seismic data, and the data quality is reduced at this level. Despite these issues, and like the stratigraphically lower Notikewin to Paddy level, it is clear that the seismic character does not show the same level of detail as the log cross-section. The seismic images show that the "Muskiki Marker", a downlap surface (i.e., MFS in the marine shales overlying the Cardium) is imaged as a trough. The top of the Cardium (Kcardium), a flooding surface corresponding to the transition from the small parasequences of the upper part of the Cardium to the overlying transgressive shales of the Muskiki Fm. is represented by a peak in the data. Counter intuitively, because it corresponds to an increase in acoustic impedance, the top of the shoreface sandstones of the Cardium (Kcard_ss) is imaged as a trough.

c. San Juan Basin Dataset

The Mesaverde Group of the San Juan Basin consists of a progradational to retrogradational package of shelf, paralic and non-marine clastic deposits thought to represent a third-order succession. Progradational shoreface to deltaic sandstones at the base of the Group are included in the Point Lookout Formation, whereas retrogradational paralic sandstones at the top of the Mesaverde are included in the Cliff House Formation. Coastal plain deposits between these two formations are included in the Menefee Formation. The Mesaverde Group is Santonian to Campanian in age. Previous studies (e.g., Holinshead and Pritchard; Cross and Lessenger, 1997) have shown that the Point Lookout and Cliff House interfinger with coastal plain deposits of the Menefee Formation to the southwest, and with heterolithic shelf deposits of the underlying Mancos Shale and overlying Lewis Shale respectively.

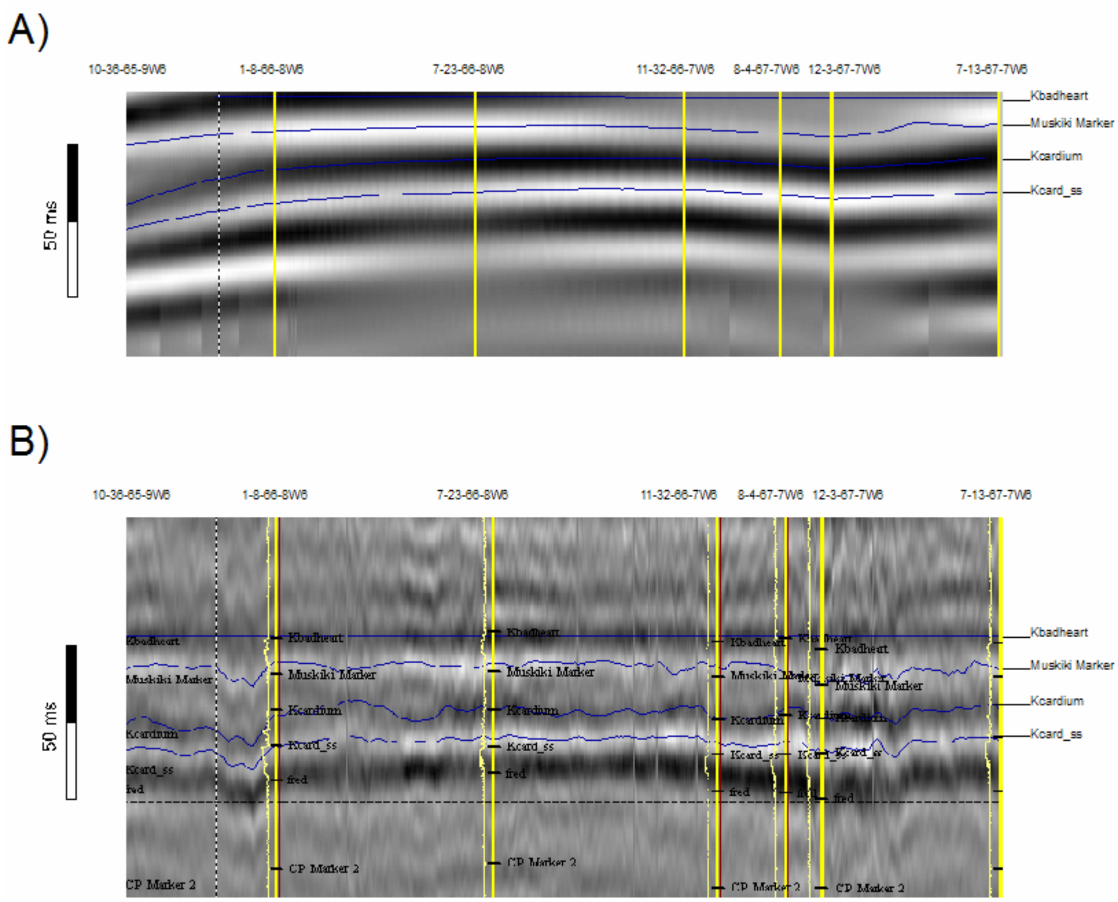


Figure 14. A) 2-D seismic model based on log cross section shown in Figure 12A. B) Arbitrary transect through 3-D seismic volume that corresponds to seismic model shown in Part A. Marked horizons correspond to log picks shown in Figure 12A. Details are described in the text, but like the underlying Notikewin/Cadotte interval (Fig. 11), it is clear that the seismic images cannot capture all of the stratigraphic details evident in the log cross section.

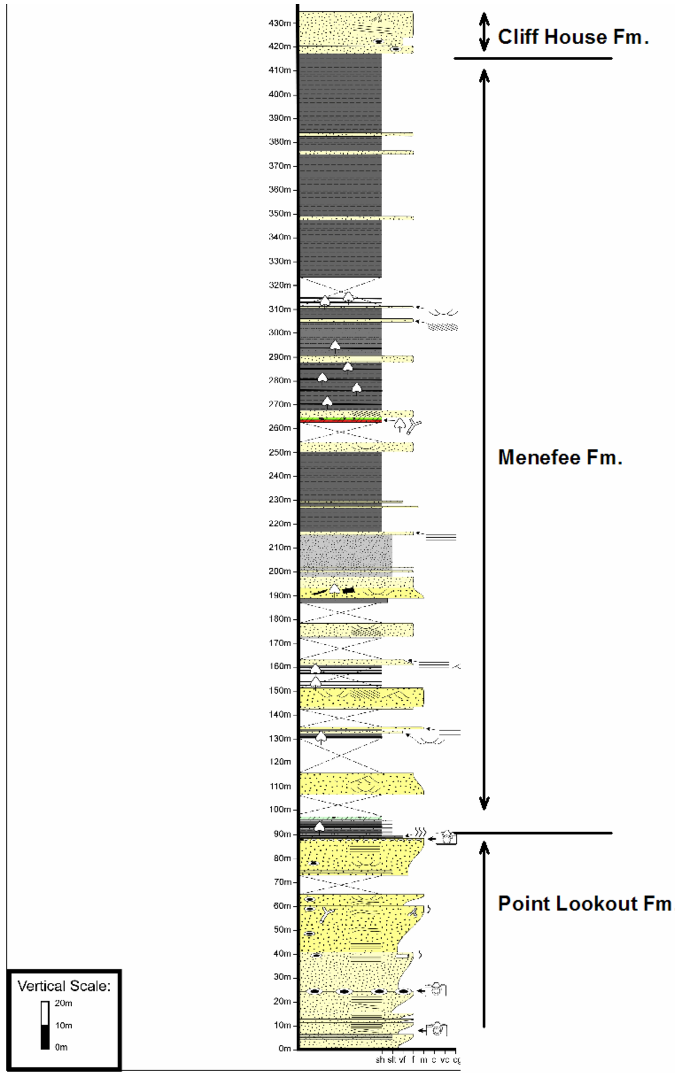


Figure 15. Measured outcrop section through the Mesaverde Group at the Hogback Monocline, west of Farmington (Location 4, Fig. 6). Note the abundance of channel sandstones in the lower portion of the Menefee Formation.

We measured a section through the Point Lookout, Menefee and basal Cliff House formations at the Hogback Monocline west of Farmington (Fig. 15). The Point Lookout consists of a succession of shelf-to-shoreface capped by flooding surfaces (i.e., parasequences). The Menefee is dominantly sandy in the lower portion but becomes mud dominated in its upper part. Cross and Lessenger (1997) suggested that these divisions could correspond to the progradational and retrogradational portions (Point Lookout, Menefee) of the Mesaverde Group respectively (Fig. 16). If this is true, then the change from the upper to lower Menefee corresponds to the surface of maximum regression for this third-order cycle, and is a sequence boundary. The 2-D seismic data we seek will allow us to look for a seismic expression of this surface.

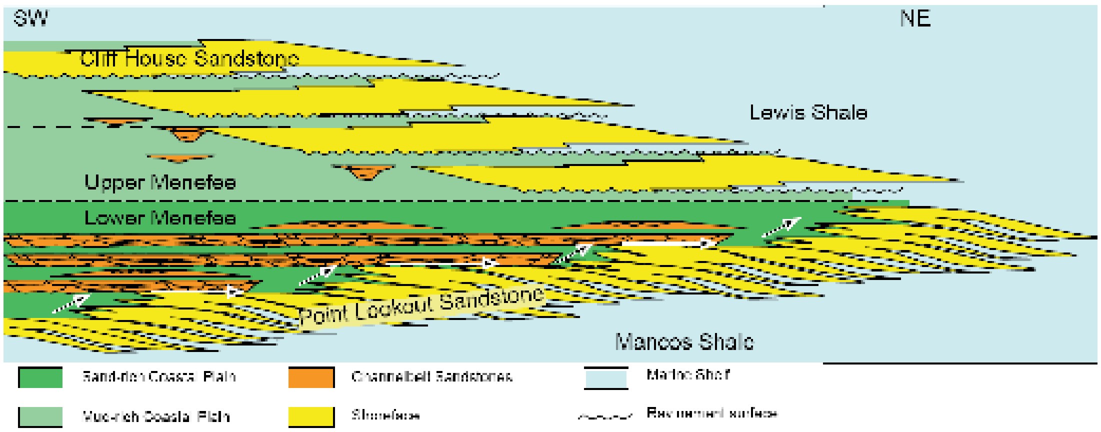


Figure 16. Schematic dip-oriented cross section through the Mesaverde Group in the San Juan Basin. The contact between the Lower and Upper Menefee corresponds to a surface of maximum regression, i.e. a sequence boundary, in T-R cycle terminology. The transition from sand- to shale-dominated section in the Menefee is visible in outcrop (Fig. 15) and may be detectable using seismic data.

4. Summary

In Year 1 we demonstrated that traditional seismic stratigraphic analyses, that is the identification of key surfaces and stratal terminations to define unconformities, flooding surfaces and maximum flooding surfaces, can be successfully employed in passive-margin settings where sequences are relatively thick. In this year, we have extended the success of that approach to the thick passive-margin deposits of the Scotian Shelf. For example, subaerial erosion surfaces (sequence boundaries) and downlap surfaces (maximum flooding surfaces) are both plainly evident there (Figs. 7, 8). On the other hand, subaerial erosion surfaces associated with lowstands of relative sea level are commonly not developed in foreland basin settings, and they are not seen in the log cross-sections or the core and outcrop sections constructed and measured for this study. As such seismic data from foreland basin deposits may not show clear evidence for erosional truncation, i.e. sequence boundaries, at least in the size of 3-D surveys that are commonly available to operators. Other commonly used reflection geometries (e.g., onlap, downlap) are not visible in seismic data through the T-R cycles we studied because they are too thin. As such, the utility of seismic data to define T-R cycles in these and similar settings is diminished significantly.

Although clear evidence for downlap, onlap, etc. may be missing in seismic data from thin T-R cycles, it may be that other types of seismic analyses, for example seismic attribute studies or stratal slicing through 3-D seismic volumes, can be used to identify systems tracts or key surfaces. For example Figure 17 shows an instantaneous phase display of a portion of the seismic transect shown in Figure 8. Instantaneous phase is useful because it is an indicator of reflection continuity. Subtle reflection terminations, that may be difficult to identify because of changes in amplitude along the reflections, are sometimes more clearly imaged in instantaneous phase displays. Other attributes can be indicators of lithology. In the case of the San Juan Basin, it may be possible to use these attributes or seismic inversion to distinguish the lower, sandstone-prone part of the Menefee from the upper mudstone-prone portion of that formation. In that case, it may be possible to identify the surface of maximum regression (sequence boundary) in the absence of lowstand incision.

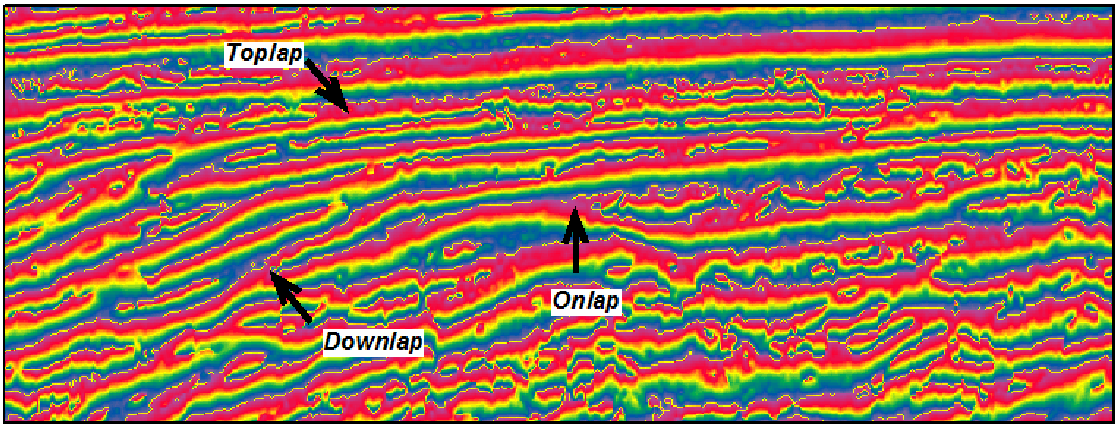


Figure 17. Instantaneous phase display of a portion of the seismic transect shown in Figure 8. This attribute is useful for identifying stratal terminations, and some such features are indicated.

C. University of Alabama Completed Dissertation—the following is from the dissertation of Kaiyu Liu

1. Introduction

The sequence stratigraphy of the Upper Cretaceous strata in the northeastern Gulf of Mexico have been studied in outcrop in central and western Alabama and eastern and northeastern Mississippi (Hancock, 1993; Mancini et al., 1996; Puckett and Mancini, 2000; Mancini and Puckett, 2003) and in the subsurface in the offshore Alabama and Mississippi area (Liu, 2004).

Sequence stratigraphic studies that are based entirely on either outcrop or subsurface data have advantages and limitations. In outcrop, sedimentary characteristics such as grain size, texture, and sedimentary structure can be observed directly. Furthermore, detailed biostratigraphic work can establish a time frame for the purpose of age estimation of the strata. Changes in sea level and depositional history can be interpreted from depositional facies and facies relationships combined with an established biostratigraphic/chronostratigraphic framework.

However, outcrop work has its limitations. First, sediment stacking patterns on a regional scale can not be seen directly and have to be interpreted from facies relationships among rocks exposed at various locations. In addition, the sections from outcrops represent only the inner and middle portions of the Late Cretaceous continental shelf. Facies changes on the continental shelf cannot be understood without knowledge of the unexposed sediment in the middle and outer portions of the continental shelf. Finally, the magnitude of the shoreline migration (coastal onlap changes), which is closely related to the magnitude of sea-level fluctuations cannot be fully understood without knowledge of the changes in sedimentary facies and depositional environments in the outer shelf area.

In subsurface studies, sediment stacking patterns on a regional scale, such as prograding (downlap) and retrogradational or backstepping (onlap), can be observed and determined directly from seismic data. Facies changes on a regional scale can be interpreted from well logs, which are available in southwestern Alabama and in areas of offshore Alabama. In addition, the outer portion and part of the middle portion of the Late Cretaceous continental shelf in the northeastern Gulf of Mexico are not exposed, and therefore, have to be studied in subsurface strata.

One of the shortcomings of subsurface studies is the limited access to rock samples of the strata; therefore, subsurface interpretations have to be made mainly based on geophysical data, such as seismic and well log information. Difficulty in dating surfaces identified from seismic sections is a limitation.

Integrated studies that incorporate surface and subsurface data can provide for an improved interpretation. The Upper Cretaceous strata in the northeastern Gulf of Mexico offer an excellent opportunity for such integrated studies. The Upper Cretaceous strata in the eastern Gulf Coastal Plain are relatively undeformed. These strata are exposed in a wide crescent-shaped belt extending from northeastern Mississippi into central Georgia (Fig. 18); and these strata dip gently toward the basin center and are encountered in the subsurface.

The objectives of this study are: 1) to review previous surface and subsurface sequence stratigraphic interpretations of the Upper Cretaceous strata in the northeastern Gulf of Mexico area, 2) to correlate important surfaces that have chronostratigraphic significance, such as sequence boundaries and maximum flooding surfaces, across the Late Cretaceous continental shelf through the study of well log data, and 3) to determine dip directional facies changes of the Upper Cretaceous strata in the established sequence stratigraphic framework.

2. Geological Setting

The study area is located in the northeastern Gulf of Mexico (Fig. 18). Late Cretaceous sediment deposition in the northeastern Gulf of Mexico began in the late Middle Cenomanian as sea level rose and marine transgression occurred on the continental shelf following the mid-Cenomanian sea-level fall, which formed a prominent unconformity known as the mid-Cretaceous Unconformity and has been recognized throughout most of the periphery of the Gulf of Mexico basin. This unconformity represents a profound change in the depositional regime from widespread carbonate deposition of Early Cretaceous times to mostly siliciclastic and mixed siliciclastic and carbonate deposition in the Late Cretaceous. Because of its significance, this mid-Cenomanian stratigraphic break has been used to mark the boundary between the

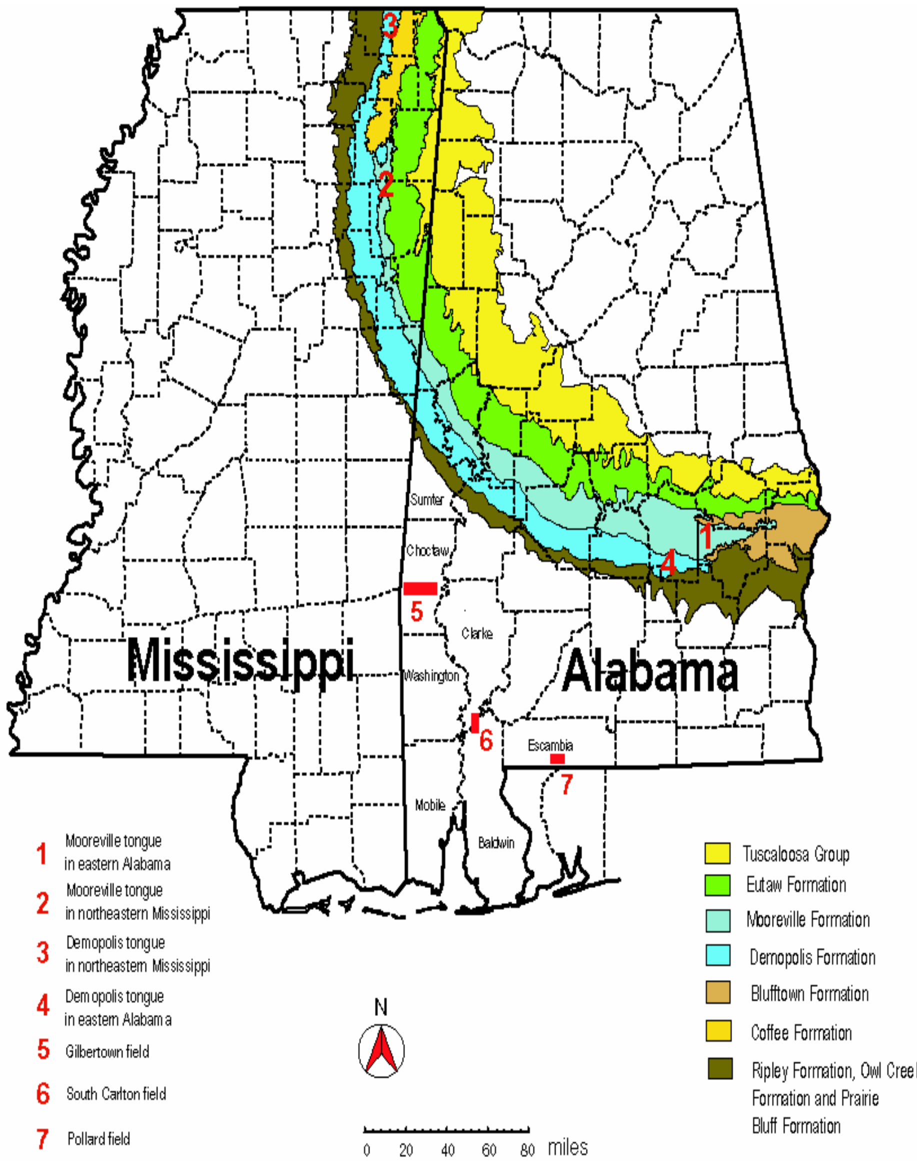


Figure 18. Upper Cretaceous strata outcrop belt, northeastern Mississippi and western and southern Alabama.

“Upper Cretaceous” and “Lower Cretaceous”, although the internationally established boundary between these two series is located at the base of the Cenomanian (Salvador, 1991).

Sea level continued to fluctuate during the Late Cretaceous and sedimentary facies migrated updip and downdip along with sea-level fluctuations. The Upper Cretaceous strata in the northeastern Gulf of Mexico are strongly overprinted by cyclic sea-level fluctuations. Salvador (1991) stated that major unconformities and associated hiatuses were caused by sea-level falls; and some of the lesser and more local unconformities are indicative of minor sea-level oscillations or are related to local tectonic and igneous episodes. Mancini and Puckett (2003) further pointed out that cycles are controlled by changes in accommodation space resulting from stratigraphic base level changes (eustatic and tectonic effects) and sediment supply and accumulation. Salvador (1991) recognized three periods marked by prominent sea-level regressions as represented by three major unconformities: Mid-Cenomanian, Late Turonian-Early Coniacian, Late Maastrichtian-Early Danian. Along the northern margin of the Gulf of Mexico, deposition was generally continuous from Santonian to Campanian time and then again from Campanian to Maastrichtian time, with minor transgressive-regressive cycles being recognized during the Campanian and Maastrichtian periods (Salvador, 1991).

3. Regional Stratigraphy in Outcrop

Lithologically, the Upper Cretaceous strata in the outcrop area are divided into several groups and formations. Figure 19 summarizes the regional stratigraphy of the study area and adjacent areas.

a. Tuscaloosa Group

The Tuscaloosa Group represents the basal unit of the Upper Cretaceous section in the study area. In areas where Lower Cretaceous strata are not exposed, the Tuscaloosa Group rests directly on the Paleozoic basement rocks (Conant, 1967). In outcrop, the Tuscaloosa Group is divided into two formations: the Coker Formation and the Gordo Formation (Conant, 1967; Copeland, 1968; Russell and Keady, 1983).

The lowest part of the Coker Formation, formerly named as the Cottondale Formation, is present only in the immediate vicinity of Tuscaloosa, Alabama and the Black Warrior River, and consists of a nonmarine sand with small amounts of quartz and chert gravels at the base. The rest of the Coker Formation is mostly of marine to marginal marine origin and consists of two members: the Eoline Member and an unnamed upper member. Most of the Eoline Member consists of stratified and cross-stratified, fine-grained glauconitic sand interbedded with dark-gray carbonaceous and lignitic clay. The upper unnamed member of the Coker Formation consists of light-colored micaceous sand with red mottled clay in the upper part (Monroe, 1964; Conant, 1967, Cook 1993; Raymond et al., 1988). The Coker Formation has been suggested to be deposited during a period of marine transgression and subsequent highstand (Cook, 1993; Pashin et al., 2000; Mancini and Puckett, 2002).

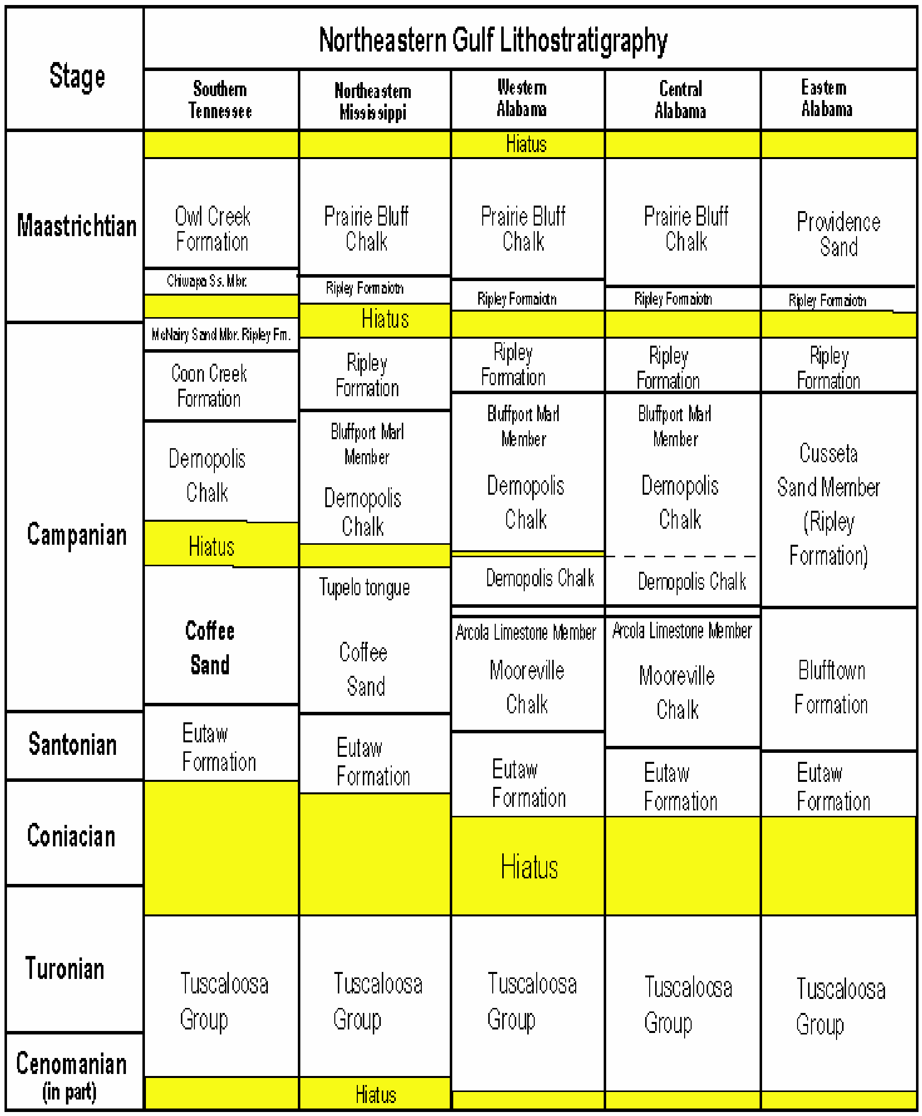


Figure 19. Upper Cretaceous lithostratigraphy for the eastern Gulf Coastal Plain, after Jones (1967), Puckett (1992), and Mancini et al. (1996).

The Gordo Formation is predominantly terrestrial in origin: its lower part consists of gravelly, medium- to very coarse-grained sand, and also contains some purple-mottled gray clay and light-gray clay. The upper part of the Gordo Formation is composed of lenticular beds of red- or purple-mottled clay and crossbedded sand (Monroe, 1964; Conant, 1967; Raymond et al., 1988; Cook, 1993). Deposition of the Gordo Formation occurred during a major marine regression (Cook, 1993; Pashin et al., 2000; Mancini and Puckett, 2002).

The contact between the Gordo Formation and the Coker Formation can be readily recognized and is easily mappable. This contact was interpreted to be an unconformity by Conant (1967).

b. Eutaw Formation

The Eutaw Formation overlies the Tuscaloosa Group; the contact between the Eutaw Formation and the Tuscaloosa Group has been interpreted to be an unconformity (Stephenson and Monroe, 1940; Monroe, 1946; Conant, 1967; Copeland, 1968). Although in the outcrop in western Alabama, the lower part of the Eutaw Formation is separated and named the McShan Formation, in this paper, the Eutaw Formation refers to the Eutaw Formation, including the McShan Formation. The Eutaw Formation consists of marine and marginal marine sediments characterized by massive glauconitic, fossiliferous sand interbedded with gray laminated clay (Cook, 1993). The Eutaw Formation was further divided into an unnamed lower member and the Tombigbee Sand Member.

The lower Eutaw Formation has been described to be very similar to the Coker Formation of the Tuscaloosa Group (Conant, 1967). That might imply these two stratigraphy units accumulated in similar environments. The Eutaw Formation has been interpreted to be deposited in a near shore, marginal marine environment of isolated, widely dispersed barrier bars and shoals with associated back-barrier and tidal inlets and tidal flat facies (Cook, 1993) during a marine transgression (Conant, 1967; Pashin et al., 2000; Mancini and Puckett, 2002; Mancini and Puckett, 2003).

The upper part of the Eutaw Formation is a massive glauconitic sand member named the Tombigbee Sand Member. The contact between the Tombigbee Sand Member and the lower Eutaw Formation is unconformable and is marked by a one to two inch sandstone bed containing phosphatic pebbles, shark teeth, and reworked fossils (Mancini and Soens, 1994). The Tombigbee Sand Member, especially in west Alabama, is a highly bored, unstratified glauconitic sand containing abundant shells of *Exogyra ponderosa*, *Gryphaea wratheri*, *Ostrea battensis*, and other fossils (Conant, 1967). It is about 174 feet in thickness in its type area near Plymouth Bluff, northwest of Columbus, Mississippi (Russell and Keady, 1983; Copeland, 1988). Smith and Mancini (1983) assigned the exposed 42-49 feet (13-15m) of the upper Tombigbee Sand Member to the Cretaceous calcareous nannofossil *Calculites obscurus* Zone (CC17) of Sissingh (1977) and Perch-Nielsen (1979). This nannofossil zone has been related to strata of latest Santonian to earliest Campanian age (Sissingh, 1977; Perch-Nielsen, 1979; Hardenbol et al., 1995; Shipboard Scientific Party, 1998).

The contact between the Tombigbee Sand Member of the Eutaw Formation and the overlying Mooreville Chalk of the Selma Group was described as an unconformity or disconformity by

Conant (1967) and Copeland (1968), because chalk nodules are present along this contact. However, Russell and Keady (1983), Mancini and Soens (1994) and Mancini et al. (1996) described this contact as gradational and conformable, because they observed no physical evidence in support of placing an unconformity at the base of the Mooreville. Detailed biostratigraphic work by Mancini et al. (1996) showed that the Mooreville-Tombigbee contact is, in fact, time-transgressive. The contact is about 23 feet below the first occurrence of the planktic foraminifer *G. elevata* near Selma in central Alabama. In west central Alabama, near Demopolis, the Mooreville-Tombigbee contact occurs above the first occurrence of the planktic foraminifer *G. elevata*, but below the last occurrence of the planktic foraminifer *D. asymetrica*. In east-central Mississippi, the Mooreville-Tombigbee Formation contact lies immediately below the last occurrence of the planktic foraminifer *D. asymetrica* (Fig. 20).

The diachronous nature of the Mooreville-Tombigbee Formation contact has been explained by a gradual inundation of the shoreline toward the updip area and the establishment of a deeper water environment characterized by a muddy carbonate shelf across the southwest Alabama (Puckett, 1992; Mancini et al., 1996).

c. Selma Group

In the outcrop area in western Alabama, the Selma Group consists of about 900 feet of mixed siliciclastic and carbonate chalk/marl sediments. In west Alabama, the Selma Group is divided into several formations, from bottom to top: the Mooreville Chalk (including the Arcola Limestone Member), the Demopolis Chalk (including the Bluffport Marl Member), the Ripley Formation, and the Prairie Bluff Chalk.

The Mooreville Chalk is a fairly uniform chalky marl that consists of interbedded gray marl (calcareous clay) beds with chalk beds. In the outcrop, this formation is about 350-400 feet thick in central Alabama, but thins to about 260-265 feet in eastern Mississippi (Stephenson and Monroe, 1940; Jones, 1967). The uppermost part of the Mooreville Chalk is a gray, indurated calcisphere limestone named the Arcola Limestone Member. It is a distinctive unit that contains very little terrigenous clastic detritus contrasted with the glauconitic, phosphatic, silty chalky marl beds in the Mooreville Chalk. The Arcola Limestone Member is about 14 feet in thickness at Hatchers Bluff, near Selma in central Alabama, and is posed of four beds with three chalky marl interbeds. These beds gradually thin toward the southeast and northwest in the outcrop belt and merge together (Smith, 1995; Tew, 2000). The Arcola Limestone Member is also found in the subsurface in southwestern Alabama. It can be identified on well logs as a unique high peak on resistivity logs in subsurface areas near the outcrop belt in Dallas, Sumter, Marengo and Choctaw counties, Alabama. The limestone bed extends southward at least to Mobile and Baldwin counties, Alabama, because chips of calcisphere limestone characteristic of the Arcola Limestone Member were found in well cuttings from these counties (Charles C. Smith, 2003, personal communications). Biostratigraphic work has shown that the Arcola Limestone Member is essentially a synchronous unit across a wide geographic area (Smith, 1995). It has been assigned to the upper part of the nannofossil CC19a zone (the lower subzone of the *Calculites ovalis* zone) and the lower part of the foraminiferal zone *Globotruncana ventricosa* of Middle Campanian age (Smith, 1995; Mancini et al., 1996). The Arcola Limestone Member can be used as an important time marker in stratigraphic correlations.

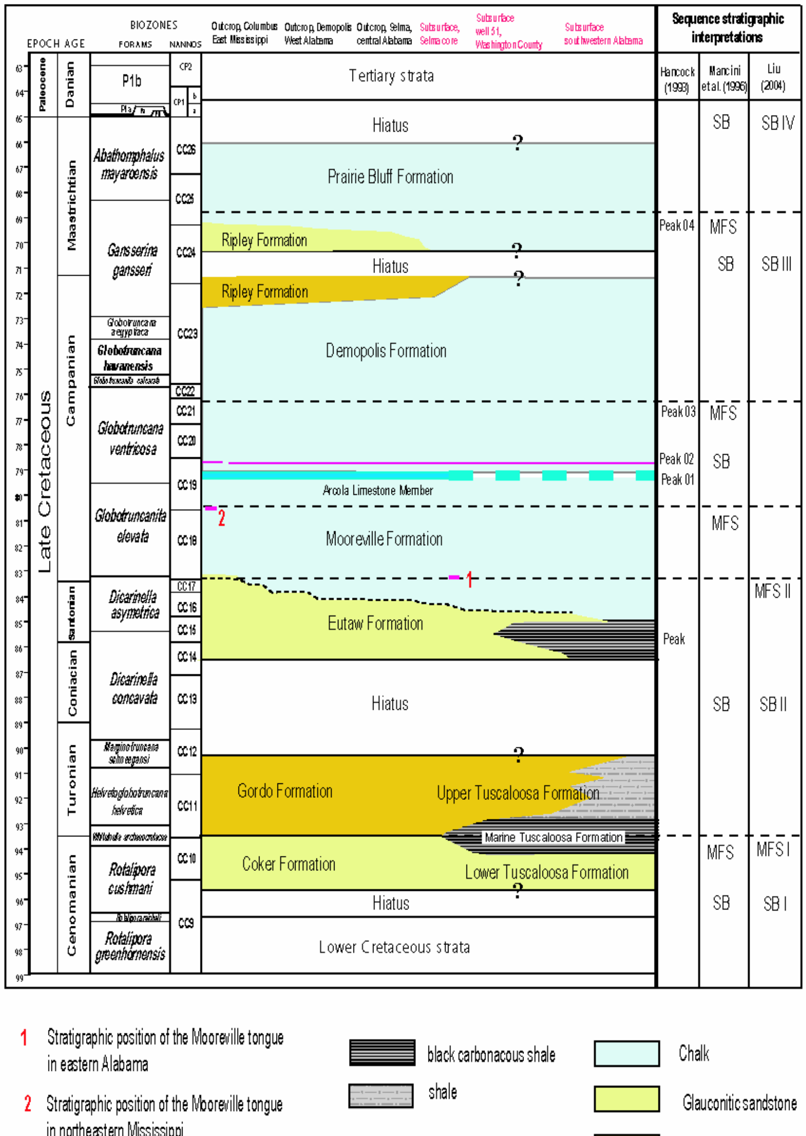


Figure 20. Biostratigraphic framework for the Upper Cretaceous strata in outcrop and subsurface in the northeastern Gulf of Mexico area. Nannofossil zones, foraminiferal zones after Shipboard Scientific Party (1998).

The Demopolis Chalk has a similar lithology as the Mooreville Chalk, but in the outcrop, the Demopolis Chalk is more chalky and indurated. The Demopolis Chalk becomes purer in chalk in the upper part of the formation (Copeland, 1968). The Demopolis Chalk has a thickness of about 450 feet in west Alabama. The upper part of the Demopolis Chalk is a fossiliferous clayey chalky marl member named the Bluffport Marl Member.

Above the Bluffport Marl Member is the Ripley Formation. The Ripley Formation consists of about 100 feet of micaceous sandy silt. The contact between the Demopolis Chalk and the Ripley Formation is gradational. The chalk beds of the Demopolis gradually become more sandy and grade into the micaceous calcareous gray and green sand and chalk beds of the Ripley Formation (Copeland, 1968). Above the Ripley Formation is the youngest unit of the Upper Cretaceous strata in the northeastern Gulf of Mexico, the Prairie Bluff Chalk in west Alabama and Owl Creek Formation in Mississippi. An important, regional mappable unconformity is recognized as an intraformational unconformity in the Ripley Formation in west Alabama (Mancini et al., 1996, 2002) and an unconformity between the Owl Creek Formation and the McNairy Sandstone Member of the Ripley Formation or an intraformational unconformity of the Ripley Formation between the Chiwapa Sandstone Member and the McNairy Sandstone Member in northern Mississippi (Russell, 1967; Swann, 1999; Swann, 2003).

The Upper Cretaceous of the northeastern Gulf of Mexico is capped by a regional unconformity that separates the Prairie Bluff Chalk or Owl Creek Formation of the Selma Group from the overlying Tertiary Clayton Formation of the Midway Group (Copeland, 1968; Donovan et al., 1987; Mancini et al., 1989; Salvador, 1991; Smith, 1997). Where the Prairie Bluff Chalk is locally absent in northern Marengo County toward the west and in southern Dallas County toward the east, the Paleogene Clayton Formation rests directly on marly sands and sandstones of the underlying Ripley Formation (Smith, 1997). The duration of the hiatus represented by this unconformity is, however, still in debate. Mancini et al. (1989) assigned the topmost beds of the Prairie Bluff Chalk in Moscow Landing, Sumter County in west central Alabama to the late Middle Maastrichtian *Racemiguembelina fructicosa* Zonule of Smith and Pessagno (1973) and the foraminifera characteristic of the *Abathomphalus mayaroensis* Zone were not observed. Therefore, Late Maastrichtian strata were described as missing at Moscow Landing. Smith (1997) also stressed that Late Maastrichtian strata were absent in the K-T boundary section at Moscow Landing, although he assigned the top beds of the Prairie Bluff Chalk at Moscow Landing to the nannofossil *Nephrolithus frequens* Zone (CC26 Zone). Many nannofossil workers relate the nannofossil zone CC26 to the planktic foraminiferal *Abathomphalus mayaroensis* Zone. Smith (1997) further cited evidence from Smith (1975) that the range of *Nephrolithus frequens* actually extends down into the upper portion of the foraminiferal *Gansserina gansseri* Zone; therefore, the presence of the nannofossil *Nephrolithus frequens* does not indicate a latest Maastrichtian age. On the contrary, Habib et al. (1992) assigned the topmost 32 cm of the Prairie Formation at Braggs, Lowndes County, Alabama to the nannoplankton *Micula prinsii* zone, which is considered the upper part of the *Nephrolithus frequens* Zone (CC26 Zone). They concluded that these beds were latest Maastrichtian in age.

4. Regional Stratigraphy in the Subsurface

In the subsurface in southwest Alabama, the Upper Cretaceous strata are divided into similar lithological units as those in the outcrop: the Selma Group, the Eutaw Formation and the Tuscaloosa Group. The Selma Group and the Eutaw Formation have been studied in detail in the Gilbertown Field in Choctaw County (Fig. 18) (Pashin et al, 2000). The Tuscaloosa Group has been studied in the South Carlton and Pollard Fields in Clarke, Baldwin and Escambia counties (Fig. 18) (Mancini and Payton, 1981; Mancini et al, 1987).

a. Selma Group

Although the Selma Group is not divided into formal formations in the subsurface, stratigraphic units can be recognized through detailed well log and well cutting studies. Eight intervals labeled S1 through S8 were identified in the Selma Group in the Gilbertown field in Choctaw County (Fig. 21) by Pashin et al. (2000). These units were correlated in the Gilbertown field and adjacent areas and with the strata in the outcrop.

The S1 interval lies sharply on the underlying Eutaw Formation. The contact is marked by a sharp positive excursion of the SP log and the resistivity log (Fig. 21), although this contact appears to be more gradational in nature in cores. The lower three intervals, S1 through S3, have higher resistivity and higher quartz and clay content than other part of the Selma Group (S4 - S8) in this area. Pashin et al. (2000) postulated that this probably reflects the reworking of sediments from the Eutaw Formation, which was still being deposited in the updip area. Interval S4 is a relatively pure chalk unit and has been interpreted as open-shelf deposition in a relative high stand of sea level. At the top of this interval, a calcisphere packstone was described, which corresponds to the Arcola Limestone Member in the outcrop. Therefore, S4 corresponds to the Mooreville Chalk observed in outcrop in west Alabama. Interval S5 is the purest chalk section, and interval S6 is a slightly argillaceous chalk; they correspond to the Demopolis Chalk and its Bluffport Marl Member in the outcrop. Interval S7 is another relatively pure chalk section in the Demopolis Chalk. The S8 interval is the Ripley Formation and the Prairie Bluff undifferentiated. The top of the Selma Group is marked by a prominent shift of the SP log to a more positive value. The Tertiary units that overlie the Selma Group are the Danian Clayton Formation and Porters Creek Formation of the Midway Group. The Clayton Formation is a sandy limestone thinner than 20 feet thick; the Porters Creek Formation is a shale unit. Both of these units have a positive SP response tracking near the shale base line.

b. Eutaw Formation

The Eutaw Formation contains about 290 feet of glauconitic sandstone interbedded with mudstone and shale in the Gilbertown field. As in the surface, the Eutaw Formation unconformably overlies the Tuscaloosa Group. The contact between the Eutaw Formation and the Tuscaloosa Group is more difficult to be defined by well log signature, because both units are sandstones. In order to clearly define this contact on the log, well cores and well cuttings need to be studied. The Eutaw Formation is a fining-up and thinning upward succession and has been divided into seven laterally correlative units designated as E1 to E7 in the Gilbertown field (Fig. 21) by Pashin et al. (2000). The glauconitic sandstone beds of the Eutaw Formation grade into chalk and marl beds assignable to the Selma Group in the basinward direction, with the thickness of the Selma Group increases at the expenses of that of the Eutaw Formation (Liu, 2005).

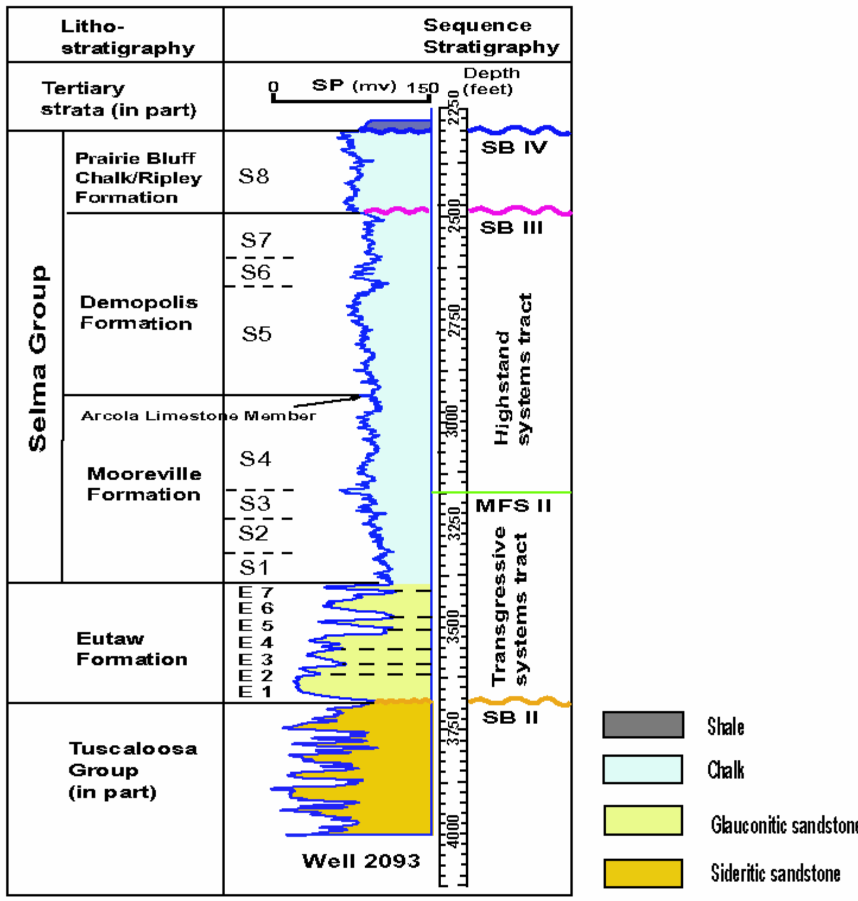


Figure 21. Well log (SP) patterns from well 2093 in the Gilbertown field, Choctaw County, Alabama, modified from Pashin et al. (2000). Sequence stratigraphic interpretation follows Liu (2004). E1 to E7 and S1 to S8 are laterally correlative units in the Eutaw Formation and the Selma Group recognized by Pashin et al. (2000). SB = sequence boundary; MFS = maximum flooding surface.

c. Tuscaloosa Group

In subsurface, the Tuscaloosa Group is divided into three parts according to well log data: the Lower Tuscaloosa Formation, the Marine Tuscaloosa Formation, and the Upper Tuscaloosa Formation (Winter 1954; Mancini et al., 1987). Figure 22 shows the tripartite division of the Tuscaloosa Group on the well log.

The Lower Tuscaloosa Formation consists of interbedded shale, siltstone and sandstone. The Lower Tuscaloosa Formation in southwestern Mississippi and east central Louisiana has been interpreted to be deposited as part of a fluvial-deltaic system (Berg and Cook, 1968; Corcoran et al., 1993). In southwestern Alabama, the Lower Tuscaloosa Formation was divided into two informally defined units: a lower Massive sand interval and the Pilot sand interval separated by a silty claystone bed of about 20-60 feet in thickness (Winter, 1954; Mancini and Payton, 1981; Mancini et al., 1987). Mancini et al. (1987) described sandstone in the Massive sand interval as well sorted, micaceous, locally fossiliferous, calcareous, glauconitic, fine grained, and quartz rich, containing angular to subangular quartz grains. The Pilot sand interval was described as a well sorted, greenish gray to green-brown, micaceous, fossiliferous, glauconitic, calcareous, very fine to medium-grained quartzose sandstone and was interpreted to have accumulated as part of a marine-bar complex (Mancini and Payton, 1981; Mancini et al. 1987). The Massive sand interval in South Carlton and Pollard fields, southwestern Alabama was interpreted as sands that were deposited in a wave-dominated, highly descriptive delta system, and the Pilot sand interval was concluded to represent shelf sands and clays that accumulated during a marine transgression (Mancini et al., 1987).

The Marine Tuscaloosa Formation overlies conformably the sand of the Lower Tuscaloosa Formation. A gray, silty oyster bed was observed at the base of the Marine Tuscaloosa Formation in parts of the South Carlton field (Mancini et al., 1987). The Marine Tuscaloosa Formation consists primarily of dark gray, silty, micaceous, fossiliferous, calcareous, laminated claystone interbedded with dark gray, silty, micaceous fossiliferous, glauconitic, calcareous siltstone and very fine-grained sandstone in South Carlton and Pollard fields. It has been reported to have been deposited in middle and outer neritic, open marine environments (Mancini and Smith, 1980; Mancini and Payton, 1981; Mancini et al., 1987). Biostratigraphic work by Mancini and Smith (1980) shows that the lower 10 to 20 feet of the 100 feet thick Marine Tuscaloosa can be assigned to the Upper Cretaceous calcareous nannoplankton CC 10 zone (*Microrhabdulus decoratus* Zone) and planktic foraminiferal *R. cushmani* total range zone. Therefore, the lowest part of the Marine Tuscaloosa Formation is Late Cenomanian in age (Fig. 20).

The Upper Tuscaloosa Formation, which lies conformably on the Marine Tuscaloosa Formation, consists of primarily greenish gray, glauconitic fossiliferous, fine to medium grained sandstone interbedded with gray and green shale in South Carlton and Pollard fields (Mancini et al., 1987). Mancini et al. (1987) interpreted the Upper Tuscaloosa Formation in South Carlton and Pollard fields as having been deposited in marginal marine and marine shelf environments. The sandstone beds of the Upper Tuscaloosa Formation grade into shale in a basinward direction.

Essentially, the Lower Tuscaloosa Formation and Marine Tuscaloosa Formation correspond to the Coker Formation updip in the outcrop area, and the Upper Tuscaloosa Formation in the

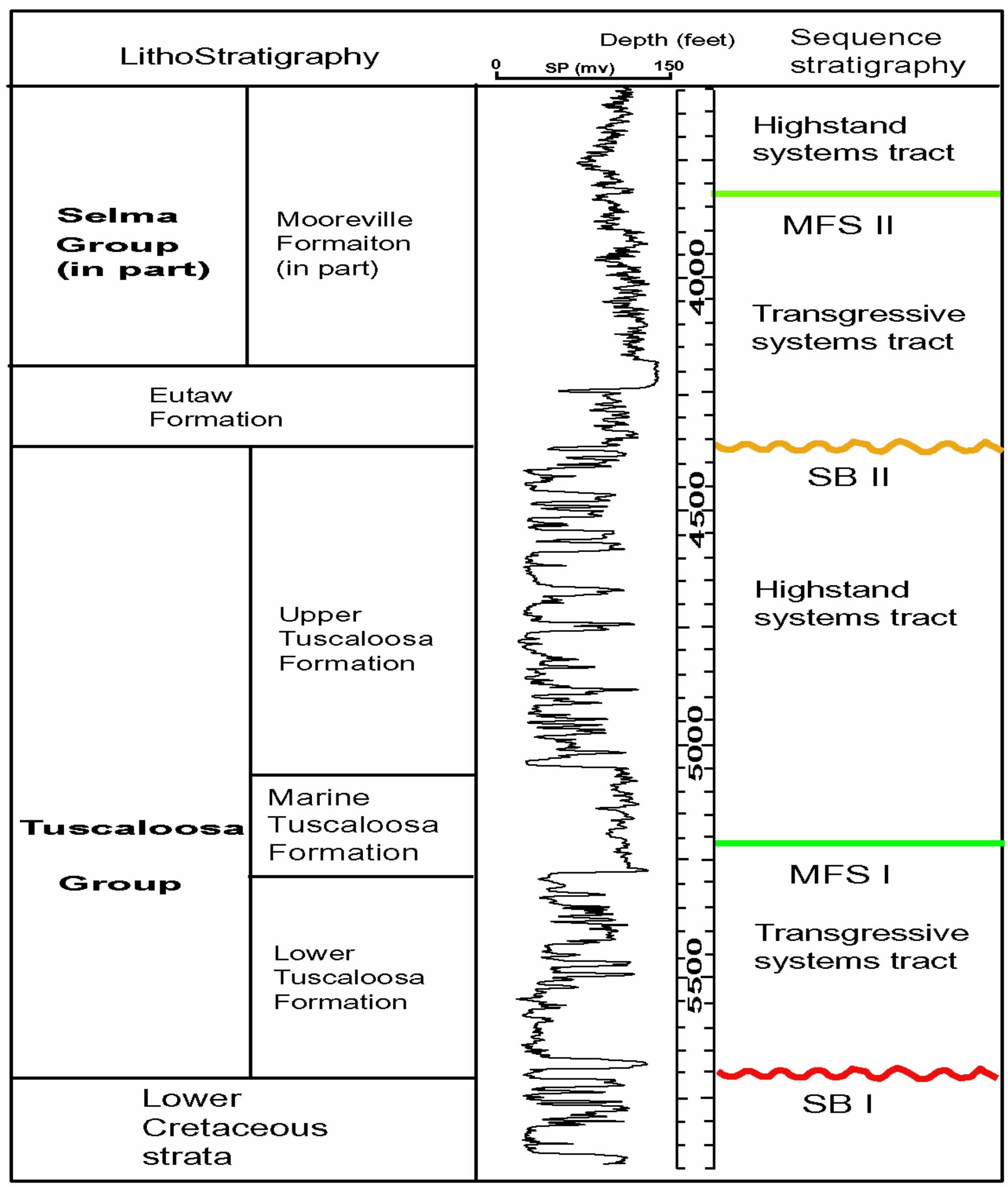


Figure 22. Well log patterns from well 2182, Clarke County, Alabama. The Tuscaloosa Group is divided into three formations in the subsurface according to well log signatures. Sequence stratigraphic interpretation follows Liu (2004). MFS = maximum flooding surface, SB = sequence boundary.

subsurface corresponds to the Gordo Formation (Mancini and Payton, 1981; Mancini et al., 1987).

5. Previous Sequence Stratigraphic Interpretations

The sequence stratigraphy of the Tuscaloosa Group, the Eutaw Formation and the Selma Group has been studied by several past workers using different methods.

a. Tuscaloosa Group

The relationship between the deposition of the Gordo Formation and the Coker Formation and sea-level fluctuations were described by Conant (1967) and Russell and Keady (1983). The Tuscaloosa Group, as observed in the outcrop, was interpreted as having been deposited in a marine transgressive-regressive cycle. The Coker Formation was deposited during an advance of the sea; while the Gordo Formation was deposited during a subsequent withdrawal of the sea (Conant, 1967; Russell and Keady, 1983).

In the subsurface, the Tuscaloosa Group has also been interpreted as having been deposited in a complete transgressive-regressive cycle or sequence (Corcoran et al., 1993; Mancini et al., 1996; Mancini and Puckett, 2002; Mancini and Puckett, 2003). A major transgression in the Late Cenomanian to Early Turonian resulted in middle shelf, open marine sediments of the Marine Tuscaloosa Formation overlying the fluvial-deltaic, marginal marine and marine sediments of the Lower Tuscaloosa Formation. A major regression occurred during the Late Turonian, which resulted in the deposition of marginal marine and marine shelf sediments of the Upper Tuscaloosa Formation. These deposits overlie the deep water, open marine shale of the Marine Tuscaloosa Formation in South Carlton and Pollard fields, southwestern Alabama.

Mancini and Puckett (2003) interpreted the depositional history of the Tuscaloosa Group using an integrated biostratigraphic and transgressive-regressive cycle (sequence) approach. The Tuscaloosa Group was interpreted to represent the Late Cretaceous T-R cycle 5 (transgressive-regressive cycle or sequence) in the northern Gulf of Mexico. The Massive sand of the Lower Tuscaloosa Formation was interpreted to represent the aggrading interval of the transgressive phase (coastal barrier deposits). The marine shale and sandstone beds of the Pilot sand of the Lower Tuscaloosa Formation and the lower beds of the Marine Tuscaloosa Formation were reported to be the backstepping interval of the transgressive phase (marine shelf deposits). The infilling interval of the regressive phase of the T-R 5 cycle was concluded to be represented by the upper beds of the Marine Tuscaloosa Formation (shallow marine deposits) and the Upper Tuscaloosa Formation (fluvial-deltaic deposits).

b. Eutaw Formation and Selma Group

Hancock (1993) recognized four major transgressive peaks (Peak no.1 to Peak no. 4) in Campanian-Maastrichtian strata of the northwestern Europe and correlated them to the Upper Cretaceous strata in several areas in North America, such as the Western Interior, New Jersey Coastal Plain and the northern margin of the Gulf of Mexico (Mississippi and Alabama). These transgressive peaks were defined as mid-points between pairs of regressive troughs, which in turn were recognized by identifying nodular chalks and hard grounds in the English Chalk (Hancock, 1990).

According to his trans-Atlantic correlation, Hancock (1993) reported that there were five transgressive peaks in the Santonian-Maastrichtian strata in the northern margin of the Gulf of Mexico in Alabama and Mississippi, including one in the Eutaw Formation (Fig. 20). This peak was dated as Santonian in age.

Hancock (1993) reported that the Eutaw Formation represented a marine transgressive peak, because it progressively overlaps the McShan Formation, Tuscaloosa gravels and Ordovician rocks in an updip direction. Hancock (1993) reported that this transgressive peak corresponded to the mid-Santonian peak as recognized in the middle of the European *Uintacrinus socialis* Zone. Hancock (1993) stated that the Tombigbee-Mooreville contact, the layer of phosphatic nodules recorded 21 feet above the bench of Tombigbee sandstone at Plymouth Bluff, Mississippi, represented a regressive event in the earliest Campanian. Hancock (1993) suggested that this regressive event corresponded to the regressive trough recognized in the *Echinocorys tectiformis* Zone in England by Hancock (1990).

Hancock (1993) reported that the Arcola Limestone Member represented a transgressive peak (Peak no.1) (Fig. 20). He reasoned that although rich in calcispheres, the Arcola Limestone Member consists of essentially chalk, which is a good indicator of a transgressive peak in a clastic succession. The Mooreville Chalk was, therefore, interpreted to be transgressive.

Hancock (1993) stated that the transgressive Peak no. 2 should be placed in the lower Demopolis Chalk. However, he did not recognize a physical surface in the lower Demopolis Chalk that can be correlated to the Peak no. 2. in Europe. Hancock (1993) concluded that the disconformity with baculitids in a white phosphate about 5.9 feet (1.8m) above the Arcola Limestone in the lower Demopolis Chalk, at Tibbee Creek, in Clay County, Mississippi probably represented the transgressive Peak no.2 (Fig. 20). He stated that this disconformity could be the result of a regression but a transgressive peak could have had similar effects in these laminated chalk and marl beds.

Hancock (1993) stated that transgressive Peak no. 3 was represented by the purest chalk section of the Demopolis Chalk (Fig. 20). Hancock (1993) stated that this section of the chalk has the lowest clay content and most resembles its European counterpart. The upper Demopolis Chalk above this purest chalk section was interpreted to be regressive. The transgressive Peak no.4 was interpreted to be represented by the middle part of the Prairie Bluff Chalk (Fig. 20).

Mancini et al. (1996) and Puckett and Mancini (2000) studied the Upper Cretaceous strata in the outcrop in central and western Alabama, and in eastern and northeastern Mississippi employing an integrated biostratigraphic and sedimentological approach. Three sequences were recognized in the Santonian to Maastrichtian strata in the eastern Gulf Coastal Plain.

UAZGC 03 Sequence: The Eutaw-Tuscaloosa formation contact was reported to be the sequence boundary of the UAZGC 03 sequence. The lower Eutaw Formation was interpreted to be the lowstand systems tract deposits. The unconformable contact between the lower Eutaw Formation and the Tombigbee Sand Member was reported to be a transgressive surface, which was marked by a one to two inch sandstone bed containing phosphatic pebbles, shark teeth, and reworked fossils (Mancini and Soens, 1994). Therefore, the lower Eutaw Formation was interpreted as lowstand systems tract deposits; and the Tombigbee Sand Member and the lower Mooreville Chalk were reported to be transgressive systems tract sediments.

The Tombigbee-Mooreville contact was described as an unconformity by Conant (1967) and Copeland (1968). Hancock (1993) interpreted this contact to have formed in a marine regression. Mancini et al. (1996), however, interpreted this contact as one of the transgressive surfaces or marine ravinement surfaces in the transgressive systems tract, because they did not observe any physical evidence supportive of placing an unconformity at the base of the Mooreville, as discussed previously.

The maximum flooding event of the UZAGC 03 sequence was recognized based on a change in trend of the relative abundance of planktic foraminifera (P/B ratios). This faunal abundance peak or transgressive peak occurs approximately 100 feet below the top of the Arcola Limestone Member (Puckett and Mancini, 2000). In addition, the high P/B ratio coincides with a particular assemblage of benthic foraminifera which is characteristic of deeper marine water (Gan, 1996; Puckett and Mancini, 2000). This maximum flooding event was, therefore, placed at the level where the deepest water level (maximum bathymetric surface) was interpreted from foraminiferal data. No distinct physical surface has been observed in the Mooreville Chalk at this horizon to delineate a maximum flooding surface.

Puckett and Mancini (2000) also used regional stratigraphic relations to interpret this maximum flooding event or transgressive peak in the UZAGC 03 sequence. They reasoned that the maximum flooding event or transgressive peak should approximate maximum transgression; thereby, separating transgressive facies below from regressive facies above. Therefore, this event should be recognized, particularly in nearshore deposits, as a deeper water marine tongue bounded by shallower water deposits below and above. Puckett and Mancini (2000) recognized two Mooreville tongues (Fig. 18): one in northeastern Mississippi and one in eastern Alabama. The Mooreville tongue in eastern Alabama occurred stratigraphically near the Eutaw-Mooreville contact in eastern Mississippi, and the tongue in northeastern Mississippi occurred higher in the Mooreville section (Fig. 20).

In northeastern Mississippi, a very thin Mooreville section is present between the Coffee Sand and its Tupelo Tongue in eastern Lee County and northwestern Itawamba County (Fig. 18). Puckett and Mancini (2000) concluded that this thin Mooreville bed, which has the lowest sand content, should approximate the maximum flooding surface. Puckett and Mancini (2000) further cited study by Stephenson and Monroe (1940) that showed that the lower Tupelo Tongue is stratigraphically equivalent to the Arcola Limestone Member. Therefore, the maximum flooding event was interpreted to be in the upper middle part of the Mooreville Chalk, slightly below the Arcola Limestone Member. This interpretation is in agreement with the observed changes in P/B ratios and changes in composition in the benthic foraminiferal populations. Therefore, the Coffee Sand proper, which is stratigraphically equivalent to the Mooreville Chalk, was interpreted to be deposits of the transgressive systems tract, and the Tupelo Tongue, which is stratigraphically equivalent to the Arcola Limestone Member, was reported to be deposits of the highstand systems tract.

The stratigraphic position of the Mooreville tongue in eastern Alabama and western Georgia, however, provides additional complexity for sequence stratigraphic analysis. Puckett and

Mancini (2000) concluded that this tongue, which occurred between two siliciclastic-dominated tongues of the Blufftown Formation in west central Russell County, Alabama (Fig. 18), represented the maximum flooding event of the UAZGC 03 sequence in eastern Alabama. However, biostratigraphic work by Puckett and Mancini (2001) showed that this Mooreville tongue is assigned to the upper part of the *D. asymetrica* foraminiferal zone (latest Santonian according to Caron, 1985); therefore, it is older in age than the Mooreville tongue in northeastern Mississippi, which is assigned to the upper portion of the *G. elevata* foraminiferal Zone (late Early Campanian according to Caron, 1985). As discussed above, the top of planktic foraminiferal *D. asymetrica* zone occurred immediately above the Tombigbee-Mooreville contact at Plymouth Bluff, eastern Mississippi (Dowsett, 1989; Mancini et al., 1996; Puckett and Mancini, 2000). Therefore, the geological age of the Mooreville tongue in eastern Alabama approximates the age of the Tombigbee-Mooreville contact in eastern Mississippi (Fig. 20). Mancini and Puckett (2003) recognized this stratigraphic relationship and concluded that the UAZGC 03 or T-R 6 cycle consists of two higher order sequences.

The highstand systems tract of the UAZGC 03 sequence was interpreted to include the upper 100 feet of the Mooreville Chalk (including the Arcola Limestone Member) and the lower 7-9 feet of the Demopolis Chalk (Mancini et al., 1996; Puckett and Mancini, 2000).

UAZGC 04 Sequence: The UAZGC 04 sequence includes most of the Demopolis Chalk (including the Bluffport Marl Member) and the lower part of the Ripley Formation. The lower sequence boundary of the UAZGC 04 sequence is represented by an unconformity updip (northern Mississippi) and it becomes conformable downdip in eastern Mississippi and western Alabama (Puckett and Mancini, 2000). This sequence boundary is recognized by an oyster bed (*Pycnodonte convexa*) above the Tupelo Tongue in Lee County, Mississippi. This oyster bed continues to the Frankstown site, where it lies above glauconitic sand beds of the Demopolis Chalk in northern Mississippi (Puckett and Mancini, 2000).

Puckett and Mancini (2000) stated that the unconformable surface between the Coffee Sand and the glauconitic sand beds, which underlies the oyster bed, represented the sequence boundary and the transgressive surface of the UAZGC 04 sequence. This sequence boundary becomes conformable to the south at the Tibbee Creek section in Clay County, eastern Mississippi, where two horizons of abundant phosphatic molds occurred between 4.5 and 7 feet above the Arcola Limestone Member. The upper one was interpreted to be the conformable part of the sequence boundary. As has been discussed above, Hancock (1993) tentatively placed his transgressive Peak no. 2 at this surface (Fig. 20).

The maximum flooding event or transgressive peak in this sequence was placed in the middle of the Demopolis Chalk based on a change in trend in relative abundance of planktic foraminifers (P/B ratios) (Mancini et al., 1996; Puckett and Mancini, 2000). No physical surface for this maximum flooding surface was identified; however, this event was located in the purest chalk section, informally named the Muldrow Chalky member, approximately 270 feet above the Arcola Limestone Member in the middle of the Demopolis Chalk (Fig. 20). This stratigraphic level corresponds approximately to the transgressive Peak no.3 of Hancock (1993).

Above the maximum flooding event, there is a marked progressive decrease in planktic foraminiferal percentages and an increase in coarser siliciclastic sediment. This maximum flooding event was, therefore, also placed at the level where the maximum bathymetric surface was interpreted from foraminiferal data.

Puckett and Mancini (2000) used regional stratigraphic relations to assist with the location of the maximum flooding event or transgressive peak of the UZAGC 04 sequence. The transgressive peak of the UZAGC 04 sequence was interpreted to be represented by a marine tongue in the Demopolis Chalk that extended into northeastern Mississippi (Fig. 18) and pinched out near Adamsville, Tennessee. Puckett and Mancini (2000) reported that this marine tongue probably represented the highest sea level of the entire Phanerozoic. In eastern Alabama, this transgressive peak is represented by a marine tongue in the middle of the Cusseta Sand Member of the Ripley Formation (Fig. 18).

The upper part of the Demopolis Chalk, the Bluffport Marl Member and the lower to middle Ripley Formation represented the highstand systems tract deposits of this sequence. The lithology of the upper UAZGC 04 sequence gradually becomes sandy, grading from the pure chalk section of the Demopolis to the interbedded chalk and marl section of the Bluffport Marl Member to the calcareous sands of the lower Ripley Formation (Mancini et al., 1996; Puckett and Mancini, 2000). This lithologic trend can be observed at the Rock Hill and Salem Church sections in Oktibbeha County, eastern Mississippi, along the Alabama River at Elm Bluff, Red Bluff, and Rocky Bluff in Dallas County, and in the Braggs area of Lowndes County, Alabama (Puckett and Mancini, 2000).

The UAZGC 04 sequence is capped by an unconformity at the base of the UAZGC 05 sequence. It can be an intraformational unconformity in the Ripley Formation and recognized at the contact between the McNairy Sand Member and the Chiwapa Sandstone Member of the Ripley Formation or the unconformity can be at the contact of the Owl Creek Formation with the Ripley Formation (Mancini et al., 1996).

UAZGC 05 Sequence: The UAZGC 05 sequence is the upper sequence in the Upper Cretaceous strata in the northeastern Gulf of Mexico area. The middle to upper Ripley sandstone beds were reported to represent the lowstand deposits of this sequence (Mancini et al., 1996). The calcareous sandstone and marl beds of the Chiwapa Sandstone Member of the Ripley Formation and the lower marl beds of the Prairie Bluff Chalk were interpreted to represent the transgressive systems tract deposits.

The maximum flooding surface of the UAZGC 05 was recognized within the Prairie Bluff Chalk (Fig. 20). A physical surface of low to non-deposition was identified in the middle of the Prairie Bluff Chalk. A decrease in planktic foraminiferal percentages (P/B ratio) was also observed above the surface. The purest chalk section in the middle of the Prairie Bluff section was interpreted to be the condensed section (Mancini et al., 1996).

The top of the UAZGC 05 sequence was marked by the Maastrichtian-Danian unconformity, which is the top of the Upper Cretaceous section in the northeastern Gulf of Mexico. The length of the hiatus associated with this unconformity is still in debate, as discussed above.

Based on the biostratigraphic and sedimentological work of Mancini et al. (1996) and Puckett and Mancini (2000), Mancini and Puckett (2003) reinterpreted the geohistory of the northern Gulf of Mexico using an integrated biostratigraphic and transgressive and regressive cycle approach discussed by Mancini and Puckett (2002). A T-R cycle is divided into two phases: a transgressive phase that includes an upward deepening event with the creation of the accommodation space and a regressive phase that includes an upward shallowing event with the filling of the accommodation space (Johnson et al., 1985). The transgressive phase of the T-R cycle usually consists of a backstepping interval and may include an aggrading interval; the regressive phase of the T-R cycle usually consists of an infilling interval, but may also include a forestepping interval (Jacquin and de Graciansky, 1998).

The Upper Cretaceous strata were divided into five transgressive-regressive cycles, from T-R 4 to T-R 8 (including the Early Cenomanian part of the Washita Group, T-R 4). As discussed previously, the T-R 5 cycle is represented by the Tuscaloosa Group in the northeastern Gulf of Mexico. The Eutaw Formation and the Selma Group were deposited during the T-R cycles 6, 7 and 8.

The T-R 6 cycle corresponds to the UAZGC 03 sequence of Mancini et al. (1996); however, Mancini and Puckett (2003) concluded that two higher order cycles or sequences probably occurred in the T-R 6 cycle. The Tombigbee-Mooreville contact was interpreted to be a significant marine transgressive and flooding event during the latest Santonian to earliest Campanian. This transgressive peak was also represented by the Mooreville tongue in eastern Alabama. The other transgressive and marine flooding event was represented by the fossil abundance (P/B) peak in the upper part of the Mooreville Chalk (late Early Campanian) and the Mooreville tongue in northeastern Mississippi. The T-R 7 cycle corresponds to the UAZGC 04 sequence of Mancini et al. (1996). The T-R 8 cycle corresponds to the UAZGC 05 sequence of Mancini et al. (1996). However, the glauconitic sandstone beds of the upper Ripley Formation, which were interpreted to be the lowstand systems tract of the UAZGC 05 sequence by Mancini et al. (1996) and Puckett and Mancini (2000), were designated as the aggrading interval of the transgressive phase of the T-R 8 cycle.

6. Sequence Stratigraphic Interpretation from Seismic Data

The sequence stratigraphy of the Upper Cretaceous strata has been studied by Liu (2004) using seismic data and well log data in offshore Alabama and Mississippi area.

Depositional sequences were interpreted on seismic sections by recognizing horizontal reflection terminations using the concepts and methods defined by Mitchum et al. (1977) and Vail (1987): sequence boundaries were identified as onlap surfaces and maximum flooding surfaces as downlap surfaces (Fig. 23). Important seismic reflections that have correlation implications, such as maximum flooding surfaces and sequence boundaries, were identified and traced across the study area.

Four sequence boundaries were identified on seismic sections and traced across the seismic data coverage area (Fig. 24). The Upper Cretaceous strata in the offshore Alabama and Mississippi area were, therefore, divided into three seismic sequences: UK I, UK II and UK III.

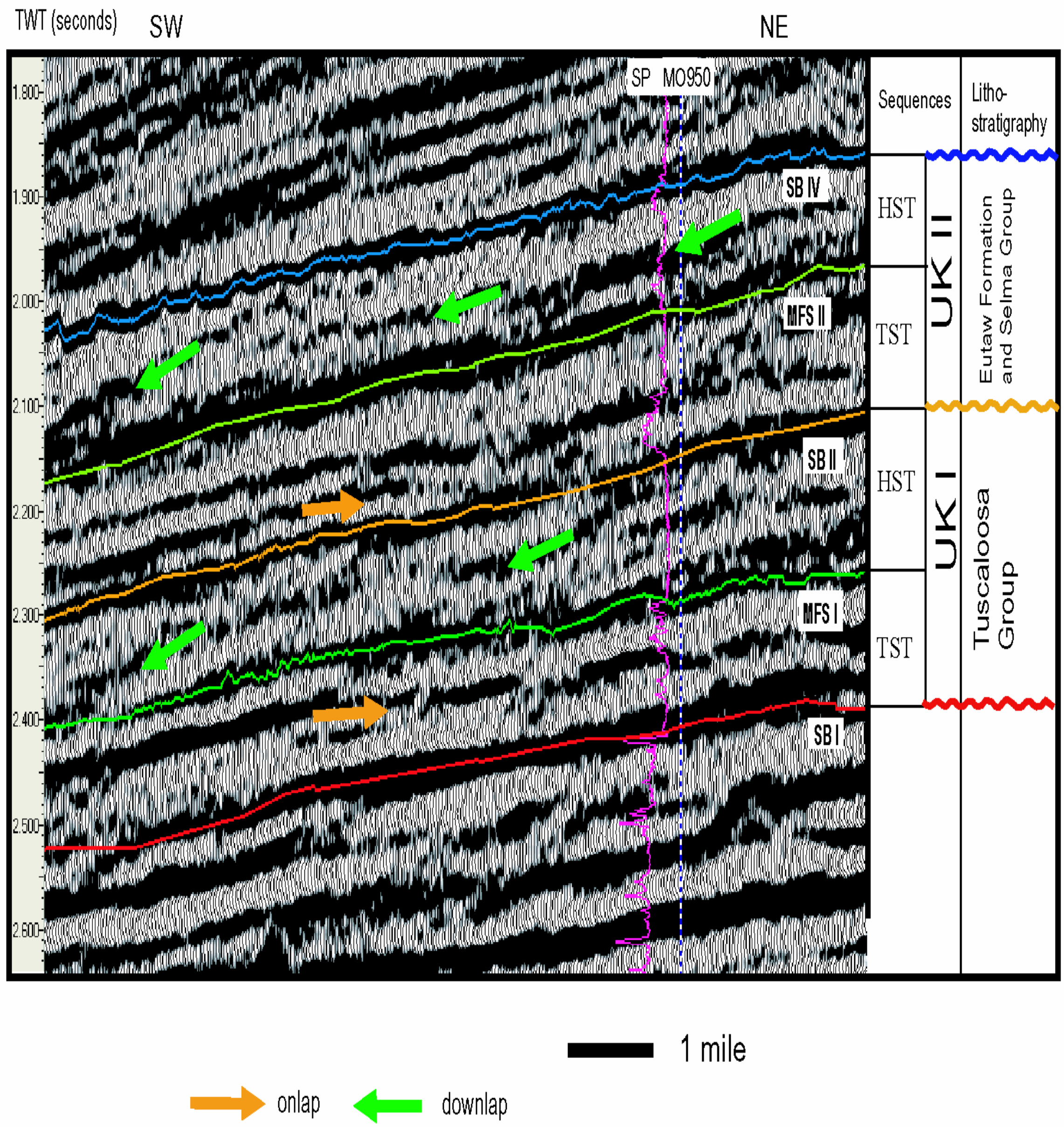


Figure 23. Seismic dip section in the Viosca Knoll area. Sequence boundaries and maximum flooding surfaces are recognized by identifying seismic reflector termination patterns: sequence boundary as onlap surface and maximum flooding surface as downlap surface. SB III is not recognized in this section because the UK III sequence is very thin here. The color of each surface is identical with that in Figures 21, 22, 24. SB = sequence boundary, MFS = maximum flooding surface, TST = transgressive systems tract, HST = highstand systems tract, TWT = two-way travel time.

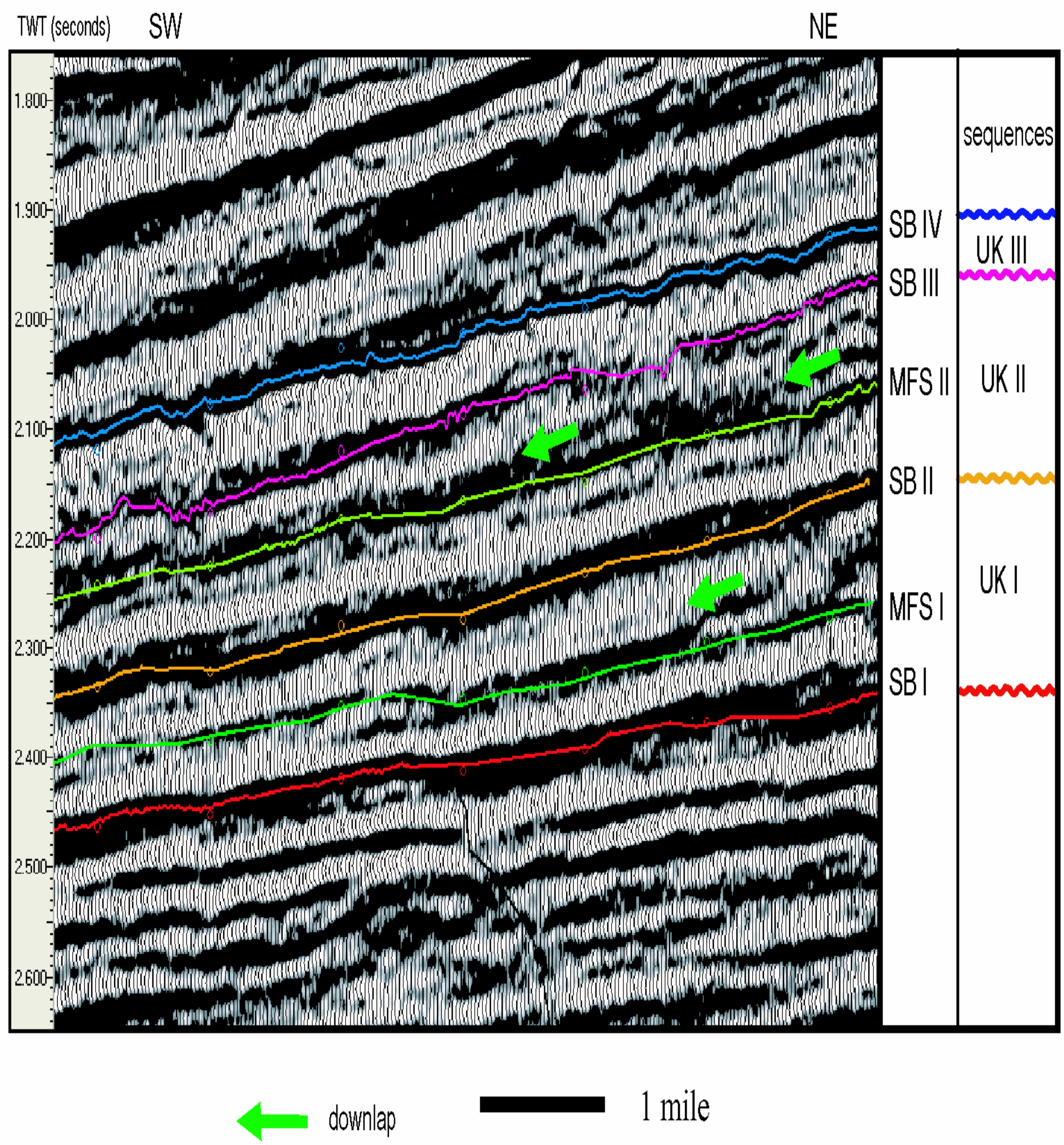


Figure 24. Seismic dip section in the Viosca Knoll area. Four sequence boundaries and two maximum flooding surfaces were identified in the Upper Cretaceous strata in the northeastern Gulf of Mexico area. Three sequences were delinated by these four sequence boundaries, and the lower two sequences were further divided by maximum flooding surfaces into a transgressive systems tract and a highstand systems tract. SB = sequence boundary; MFS = maximum flooding surface; TWT = two-way travel time.

Two maximum flooding surfaces recognized as downlap surfaces were identified in the two lower seismic sequences, therefore, the UK I and UK II sequences were further divided by the two maximum flooding surfaces into a transgressive systems tract and a highstand systems tract respectively (Fig. 24). Seismic sequence boundaries and maximum flooding surfaces identified on the seismic sections were projected onto well logs by using checkshot surveys and checkshot survey calibrated synthetic seismograms (Liu, 2004). Therefore, sequence boundaries and maximum flooding surfaces recognized from seismic data can be correlated to areas outside of the seismic data coverage area.

7. Correlation from Subsurface to Surface

A cross section based on well log data was established to correlate surfaces identified in offshore Alabama and Mississippi area, where seismic data have been interpreted, to areas near the southern limit of the outcrop belt (Figs. 25 and 26).

The sequence boundaries recognized from seismic sections were found to be correlative with major unconformities identified in previous outcrop and subsurface studies: the SB I corresponds to the basal Tuscaloosa unconformity; the SB II corresponds to the unconformity between the Eutaw Formation and the Tuscaloosa Group; the SB III corresponds to the intraformational unconformity in the Ripley Formation in Alabama; and the SB IV corresponding to the unconformity between the Selma Group and the Tertiary Midway Group.

The UK I sequence interpreted from seismic data corresponds to the Tuscaloosa transgressive-regressive cycle or sequence (Mid-Cenomanian to Late Turonian) recognized by previous outcrop and subsurface studies (Conant, 1967; Russell and Keady, 1983; Corcoran et al., 1993; Mancini and Puckett, 2002; Mancini and Puckett, 2003).

The base of this sequence, SB I (the red line on Figures 23 and 24), corresponds to the mid-Cretaceous Sequence Boundary. This sequence boundary is a prominent reflector on most of the seismic lines in the study area, and has been observed by previous authors in the Gulf of Mexico (Shaub et al., 1984; Addy and Buffler, 1984; Faust, 1990). Onlap patterns that terminate against this sequence boundary were observed by Liu (2004) on seismic sections in the outer shelf area near the mid-Cretaceous shelf break (Fig. 23). This observation suggests that sea level dropped at least below the onlap point in the outer shelf area. This interpretation agrees with the fluvial-deltaic and marginal marine nature of the Lower Tuscaloosa Formation observed in well cores, logs, and cuttings in southwestern Mississippi, east central Louisiana, and southwestern Alabama (Berg and Cook, 1968; Mancini et al., 1987; Corcoran et al., 1993). Therefore, during the period when the mid-Cretaceous sequence boundary developed, most of the shelf was exposed, and the shelf area was probably subjected to subaerial erosion.

A prominent downlap surface, recognized by Liu (2004) as the MFS I (the dark green line on Figures 23 and 24), divides the UK I sequence into two systems tracts, which have different seismic reflection patterns. Reflectors below the MFS I exhibit a divergent pattern and were interpreted as the transgressive systems tract. The upper part of UK I sequence exhibits a strong prograding pattern on seismic sections and was interpreted as the highstand systems tract (Liu, 2004). Liu (2004) placed the MFS I surface in the middle of the Marine Tuscaloosa Formation by constructing synthetic seismograms and by using checkshot surveys.

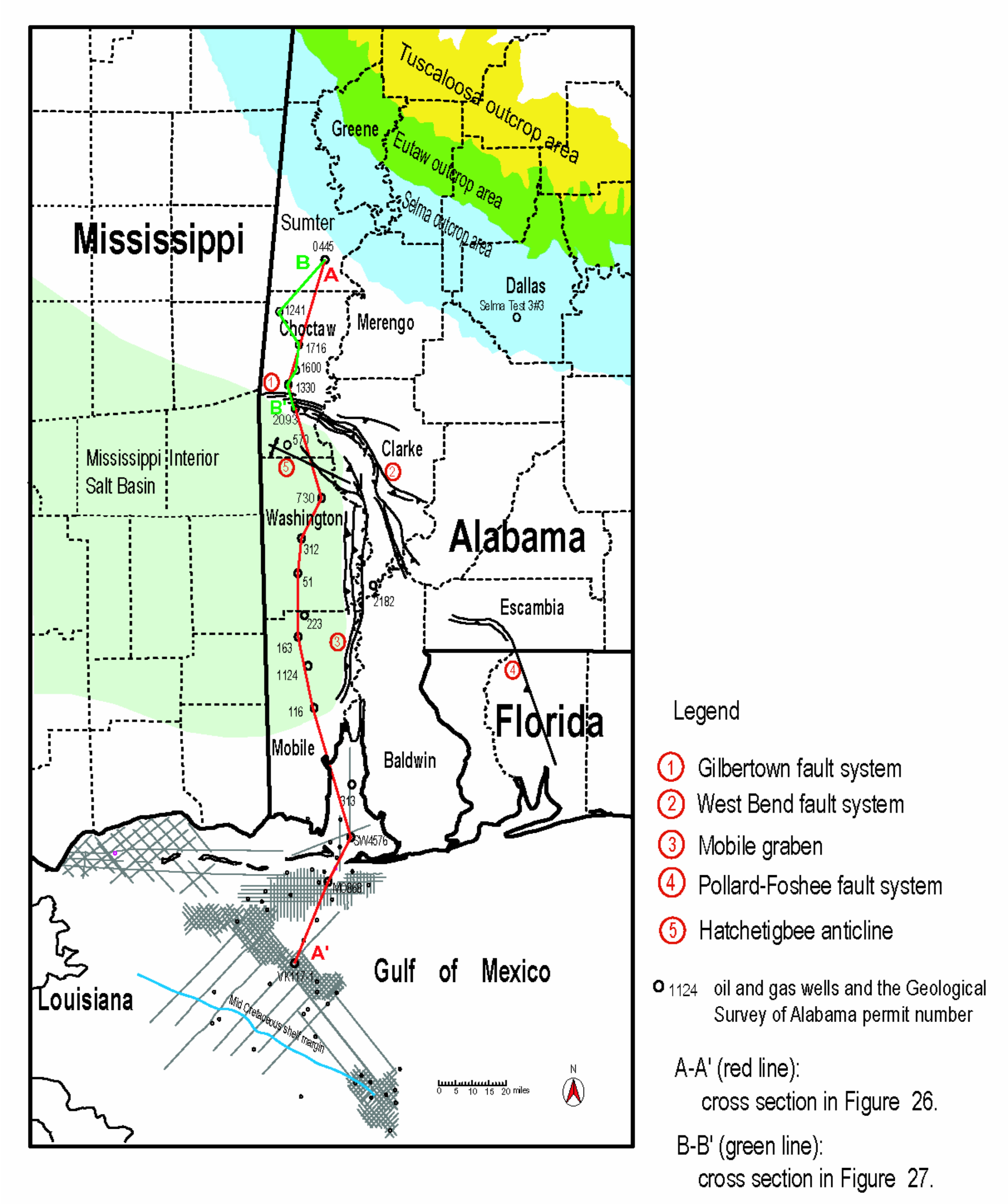


Figure 25. Location of cross sections and seismic data.

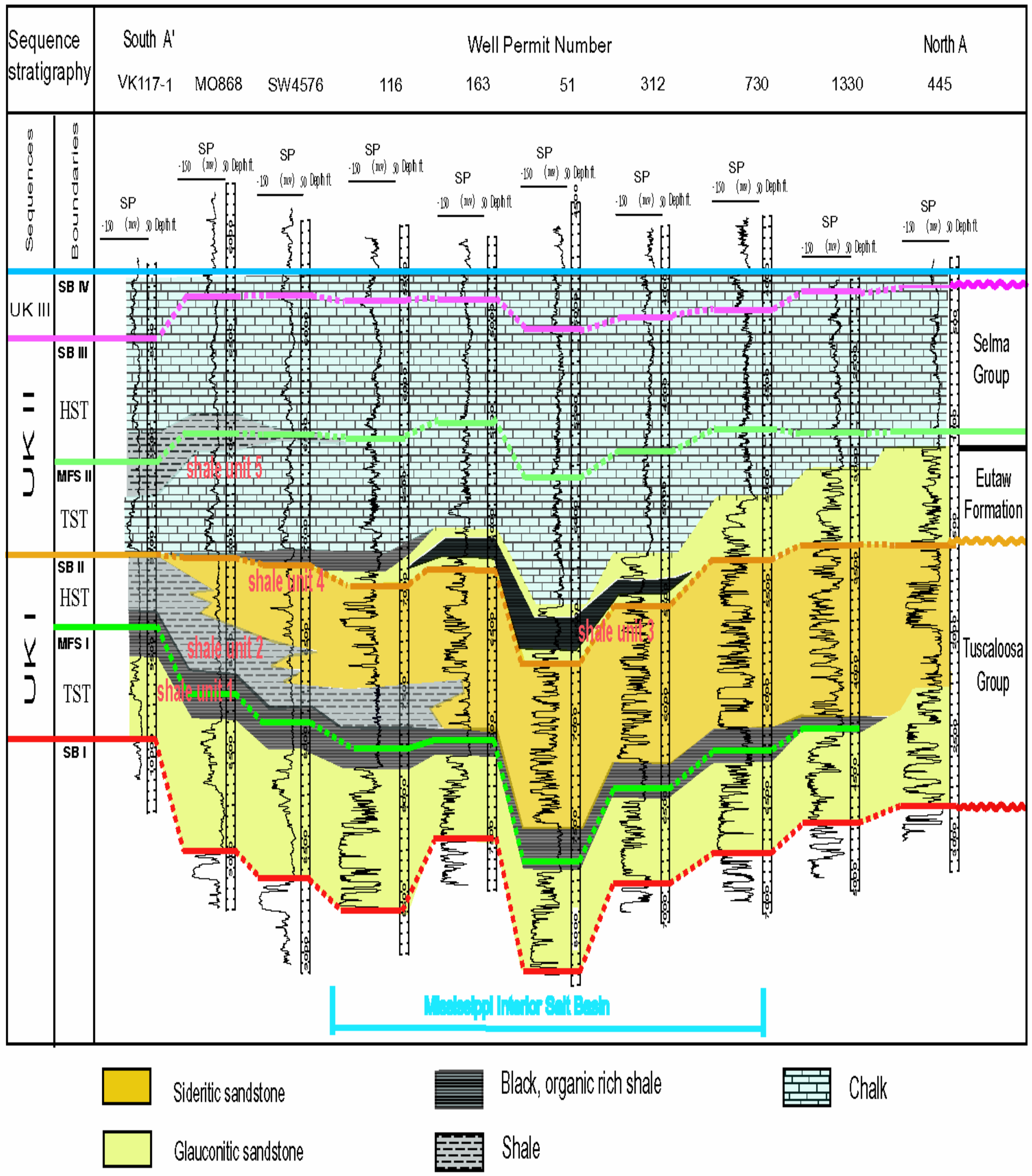


Figure 26. Cross section A-A' from the offshore area to the outcrop belt area showing the facies changes on the continental shelf. See Figure 8 for well locations and the position of the cross section. Sequence boundaries and maximum flooding surfaces were recognized from seismic data (see Figures 23 and 24) and projected onto well logs using synthetic seismograms and check shots (Liu, 2004).

Therefore, the seismic interpretation of the Tuscaloosa Group by Liu (2004) agrees with the T-R cycle (sequence) interpretation of Mancini and Puckett (2003). The transgressive systems tract recognized on seismic data corresponds to the Lower Tuscaloosa Formation and the lower part of the Marine Tuscaloosa Formation; the highstand systems tract corresponds to the upper part of the Marine Tuscaloosa Formation and the Upper Tuscaloosa Formation (Figs. 22 and 26).

The seismic reflection termination patterns revealed a fundamental difference between the Lower Tuscaloosa Formation and the Upper Tuscaloosa Formation. Younger sediments of the Lower Tuscaloosa Formation were deposited progressively landward toward the basin margin, therefore, coastal onlap migrated progressively landward against the sequence boundary or initial surface of deposition; whereas, the sediments of the Upper Tuscaloosa Formation prograded progressively downdip onto the maximum flooding surface.

On well logs (Figs 22 and 26), the MFS I, located in the Marine Tuscaloosa Formation, can be traced updip to well 445 in Sumter County. Further updip, the marine shale layer pinched out and the Tuscaloosa Group is divided into the Coker Formation and the Gordo Formation. The maximum flooding surface approximately corresponds to the boundary between the Gordo Formation and Coker Formation (Fig. 20).

Facies changes in the Upper Tuscaloosa Formation and Lower Tuscaloosa Formation were revealed by the well log cross section. Both the Lower Tuscaloosa Formation and the Upper Tuscaloosa Formation became sandier and thicker toward the basin margin or updip area, where the siliciclastic input originated. However, depositional patterns in these two formations are different. The Lower Tuscaloosa Formation/Coker Formation exhibits a retrogradational pattern; where as the Upper Tuscaloosa Formation/Gordo Formation exhibits a progradational pattern (Figs. 23, 24, and 26). The Upper Tuscaloosa Formation graded essentially into a thick shale unit in the outer shelf area, while the Lower Tuscaloosa Formation remained primarily a sandy unit (Fig. 26).

The UK II sequence includes the Eutaw Formation and the lower part of the Selma Group (Mooreville Chalk, Demopolis Chalk, and the lower beds of the Ripley Formation). Therefore, the UK II sequence identified on the seismic data includes the UAZGC 03 and UAZGC 04 sequences of Mancini et al. (1996) and Puckett and Mancini (2000) and the T-R 6 and 7 cycles (sequences) of Mancini and Puckett (2003).

The SB II boundary (the golden line in Figures 23 and 24) separates this sequence from the underlying siliciclastic Tuscaloosa Group. The SB II boundary was observed to truncate the underlying prograding sediment wedges and to be onlapped by the overlying strata on seismic sections in the Viosca Knoll area (Fig. 23). This sequence boundary can be correlated with the unconformity between the Eutaw Formation and the Tuscaloosa Group in the updip area, which was interpreted as the lower sequence boundary of the UAZGC 03 by Mancini et al. (1996) and Mancini and Puckett (2000) or the surface of maximum regression between the TR 5 and 6 cycles (sequences) of Mancini and Puckett (2003). Coastal onlap terminated against SB II were observed on seismic sections in the outer shelf area (Fig. 23). It can be inferred that sea level dropped at least below this point when SB II developed during the Late Turonian-Early Coniacian and most of the Late Cretaceous continental shelf area was subaerially exposed.

The UK II sequence is further divided into two systems tracts by a downlap surface, MFS II (the light green line in Figures 23 and 24), recognized by Liu (2004) on seismic sections. Reflectors below the MFS II onlap onto the SB II boundary; these strata were interpreted as part of the transgressive systems tract. Reflectors above the MFS II downlap onto this surface and were interpreted as the highstand systems tract (Figs. 23 and 24).

In the outer shelf area, the downlap surface, MFS II, is located in a thick shale unit (250 feet in well VK 117-1; 200 feet in well MO686, Fig. 26). This shale bed becomes thin in a landward direction and pinches out in the Mobile Bay area and southern Mobile County (Liu, 2004). However, the unique log signature associated with this pinch-out point can be traced across the Late Cretaceous continental shelf area to near the southern limit of the outcrop belt. This surface was found to be in the lower Mooreville Chalk about 260 feet below the Arcola Limestone Member of the Mooreville Chalk (well 445, Figs. 26 and 27). Nannoplankton analysis of the Selma Site Test core in Dallas County indicates that it is latest Santonian-earliest Campanian in age (in the upper CC17 zone, Fig. 20). Cyclostratigraphic study of the Milankovitch-scaled cycles from the same Selma Site Test core provided an accurate chronology for the time period represented by the Mooreville Chalk. Sedimentation rate derived from this chronology has shown that sedimentation rate was very low (about 60 inch/ma.) at this level. Therefore, MFS II correspond to a condensed section in the Mooreville Chalk in central Alabama. This downlap surface, MFS II, can also be correlated to the Mooreville tongue in eastern Alabama and the Eutaw-Mooreville contact in eastern Mississippi (Fig. 20).

The maximum flooding surface is usually represented by the development of a sediment starvation surface across the shelf (Loutit et al., 1985), whereas in the updip area near the shoreline, the maximum flooding surface is usually represented by a transgressive surface (sometimes with transgressive lags), which is formed by the last major transgression at the top of the transgressive systems tract (Banerjee and Kidwell, 1991; Kidwell, 1991; Hettinger et al., 1994). The Eutaw-Mooreville contact has been interpreted as a diachronous transgressive surface in western Alabama and eastern Mississippi by Mancini et al. (1996), Puckett and Mancini (2000), and Mancini and Puckett (2003). The Tombigbee Sand Member has been interpreted to be the backstepping interval of the transgressive phase of the T-R 6 cycle (sequence) by Mancini and Puckett (2003). The backstepping geometry of the top of the Eutaw Formation or Tombigbee Sand Member can also be identified in subsurface on well log cross sections in southwest Alabama (Figs. 26 and 27). Therefore, the Eutaw-Mooreville Chalk contact is interpreted as a series of backstepping transgressive surfaces that formed by a series of major transgressive events. The coincidence of the downlap surface, MFS II, identified on the seismic data with the Eutaw-Mooreville contact in eastern Mississippi (Fig. 20) indicates that the transgressive event represented by the Eutaw-Mooreville contact in eastern Mississippi was the last major transgression in the northeastern Gulf of Mexico area, which occurred in latest Santonian-earliest Campanian times.

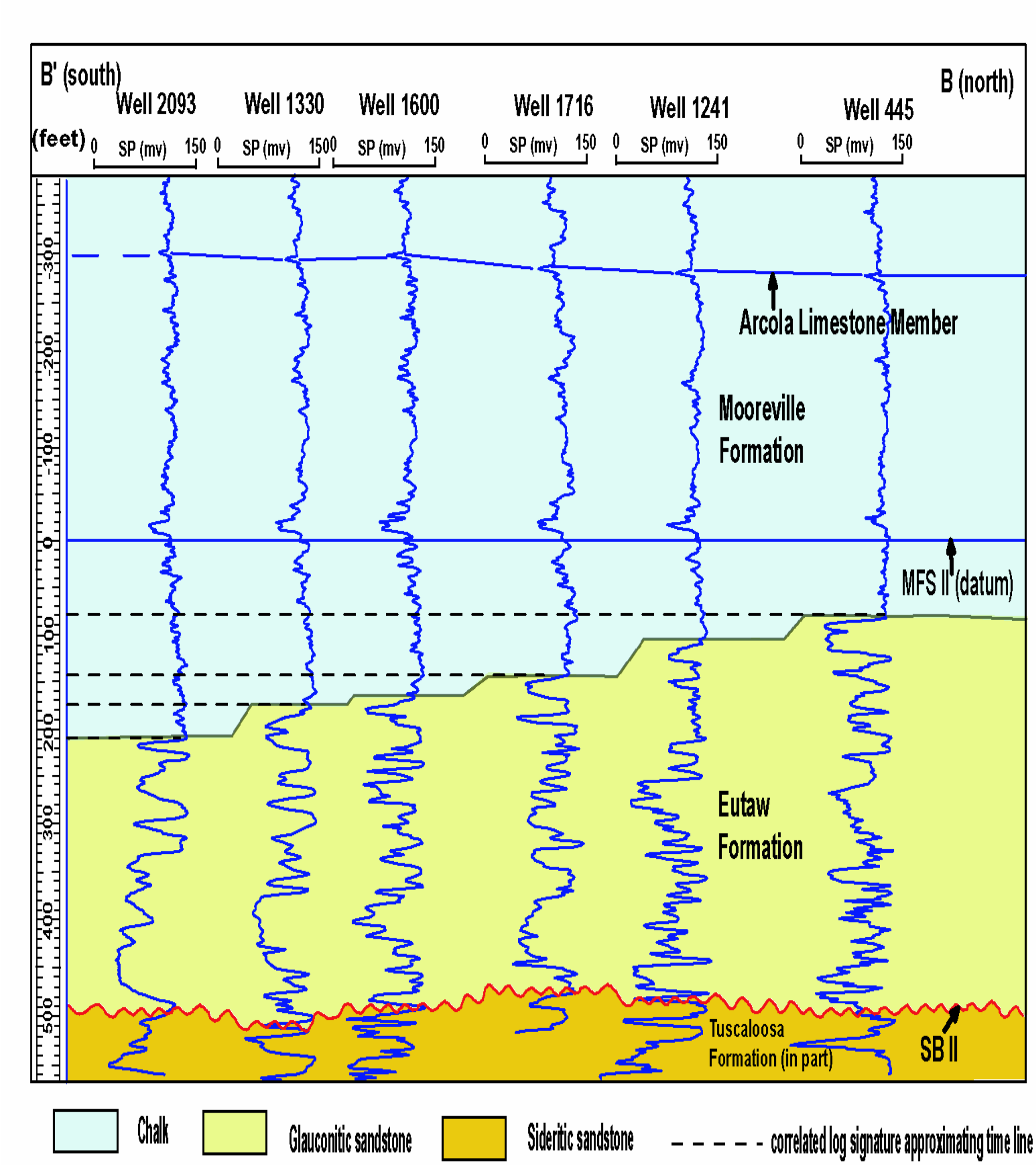


Figure 27. Cross section B-B' showing the backstepping pattern of the Eutaw-Mooreville contact. Sand facies of the Eutaw Formation grade basinward into chalk beds assigned to the Selma Chalk. The MFS II surface identified by Liu (2004) serves as the datum. The Eutaw-Selma formation contact is a time-transgressive surface that intersects with time lines. The Arcola Limestone Member is an essentially synchronous unit that parallel to the datum. See Figure 25 for location of wells (The distance between well 445 and 2093 is about 41 miles; horizontal distance not in scale). SB = sequence boundary, MFS = maximum flooding surface.

Outcrop studies by Mancini et al. (1996) and Puckett and Mancini (2000) placed the maximum flooding event of the UAZGC 03 sequence at one of the reflection points on the planktic/benthic foraminifer ratio curve, which is about 100 feet below the Arcola Limestone Member (Fig. 20). The downlap surface recognized from seismic sections is about 160 feet lower than the maximum flooding event recognized in outcrop. The P/B ratio is a good indicator of paleo-water depth (Gibson, 1989; Van der Zwaan et al., 1990; Van der Zwaan et al., 1999). However, the maximum bathymetric surface in a sequence, represented by the P/B ratio reflection point, does not always coincide with the maximum flooding surface, if the sedimentation rate variation in a strike direction is considered (Catuneanu et al., 1998; Catuneanu, 2002). In addition, Naish and Kamp (1997) suggested that the maximum bathymetric surface identified from foraminiferal or trace fossil paleobathymetry, which is lithologically undeterminable, is usually located in the early highstand systems tract above the maximum flooding surface, although the difference is within 16 feet. This significant distance between the maximum bathymetric surface and the maximum flooding surface is probably caused by variations in siliciclastic sediment input along the coast. According to the sequence stratigraphic model of Vail et al. (1977), Posamentier and Vail (1988) and Posamentier et al. (1988), sea level continues to rise during deposition of the sediments of the highstand systems tract, but the rate of sea-level rise slows to a degree that siliciclastic sediment input exceeds the accommodation space provided by the slower sea-level rise. Therefore, sediment begins to prograde out to form clinoforms that downlap onto the maximum flooding surface. However, if variations in sediment input along the coast are considered for areas with relatively lower siliciclastic input, the rising sea level may result in the creation of more accommodation space and the deposition of deeper water sediments in local or regional transgressions. The area where the Mooreville Chalk was deposited, including west and central Alabama and eastern Mississippi, had very low sediment input because it was located between two major sediment supply sources that have been interpreted to have existed in northeastern Mississippi and eastern Alabama during the Late Cretaceous (Mancini et al., 1996). Therefore, the lower sedimentation rate during deposition of the Mooreville Chalk might have resulted in a lag of the timing of the occurrence of the deepest water deposition (maximum bathymetric surface) in the Mooreville Chalk updip and the downlap surface (maximum flooding surface) recognized on seismic data downdip.

However, the maximum flooding surface identified in outcrop is only 160 feet above the correlated log signature associated with the pinch-out point of the outer shelf shale unit. This depth difference is only represented by 0.014 second on seismic section. Therefore, the possibility cannot be ruled out that the maximum flooding surface identified in outcrop is correlatable to the downlap surface in outer shelf area at the current seismic resolution.

The Eutaw Formation and the lower Mooreville Chalk were interpreted to represent the transgressive systems tract of the UK II sequence, as interpreted by Mancini and Puckett (2003). The highstand systems tract of the UK II sequence includes the upper Mooreville Chalk (including the Arcola Limestone Member) and the Demopolis Chalk and the lower Ripley Formation.

The sequence boundary identified above the Arcola Limestone Member by Mancini et al. (1996) and Puckett and Mancini (2000) or the surface of maximum regression by Mancini and Puckett (2003) was not identified on seismic data (Figs. 23 and 24). As Mancini et al. (1996) and Puckett and Mancini (2000) described, this sequence boundary becomes conformable in east Mississippi and west Alabama. When this sequence boundary formed, most of the shelf was still under sea water and sedimentation continued. Therefore, this sequence boundary was probably formed by a minor sea-level drop or excessive sediment in the updip area during this period and represented no significant impact on the outer shelf areas.

The UK III sequence (Early Maastrichtian to Late Maastrichtian) is the thinnest of the three sequences on seismic data, and it includes the uppermost part of the Selma Group. The sequence is defined by the SB III boundary (the pink line in Figures 24) and the Maastrichtian-Danian unconformity (the blue line in Figures 23 and 24).

This sequence is only resolved on seismic data in areas near the mid-Cretaceous shelf break. No internal structure of the UK III sequence has been recognized from the seismic data, probably due to lithological uniformity of the Maastrichtian marly chalk in the outer shelf area. Well log data indicate that UK III sequence is about 150 feet thick in the Mobile Bay area, and about 300 feet thick in the Viosca Knoll area (well VK117-1, Fig. 26). The greatest thickness of the sequence is observed near the shelf-slope break (about 550 feet thick, estimated on seismic data), where the underlying two sequences nearly pinch out (Liu, 2004).

Since no internal structure has been identified on the seismic data, the position of the coastal onlap and the magnitude of sea-level drop associated with this sequence boundary can not be determined from seismic data. Since the majority of the sequence in the subsurface is composed of chalk, sea-level drop associated with this sequence boundary is probably much less than that associated with the lower two sequence boundaries.

The UK III sequence is overlain by the Maastrichtian-Danian unconformity. On seismic data, the Maastrichtian-Danian unconformity is a high amplitude, high frequency reflector that can be traced across the seismic coverage area (Figs. 23 and 24). This sequence boundary is clearly expressed in well log data and can be correlated on log curves throughout the study area (Figs. 21 and 26). The gamma-ray logs show a large shift to much lower values, and the sonic velocity increases abruptly below this sequence boundary (Liu, 2004). The lithology contrast between the shale of the basal Midway Group and the chalk of the Selma Group across this sequence boundary is the major reason for these changes.

No coastal onlap against this sequence boundary has been observed in the seismic data coverage area; therefore, the sea-level drop associated with this sequence boundary cannot be determined from current seismic data.

8. Conclusions

Sequence stratigraphy of the Upper Cretaceous strata in the northeastern Gulf of Mexico was studied independently by previous authors in both outcrop and subsurface. Outcrop studies investigated the upper and middle portions of the Late Cretaceous continental shelf, which were dominated by continental and coastal environments during low stands of sea level and by coastal, inner or middle neritic environments during high stands of sea level, whereas subsurface studies examined the middle and outer portions of the shelf, which were dominated by fluvial-deltaic environments in low stands of sea level and by outer neritic environments in high stands of sea level.

An integrated sequence stratigraphic framework was established by correlating important surfaces that have chronostratigraphic significance such as maximum flooding surfaces and sequence boundaries from subsurface to surface. Facies changes of Upper Cretaceous strata in a dip-oriented direction were determined in the established sequence stratigraphic framework.

Four sequence boundaries recognized on seismic data, SB I to SB IV, in the offshore Alabama and Mississippi area were correlated to areas near the southern limit of the outcrop belt. These sequence boundaries were found to correspond to four major unconformities identified in previous outcrop and subsurface studies. SB I corresponds to the mid-Cretaceous unconformity/sequence boundary; SB II corresponds to the Late Turonian-Early Coniacian unconformity, which separates the Eutaw Formation from the Tuscaloosa Group; SB III corresponds to the Late Campanian-Early Maastrichtian unconformity, which separates the lower and middle Ripley Formation from the upper Ripley Formation and Owl Creek Formation; and SB IV corresponds to the Late Maastrichtian-Early Danian unconformity, which separates the Prairie Bluff Chalk and Owl Creek Formation from the overlying Tertiary Midway Group.

The UK I and UK II sequences were further divided into transgressive systems tract and highstand systems tract by two maximum flooding surfaces, MFS I and MFS II, which were identified as downlap surfaces from seismic data. The MFS I lies in the Marine Tuscaloosa Formation and was correlated updip to the disconformity observed between the Gordo Formation and the Coker Formation. The MFS II was correlated to a major transgressive surface at the base of Mooreville Chalk in eastern Mississippi, a sediment starvation in central Alabama and the Mooreville tongue in eastern Alabama. The MFS I was dated as Late Cenomanian, and the MFS II was dated latest Santonian to earliest Campanian by nannoplankton and foraminiferal biostratigraphic data.

Similar internal structures or depositional patterns were found for sediments that belong to the same systems tracts. Sediments of the transgressive systems tract such as the Eutaw Formation and the Lower Tuscaloosa Formation exhibit onlap patterns onto the sequence boundary on seismic data; and they were found to be backstepping/retrogradational in well logs and in the outcrop. Sediments of the highstand systems tract such as the Upper Tuscaloosa Formation exhibit downlap patterns onto the maximum flooding surface on seismic data; and they were found to be progradational in well logs and in the outcrop. No significant depositional pattern was identified for the carbonate dominated Mooreville Chalk and Demopolis Chalk in the updip area. However, these chalk sediments grade into shale and chalky shale in the middle and outer shelf areas where retrograding and prograding patterns were recognized on both well logs and seismic sections.

D. University of Alabama In Progress Dissertation—the following is from the dissertation of Jamal Obid

1. Introduction

The Gulf of Mexico is a divergent passive continental margin; with shelfal areas characterized by non-marine to marine siliciclastic and marine carbonate deposits. A stratigraphic analysis, using third-order depositional sequences, as defined by Mitchum (1977), may provide reliable means for correlating marine shelf deposits with slope and deep marine abyssal deposits. Conversely, studying non-marine deposits of shelfal areas requires an alternate approach using the concepts of transgressive-regressive sequences.

A stratigraphic analysis based on the cyclicity (transgressive-regressive sequences) recorded in the strata and their patterns, which are driven by tectonic-eustatic events, has utility as a tool for constructing a stratigraphic framework for correlation. Moreover, on such passive margins, the stratal patterns are created by a combination of sea level, tectonics, climate, and sediment supply, with a difficulty in distinguishing the role each of these factors may play. The geometry of non-marine strata accumulating above sea level is governed by factors that are controlled by base level changes influenced by sediment supply, tectonics, climate and eustacy. In the shelfal areas of the northeastern Gulf of Mexico, the non-marine and coastal plain deposits of the Jurassic are controlled by changes in stratigraphic base level, which includes changes in sea level.

The purpose of this paper is to analyze seismic sections and well log data from selected wells for the Upper Jurassic section in the study area, recognize stratigraphic surfaces, define transgressive-regressive sequences, and to establish a chronostratigraphic framework for the correlation of strata north and south of the Wiggins Arch.

2. Geological Setting and Lithostratigraphy

The study area is located in the northeastern Gulf of Mexico, southwest of the state of Alabama (Fig. 28). The structural framework of the study area was established by rifted continental margin tectonics associated with the opening of the Gulf of Mexico (Wood and Walper, 1974) and by the extension of the ridges and valleys of the Appalachian structural trend (Salvador, 1987). The resulting paleotopography influenced sedimentation during the Triassic and Jurassic with the presence of positive structures, such as the Wiggins arch and the Conecuh ridge, and negative structures, such as the Mississippi interior salt basin, the Manila subbasin, and the Conecuh subbasin (Mancini et al., 1985) (Fig. 29). Differential subsidence of the basement led to a thick buildup of siliciclastic, carbonate, and evaporate deposits in grabens and basins, and thin accumulations of such deposits over pre-Jurassic highs and Jurassic topographic highs (Wilson, 1975; and Mancini et al., 1985).

The Wiggins Arch complex forms a major, east-west basement uplift of Paleozoic age in southern Mississippi and southwestern Alabama. The arch lies between two major Jurassic productive trends: an oil and gas-condensate trend of the Mississippi Interior Salt basin to the north, and a deep natural gas trend to the south. The Wiggins Arch complex covers over 2000 sq.mi (5180 sq.km), and has been sporadically explored during the past several years (Montgomery, 2000). The origin of the Wiggins Arch remains undetermined, but appears to date from Triassic rift-related tectonism (Salvador, 1987). Sawyer et al. (1991) proposed that the arch complex represents an elevated horst block associated with crustal extension and rifting. Cagle and Khan (1983) suggested that the Wiggins Arch might be a remnant of the rifted continental margin of North America. They reported that this basement feature is comprised of pre-rift Paleozoic rocks of metamorphic and granitic nature (Cagle and Khan, 1983).

The Upper Jurassic in southwest Alabama (northeastern Gulf of Mexico) consists of a number of lithologic units: the Norphlet Formation (Oxfordian), the Smackover Formation (Oxfordian), the Haynesville Formation (Kimmeridgian), and the Cotton Valley Group (Tithonian to Berriasian/Lower Valanginian) (Mancini et al., 1990a) (Fig. 30). The Norphlet

Figure 28. The study area located in the northeastern Gulf of Mexico. Two wells (1910-A and 1862) north of the Wiggins Arch, and four wells (SW-4576, SW-3840, MO-867, and MO-909) south of the Wiggins Arch, were selected for this study.

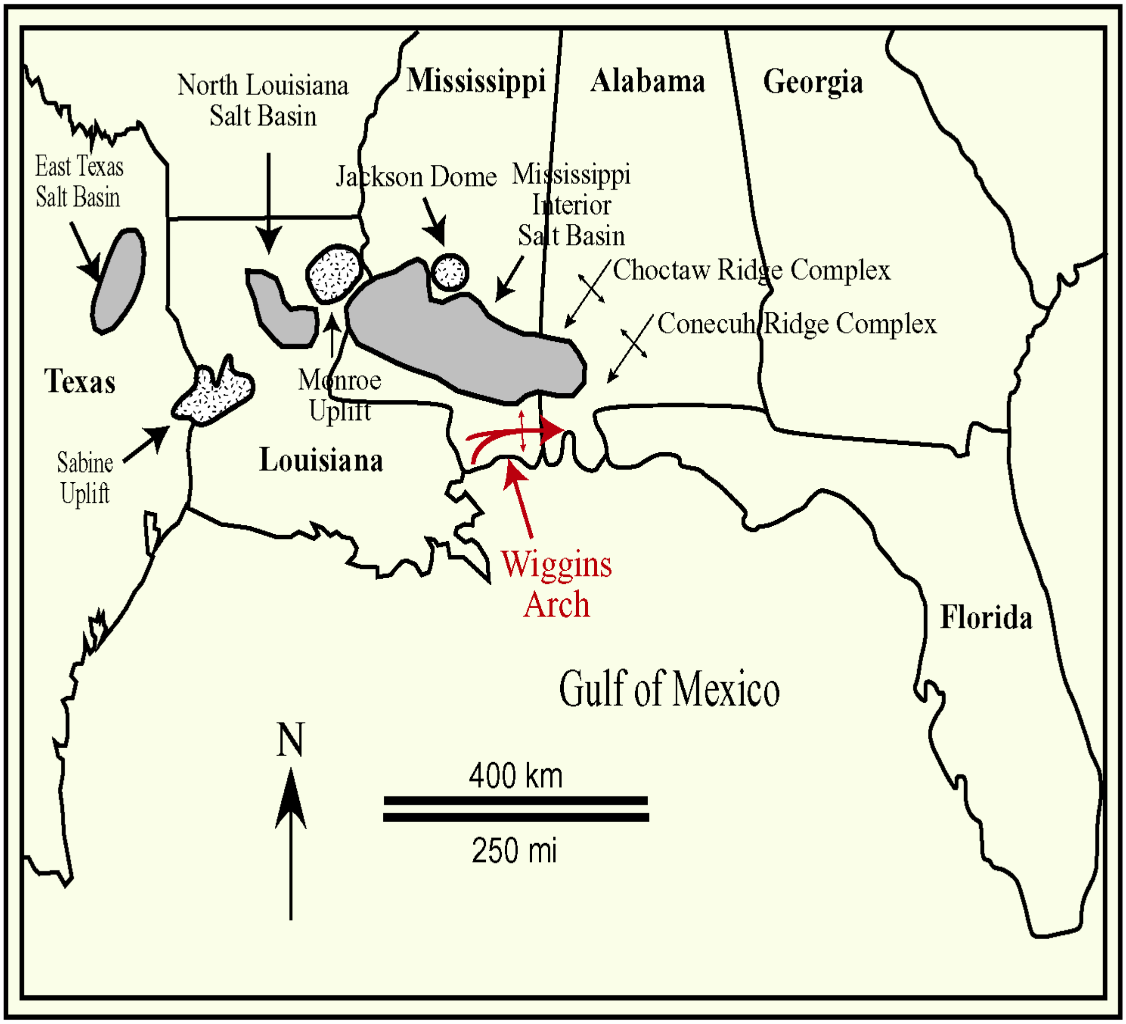


Figure 29. Index map of northeastern Gulf of Mexico Coastal Plain showing major structural features, including the Wiggins Arch (modified from Mancini et al., 2002).

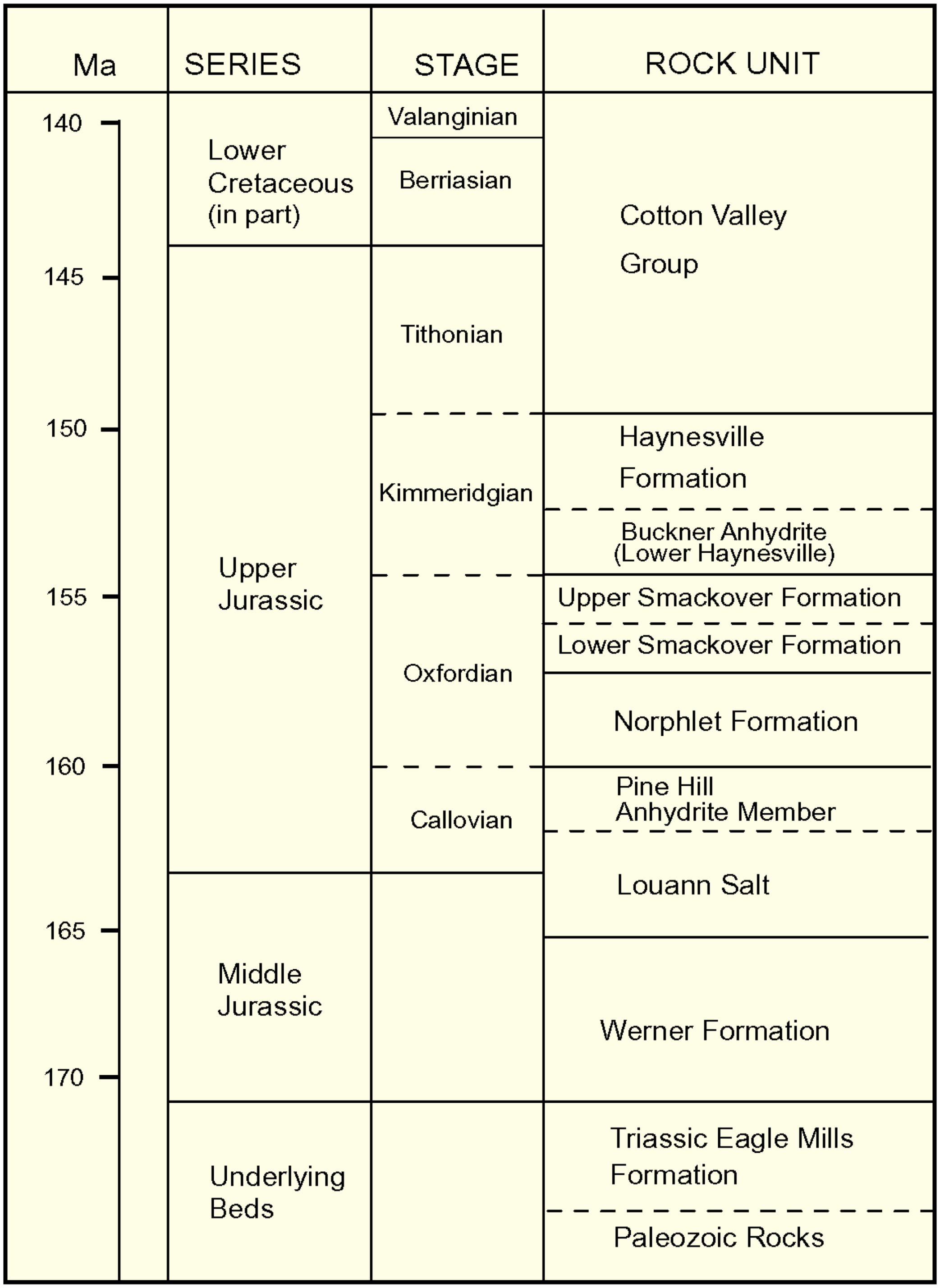


Figure 30. General stratigraphy of the Upper Jurassic section, northeastern Gulf of Mexico area (modified from Mancini et al., 1990a).

Formation is a distinctive stratigraphic unit recognized as the first siliciclastic unit below the limestone of the overlying Smackover Formation. It is regionally extensive, mainly continental, siliciclastic deposits, which accumulated in an arid to semi-arid climate. The Norphlet deposits, therefore, represent alluvial fan and plain, fluvial (wadi), eolian dune and interdune, and playa lake environments (Mancini et al., 1999).

The Oxfordian Smackover Formation overlies the Norphlet Formation, and is a regionally extensive Late Jurassic carbonate unit. The Smackover Formation represents the earliest carbonate deposition in the Gulf of Mexico. The deposition of the Smackover Formation was associated with a major Jurassic transgression of marine waters during a major cycle of sea level rise and fall, and was controlled by paleotopography related to basin subsidence and salt tectonics. In general, accumulation of carbonate rocks took place on a carbonate ramp depositional setting in subtidal to intertidal environments (Mancini et al., 1990a). The Smackover lithofacies, recognized in the northeastern Gulf of Mexico, include lower, middle, and upper units. The lower unit is an intertidal to subtidal deposit of lime mudstone and peloidal and oncolitic wackestone and packstone. The middle unit represents subtidal lime mudstone deposits with peloidal and skeletal wackestone and packstone. The upper unit is a subtidal to intertidal oolitic, oncolitic, and peloidal grainstone and packstone interbedded with laminated lime mudstone deposits, chiefly representing moderate to high-energy facies (Mancini et al., 1990a).

The Kimmeridgian Haynesville Formation conformably overlies the Oxfordian Smackover Formation, and includes evaporates, carbonates and terrigenous clastics. In southwest Alabama, the Haynesville Formation is generally comprised of interbedded limestone, anhydrite, sandstone, and shale, with lesser amounts of dolomite. Three units have been identified within this formation: a lower unit of massive anhydrite, recognized onshore as the Buckner Anhydrite Member (the offshore equivalent to this member is the lower Haynesville with its limestone deposits interbedded with shale, dolomite, and sandstone); a middle unit consists of interbedded sandstone, shale, and anhydrite; and an upper unit consisting of interbedded limestone, sandstone, shale and anhydrite (Mancini et al., 1990b, and Mancini et al., 1999).

The Late Jurassic to Early Cretaceous (Tithonian to Berriasian/Lower Valanginian) Cotton Valley Group overlies the Haynesville Formation, and consists of conglomeratic sandstone, shale and coal. The Cotton Valley Group was deposited in marginal marine to continental environments (Mancini et al, 1990c). In the northeastern Gulf of Mexico, the Cotton Valley Group consists of the Schuler Formation, which comprises two members, a lower sandy Shongaloo and an upper shaley Dorcheat Member. Moore (1983) divided the Cotton Valley Group into three intervals, lower (sandy), middle (less sandy) and upper (the least amount of sandstone and more limestone) informal members. The updip limit of limestone occurrence in the upper Cotton Valley was mapped by Moore (1983), and was termed the Knowles Limestone, which is comprised of gray to dark brown dolomitic mudstone and wackestone. Moore (1983) also interpreted the Cotton Valley as being deposited in fluvial, deltaic, strandplain and nearshore marine environments (Moore, 1983).

3. Dataset and Methodology

a. Well logs and Cuttings

The dataset consists of well log, mudlog and well cutting data. Well log data used are from wells available in onshore (i.e. north of the Wiggins Arch) and offshore (i.e. south of the Wiggins Arch) Alabama (Fig. 28). The onshore wells were selected from the Mississippi Interior Salt Basin of Alabama, while the offshore wells were selected from Mobile Bay and Mobile area. Lithology was described using mudlog and/or well cutting data available for each of the six selected wells. Varieties of well log curves were available for the selected wells. The spontaneous potential (SP) and deep resistivity (ILD) log curves were common for all wells, and therefore were chosen for all six wells. In addition, for the four offshore wells, gamma ray (GR) log curves were also chosen for optimal correlation. The GR log curve was not available for the other two onshore wells. Well log curves were digitized using NEURALOG software. The digitized well log curves were then loaded into PETRA software for the purposes of displaying, preparing cross sections, and correlation and interpretation.

When using well logs, and at the start of the sequence stratigraphic interpretation process, identifying first the predominant of sequence stratigraphic surfaces is of great importance. The most important of these surfaces, and the first that was recognized, is the surface of maximum transgression (SMT) (i.e. maximum flooding surfaces (MFS)). According to Posamentier et al. (1999), the SMT surface is a surface of deposition at the time the shoreline is at its maximum landward position. The surface marks the time of maximum flooding or transgression of the shelf, and separates the transgressive and regressive systems tracts in a T-R sequence. A SMT is often distinguished by the presence of radioactive and often organic rich shales, glauconite, and widespread thin-bedded concentrations of fauna (condensed sections) with high abundance and diversity. A SMT can often be the only portion of a sedimentary cycle that is rich in fauna. Such a surface can be recognized on well logs as a sharp to gradational change from sand to shale, with maximum GR (or SP), and minimum resistivity log responses (Fig. 31 and 32).

The recognition of SMT is followed, when possible, by the recognition of the transgressive surface (TS). Both SMT and TS coincide and are correlated with radioactive shales (use of the gamma log or SP) that are interpreted to have been deposited across relatively flat surfaces. The transgressive surface (TS) is a marine-flooding surface that forms the first significant flooding surface in a sequence. The transgressive surface, in most siliciclastic and some carbonate successions, marks the onset of the period when the rate of creation of accommodation space is greater than the rate of sediment supply. Where the rate of sediment supply is low, the transgressive surface may merge landward with the surface of maximum transgression. Once the SMT and TS surfaces are established and tied, then the sequence boundaries (SB) of both carbonate and siliciclastic sedimentary strata are identified. The SB can be recognized on well logs simply as a sharp change from shale to sand on SP and/or GR log responses (Fig. 31 and 32).

b. Seismic Data

The dataset for this study consists of seismic reflection data, which were acquired in the offshore Alabama and Mississippi area (Fig. 33). It includes about 3500 km, of two dimensional, multi-channel seismic reflection sections. The seismic data are CDP reflection data

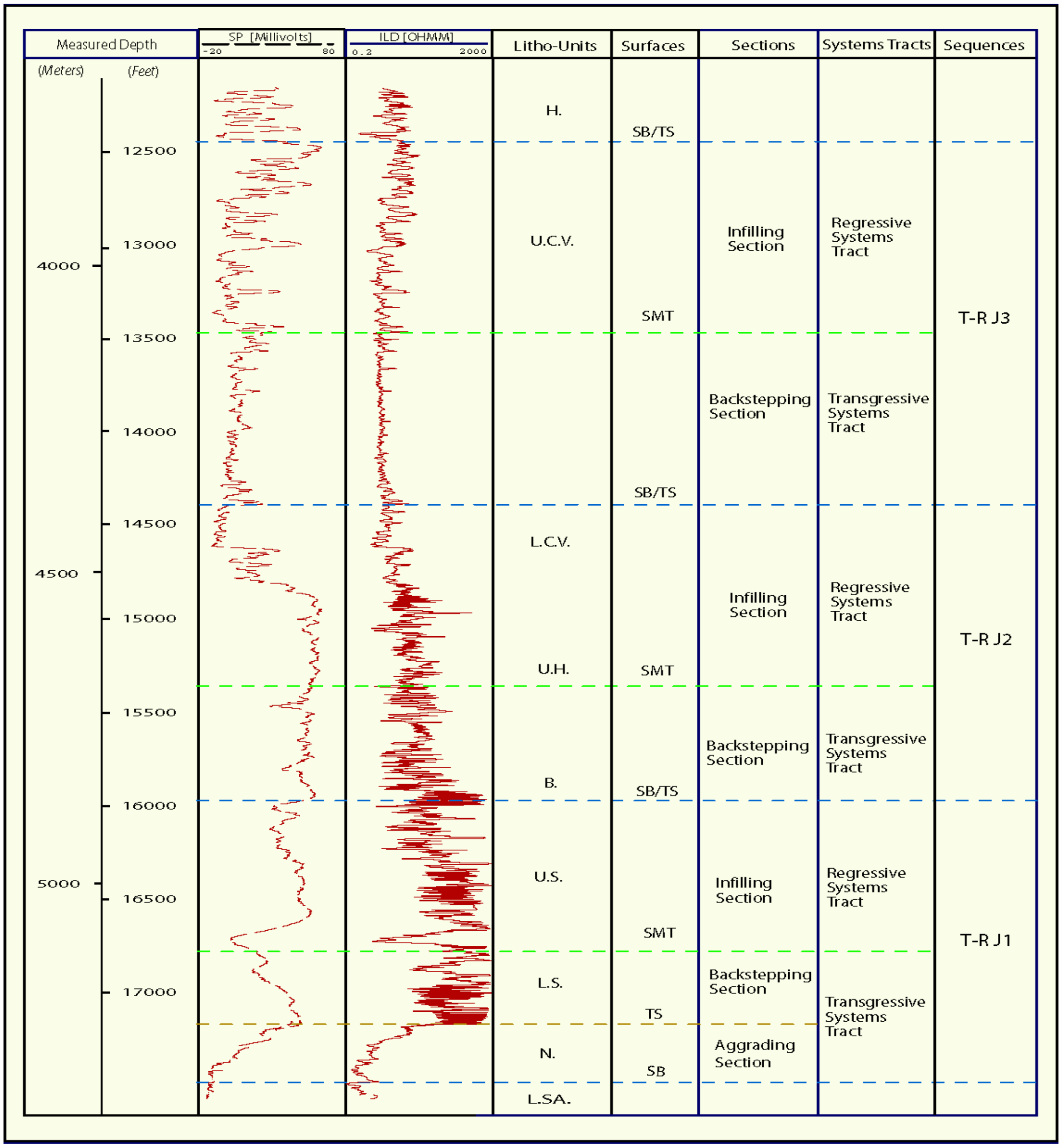


Figure 31. Well log patterns from Well Permit 1910-A, Washington County, AL, showing well log responses characteristic for the Upper Jurassic transgressive-regressive sequences and their related sections. SP=spontaneous potential, ILD=Deep Induction (resistivity). SB=sequence boundary, SMT=surface of maximum transgression, TS=transgressive surface. L.SA.=Louann Salt, N.=Norphlet Formation, L.S.=lower Smackover Formation, U.S.=upper Smackover Formation, B.=Buckner Anhydrite Member, L.H.=lower Haynesville, U.H.=upper Haynesville, L.C.V.=lower Cotton Valley, U.C.V.=upper Cotton Valley, H.=Hosston Formation.

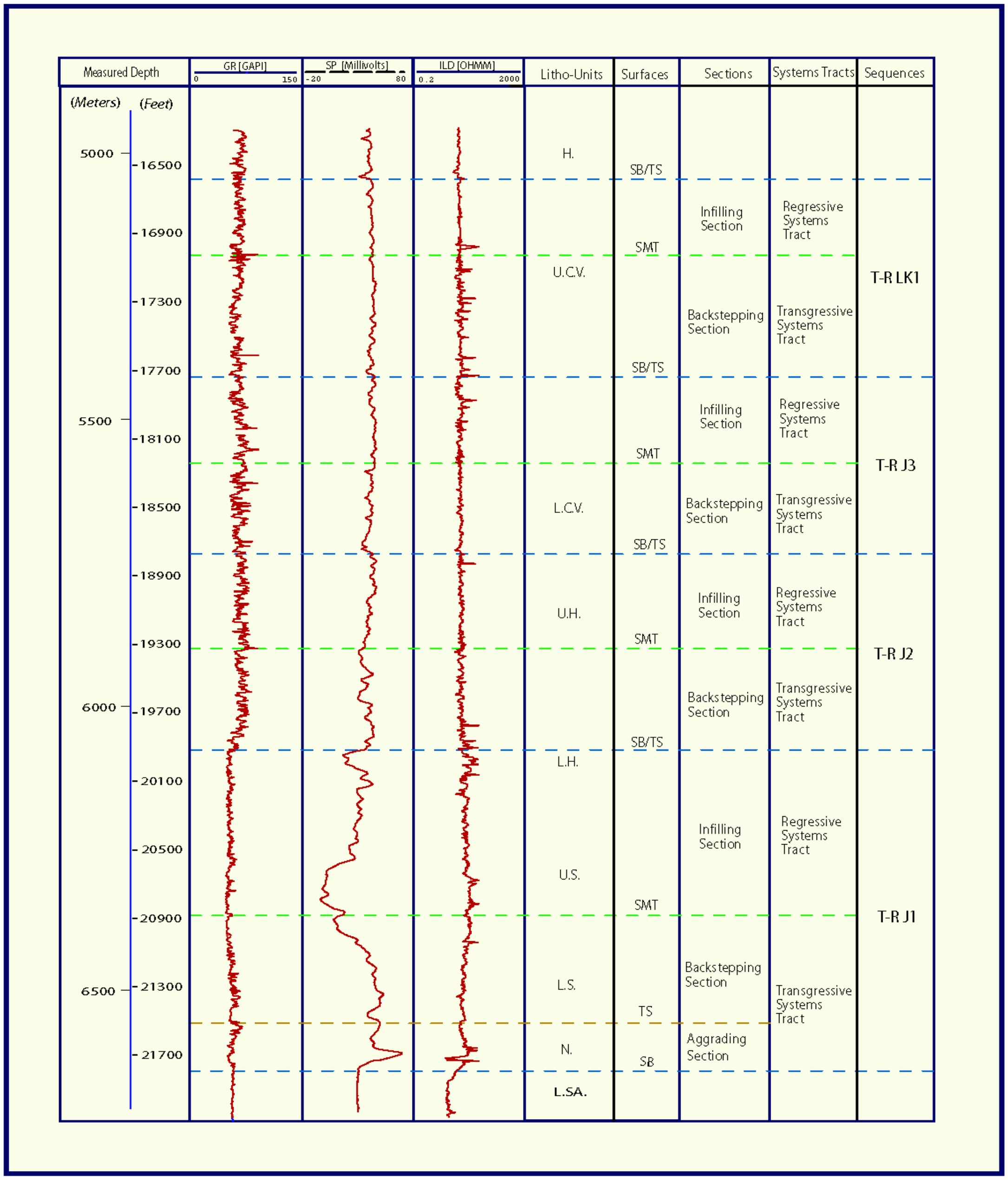


Figure 32. Well log patterns from Well Permit MO-867, Mobile Area, offshore Alabama, showing well log responses characteristic for the Upper Jurassic transgressive-regressive sequences and their related sections. SP=spontaneous potential, GR=gamma ray, ILD=Deep Induction (resistivity). SB=sequence boundary, SMT=surface of maximum transgression, TS=transgressive surface. L.SA.=Louann Salt, N.=Norphlet Formation, L.S.=lower Smackover Formation, U.S.=upper Smackover Formation, B.=Buckner Anhydrite Member, L.H.=lower Haynesville, U.H.=upper Haynesville, L.C.V.=lower Cotton Valley, U.C.V.=upper Cotton Valley, H.=Hosston Formation.

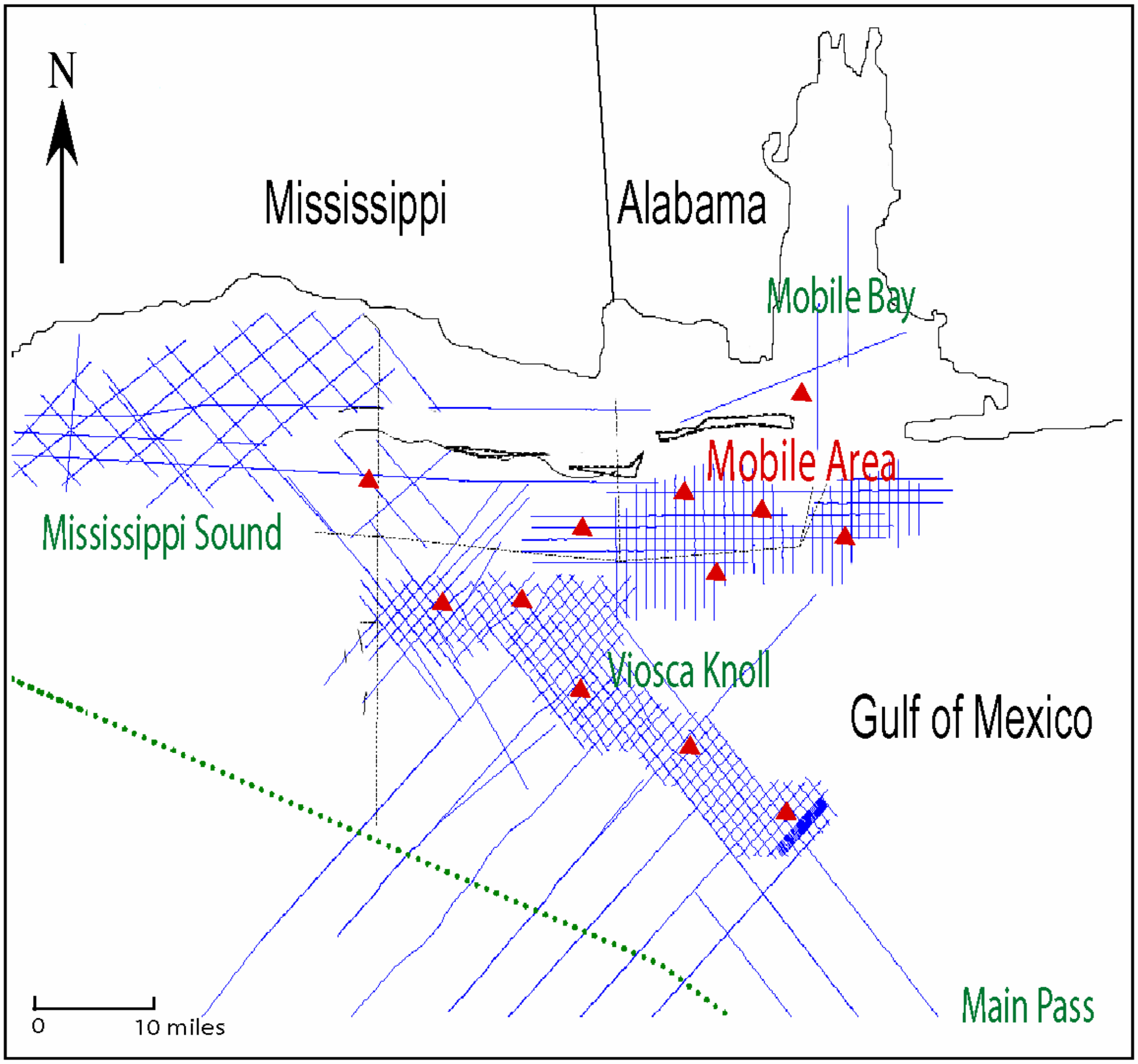


Figure 33. Map of the study area, Mobile Area, offshore Alabama, northeastern Gulf of Mexico. Blue lines represent seismic lines in the area. Wells, within and surroudning the study area, are represented by red triangles.

having 90-fold stacking and post-stacking migration processing. Seismic lines cover the following: Mobile Bay area, Mobile area, Mississippi Sound area, Viosca Knoll area, and Main Pass area. Acquisition parameters were available only for the Mobile area, where seismic data were acquired using LRS-888 recording system and an Aquapulse source with six guns. Western Geophysical Company performed the acquisition and processing of the seismic data that were mainly acquired in 1981 for the Mobile Area. In other areas (e.g. Viosca Knoll, Mississippi Sound), seismic data were acquired between 1984 and 1992. The quality of the 1992 seismic data is higher than those for 1984 and 1981. For the purpose of interpretation, seismic data were loaded into the Kingdom Suite (Version 7.3) software developed by Seismic Micro-Technology.

The author has applied a variety of bandpass filtering parameters for optimum display of the seismic reflection data at the depths of interest. Color display was also deemed a factor in enhancing the interpretation process. It has been determined that color schemes display would affect the interpretation. Some color schemes positively improved the interpretation, as opposed to others that seemed to affect interpretation adversely.

Using the available reflection seismic data for the Mobile area, offshore Alabama, seismic sequences were outlined (Fig. 34) by identifying reflection termination patterns on reflection seismic sections following the methods defined by Mitchum et al. (1977). Such termination patterns of seismic reflectors include onlaps, downlaps, toplaps, and erosional truncations (Fig. 35). Reflection configuration and geometry were also used to identify sequences and to infer seismic stratigraphic surfaces such as, sequence boundaries (i.e. subaerial unconformities, shoreface ravinement surfaces, transgressive surfaces) and downlap surfaces (i.e. surfaces of maximum transgression or maximum flooding surfaces) (Figs. 36, 37 and 38).

The method of Mitchum et al. (1977) continues to be used successfully by seismic stratigraphers to recognize seismic stratigraphic surfaces and in defining third order depositional seismic sequences. However, to date reflection configuration and geometry and termination patterns (Fig. 35) have not been used to delineate transgressive-regressive sequences. In this paper, these will be used to recognize the stratigraphic surfaces that delineate transgressive-regressive (T-R) sequences, as defined by Embry (1993, 2002), Jacquin and de Graciansky (1998), and Mancini and Puckett (2002).

In the study area, which is located on the present day inner to middle shelf of the northeastern Gulf of Mexico, seismic reflectors lacked any apparent recognizable significant termination patterns, such as onlaps or downlaps (Fig. 34). Therefore, it was impractical to attempt to recognize sequences using only those seismic sections in the Mobile Area alone. Consequently, most of the sequences and inferred stratigraphic surfaces were recognized and delineated using seismic sections in the Viosca Knoll area (mid-outer shelf) (Fig. 33), where processing and the quality of seismic data permitted an improved sequence recognition in terms of seismic stratigraphy. In this area, reflection termination patterns, such as toplap/truncation (Fig. 36) and downlap (Fig. 37) were observed, stratigraphic surfaces identified (Fig. 38), sequences delineated and then traced throughout the study area (i.e. Mobile Area), where possible. Seismic lines in the western part of Mobile Area allowed for better recognition of sequences, as opposed to those in the eastern part of the Mobile Area, where sequences could not be reasonably traced and/or recognized.

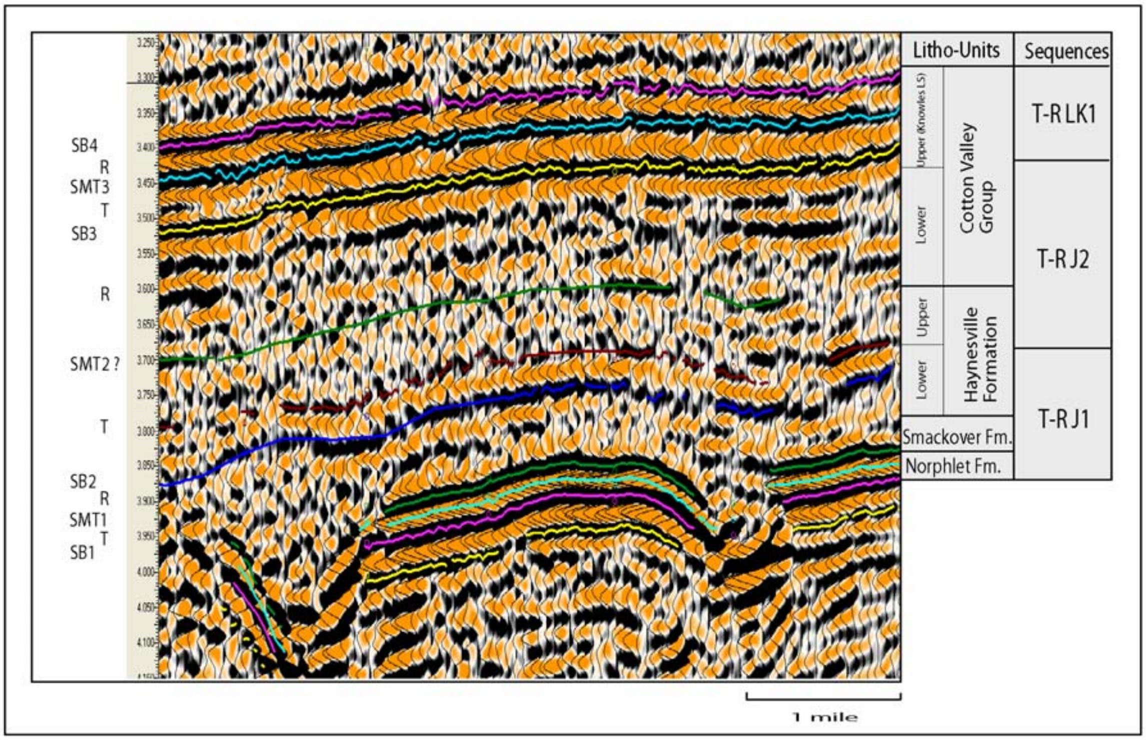


Figure 34. Seismic section from Mobile Area, offshore Alabama, showing the three recognized T-R sequences. SB=sequence boundary, SMT=surface of maximum transgression, T=transgressive systems tracts, R=regressive systems tracts.

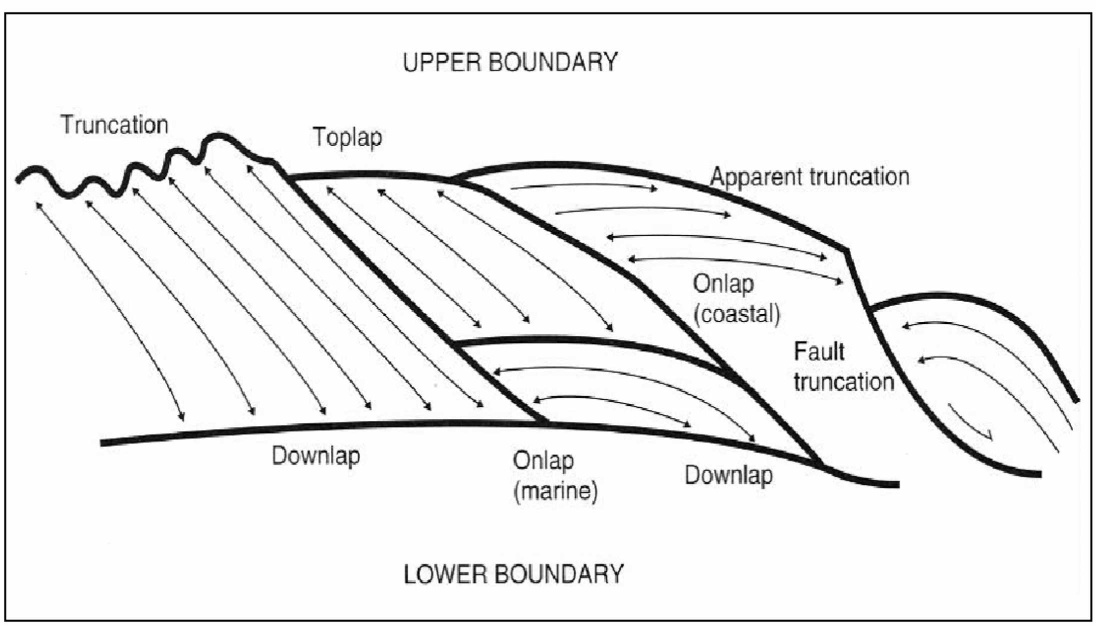


Figure 35. Types of reflection termination patterns that can be observed on reflection seismic sections (figure from Emry and Myers, 1996).

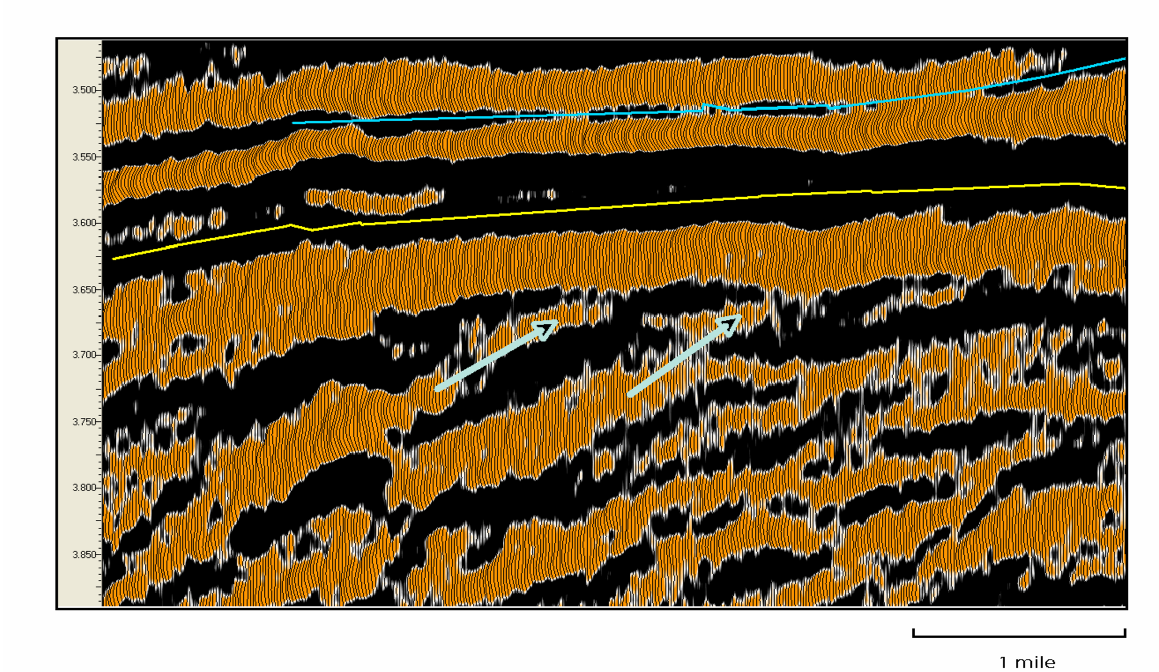


Figure 36. A seismic section from the Viosca Knoll area, offshore Alabama. Refelction termination patterns (toplap/truncation) are shown by blue arrows, indicating unconformity/sequence boundary (SA) for the T-R LK1 sequence.

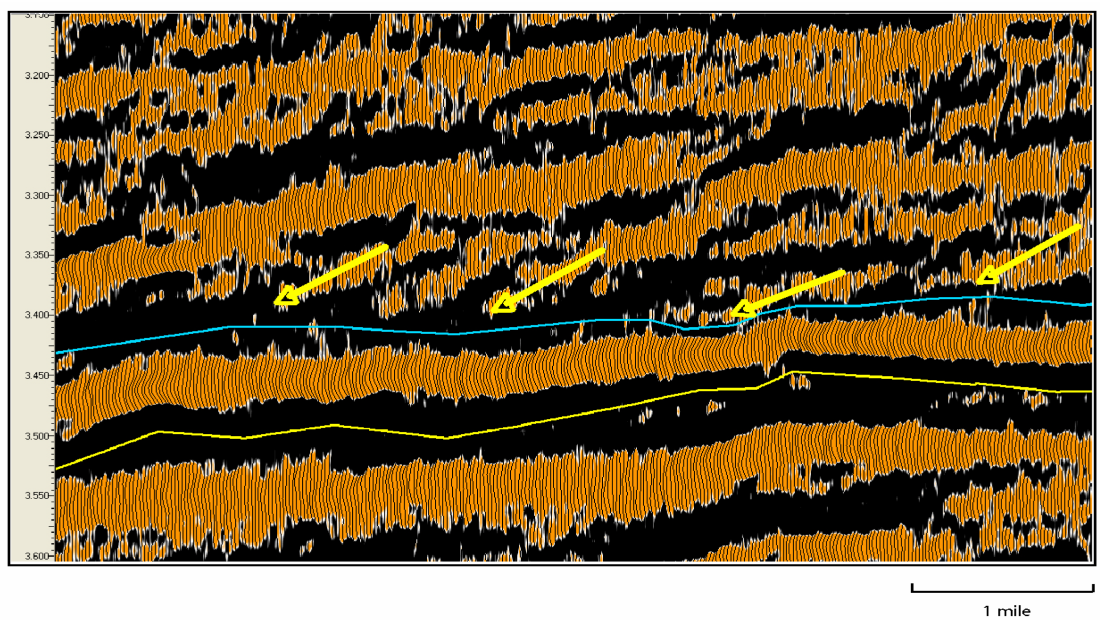


Figure 37. A seismic section from the Viosca Knoll area, offshore Alabama. Downlap refelction termination patterns are shown by yellow arrows, indicating a surface of maximum transgression (SMT) for the T-R LK1 sequence.

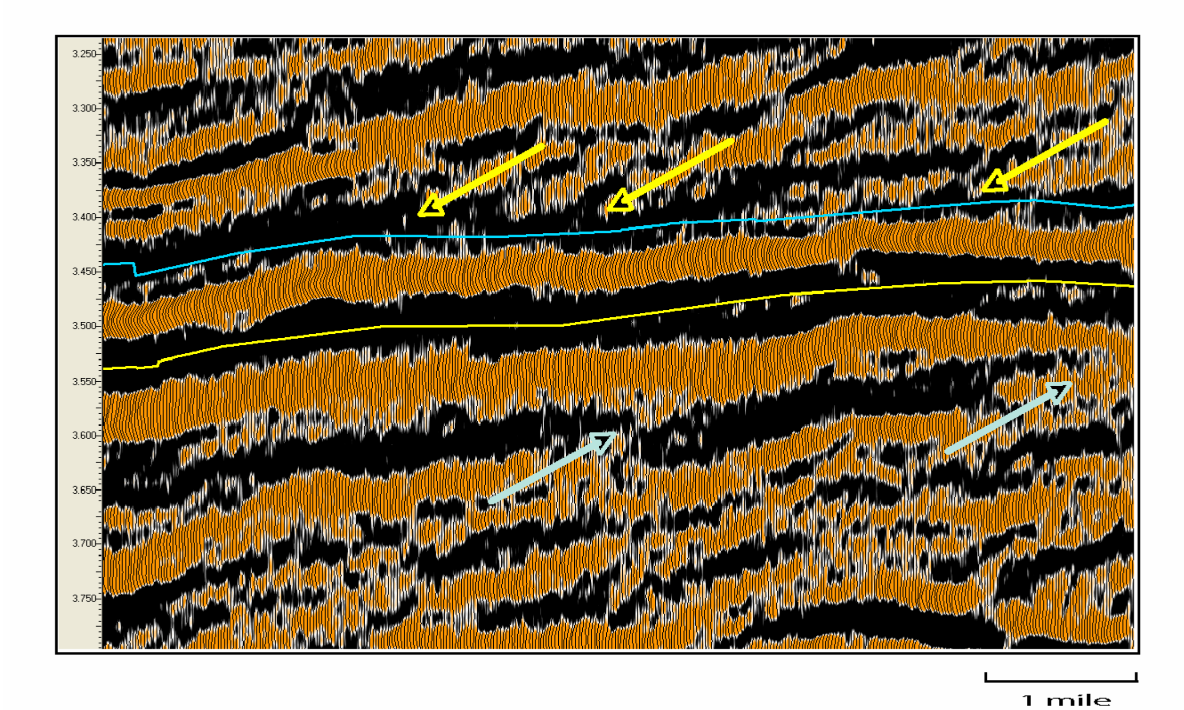


Figure 38. A seismic line from the Viosca Knoll area, offshore Alabama, showing seismic reflection termination patterns. Downlaps (yellow arrows) indicate a surface of maximum transgression (SMT), and reflector truncations (blue arrows) indicate a sequence boundary for the T-R LK1 sequence.

4. Seismic Facies Analysis

According to Vail and Mitchum (1977) and Sangree and Widmier (1977), seismic facies analysis involves delineating and interpreting seismic reflection parameters, such as reflection configuration and geometry, continuity, amplitude, frequency, and interval velocity as well as the external form of reflectors within the framework of depositional sequences. Each of the above mentioned seismic reflection parameters contain information of stratigraphic significance. The geologic interpretation of seismic facies involves deciphering the sedimentary environment and lithofacies. This is possible since energy of deposition influences seismic facies. Seismic facies analysis could also be helpful in interpreting sequence boundaries. In certain cases, sequence boundaries may correspond to abrupt changes in facies.

Four seismic facies (A, B, C, and D) have been recognized on seismic reflection sections in the Mobile area, offshore Alabama (Fig. 39). Below sequence boundary SB1 at around 3.90 ms, the seismic facies appear chaotic, possibly reflecting either basement rocks, or salt deposits, or both. Seismic reflectors between 3.80-3.90 ms represent the Louann Salt, Norphlet, Smackover and lower Haynesville units. Seismic reflectors at these depths appear to be parallel semi-continuous reflectors, showing higher amplitude and lower frequency (seismic facies A), reflecting sharp velocity and density contrasts for the sediments of the Norphlet sandstone and

Smackover carbonate. The partial lack of continuity for these reflectors, as shown in Figure 39, is attributed mainly to salt movement that created a faulted and folded antecedent topography structural pattern for these post-rift deposits.

Above seismic facies A, seismic reflectors appear to have a chaotic pattern with a very low amplitude, high frequency, and very poor continuity (seismic facies B) (Fig. 39). This facies reflects the siliciclastic (interbedded shale and sandstone) influence of the deposits of the lower Haynesville Formation (regressive systems tract of the T-R J1 sequence). Overlying seismic facies B, seismic reflectors appear to be parallel semi-continuous to discontinuous with medium amplitude, medium to good continuity and low frequency (seismic facies C) (Fig. 39). This seismic facies possibly reflects a facies change in the deposits below sequence boundary SB2.

Above sequence boundary SB2, at about 3.65 ms, a chaotic reflection pattern similar to that of seismic facies B is identified, suggesting proximity to the sediment source and significant siliciclastic influence for the conglomeratic sandstone and of the upper Haynesville Formation and sandstone of the lower Cotton Valley Group (regressive systems tract of the T-R J2 sequence). An abrupt seismic facies change occurs at sequence boundary SB3. Above this sequence boundary, seismic reflectors appear to be parallel continuous with medium to high amplitude, low frequency, and very good continuity (seismic facies D) (Fig. 39). The change in lithology from siliciclastic strata of the lower Cotton Valley below sequence boundary SB3 to carbonate strata (i.e. Knowles Limestone of the upper Cotton Valley Group) above the sequence boundary produces this distinct seismic facies change (Fig. 39).

Sequence boundaries SB3 and SB4 correspond to the lower and upper boundaries of seismic facies D, as shown in Figure 39. Such correspondence suggests a major influence of sea level changes on the character of seismic facies D. Conversely, sequence boundaries SB1 and SB2 do not correspond to seismic facies boundaries, suggesting a combined influence of sea level and tectonic changes on the character of seismic facies A, B, and C (Fig. 39).

5. Upper Jurassic Transgressive-Regressive Sequences

T-R sequences, in this study, are recognized in the onshore/offshore Upper Jurassic strata of the northeastern Gulf of Mexico basin based on wireline logs and seismic data. The following general well log responses were used to delineate the systems tracts and sections of the T-R sequences in the subsurface strata in the study area. The SMT separates the transgressive systems tract, with its backstepping section, from the regressive systems tract, with its infilling section, of a T-R sequence. As a general rule, a transgressive backstepping section of a transgressive systems tract can be identified by an overall increase in gamma ray, or more positive SP log response (i.e. fining upward trend) from top of a discontinuity (unconformity) to base of surface of maximum transgression (Figs. 31 and 32). Alternatively, a general decrease in gamma ray, or less positive SP log response (i.e. coarsening upward trend) from top of surface of maximum transgression to base of a discontinuity (unconformity) represents a regressive infilling section of a regressive systems tract. The surface of maximum transgression, therefore, can be defined as the surface between a retrograding unit and an overlying prograding unit. A rectangular gamma ray or SP log pattern is used to recognize the transgressive aggradational section of a transgressive systems tract (Figs. 31 and 32).

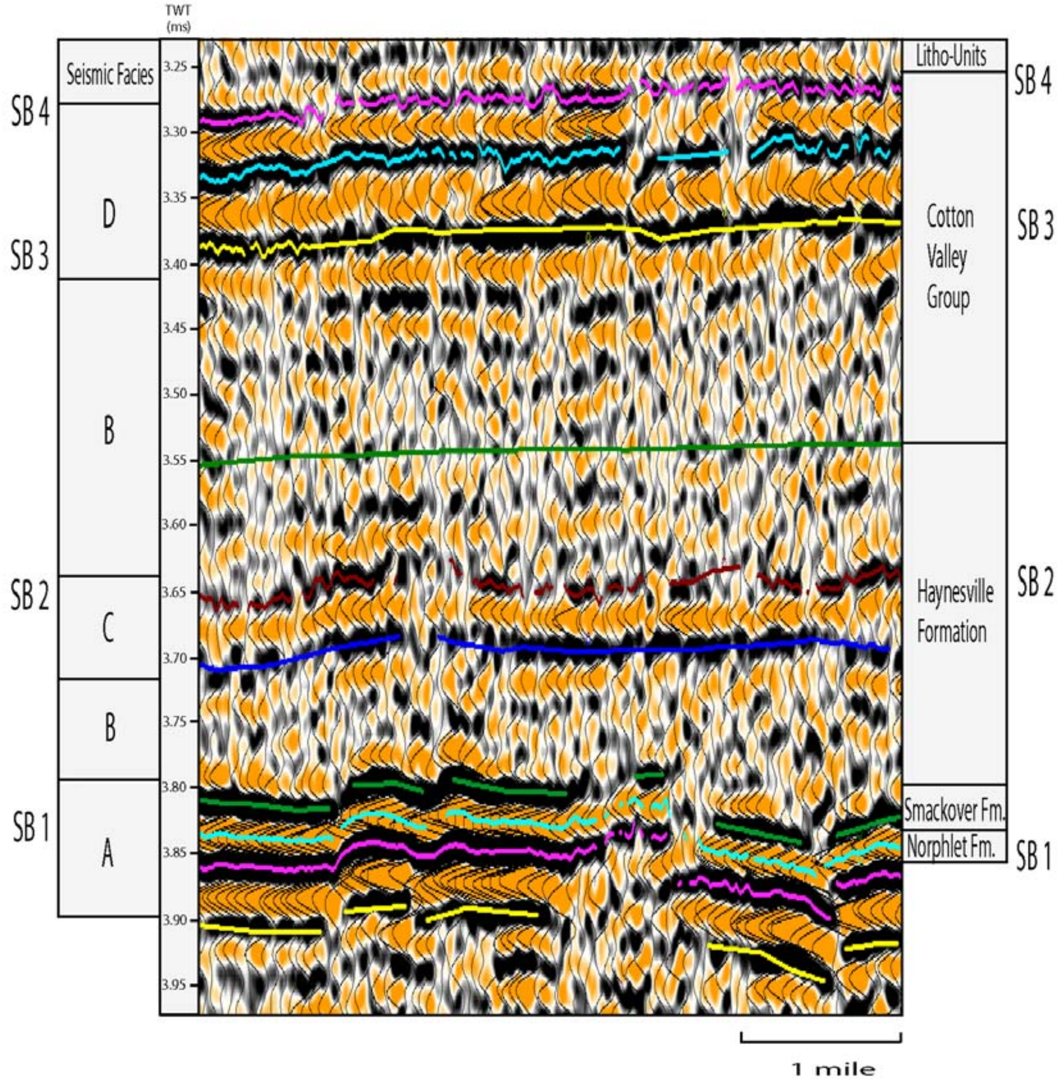


Figure 39. Four Seismic Facies (A, B, C and D) identified on seismic sections in the Mobile Area, offshore Alabama, northeastern Gulf of Mexico. SB=Sequence Boundary.

Three, 3-7 million years in duration, T-R sequences (T-R J1, T-R J2, T-R J3) are recognized in the Upper Jurassic onshore and offshore strata of the northern Gulf of Mexico (Figs. 31, 40 and 42). In addition, a fourth sequence (T-R LK1) that is 3-4 million years in duration is also recognized only in the offshore strata (Figs. 32, 41 and 42). These Oxfordian to Berriasian (onshore)/Lower Valanginian (offshore) sequences consist of transgressive backstepping sections and regressive infilling sections.

The Oxfordian to Kimmeridgian (T-R J1) sequence includes the Norphlet Formation, the Smackover Formation, and the lower beds of the Buckner Anhydrite Member of the Haynesville Formation onshore (Fig. 31), or the lower Haynesville Formation offshore (Fig. 32). The contact between the sandstone of the Norphlet Formation and the underlying Louann Salt is sharp and can be identified by a discontinuity on well log response and in lithology. Such a contact is recorded on well log pattern in low resistivity, negative SP, and low gamma log responses for the Norphlet sandstone, which is interpreted as the aggrading section (continental deposits) of the transgressive systems tract of the T-R J1 sequence. The contact of the carbonate Smackover Formation with the underlying Norphlet sandstone strata is recognized as a discontinuity in well log pattern as well as in lithology, representing an inferred transgressive surface (TS). On well log response, this contact is identified in low resistivity, negative SP, and low gamma log responses for the Norphlet strata. The continental sandstone of the Norphlet is overlain, in places in the region, by marine sandstone shoreface deposits, representing marine reworking of the continental facies of the Norphlet. The contact between the continental Norphlet and the overlying marine Norphlet is disonformable, representing an erosional ravinement surface. The contact between the Smackover carbonates and the underlying shoreface deposits of the Norphlet is gradational.

The backstepping section of the transgressive systems tract of this T-R J1 sequence comprises the Norphlet marine sandstone and lower to middle Smackover intertidal to subtidal packstone, wackestone, and lime mudstone strata. The infilling section of the regressive systems tract of this sequence includes the upper Smackover microbial boundstone, the bioturbated wackestone, packstone and grainstone (shoal complex), and lime mudstone (tidal flat) beds and lower Buckner Anhydrite Member (sabkha deposits) of the Haynesville Formation (Fig. 31). The offshore equivalent of the Buckner Anhydrite Member is the lower Haynesville deposits (Fig. 32).

The two systems tracts (transgressive and regressive) of this sequence are separated by a surface of maximum transgression (SMT) that represents a change from an upward deepening (fining) to an upward shallowing (coarsening) sections (Figs. 31, 32, 42 and 43). The SMT can be recognized in the middle Smackover by a maximum gamma log response. It can also be recognized by more positive SP and lower resistivity log responses.

The Kimmeridgian to Tithonian (T-R J2) sequence comprises the onshore upper Buckner (subaqueous) Anhydrite Member, the upper Haynesville deposits, and the lower Cotton Valley deposits (Figs. 31 and 40). The same sequence occurs offshore (Figs. 32 and 41), with the Buckner anhydrite strata being replaced by the lower Haynesville grainstone strata, which directly overlie the Smackover grainstone beds.

The contact of the upper (subaqueous) Buckner anhydrite deposits with the underlying lower Buckner anhydrite deposits is identified on well logs at the top of the blocky resistivity log pattern, characteristic of a massive anhydrite of the lower Buckner deposits, and representative of a transgressive surface with subaqueous anhydrite overlying sabkha anhydrite deposits. Onshore, the bedded anhydrite deposits grade upward into interbedded shale and anhydrite and interbedded shale and limestone deposits of the upper Haynesville Formation.

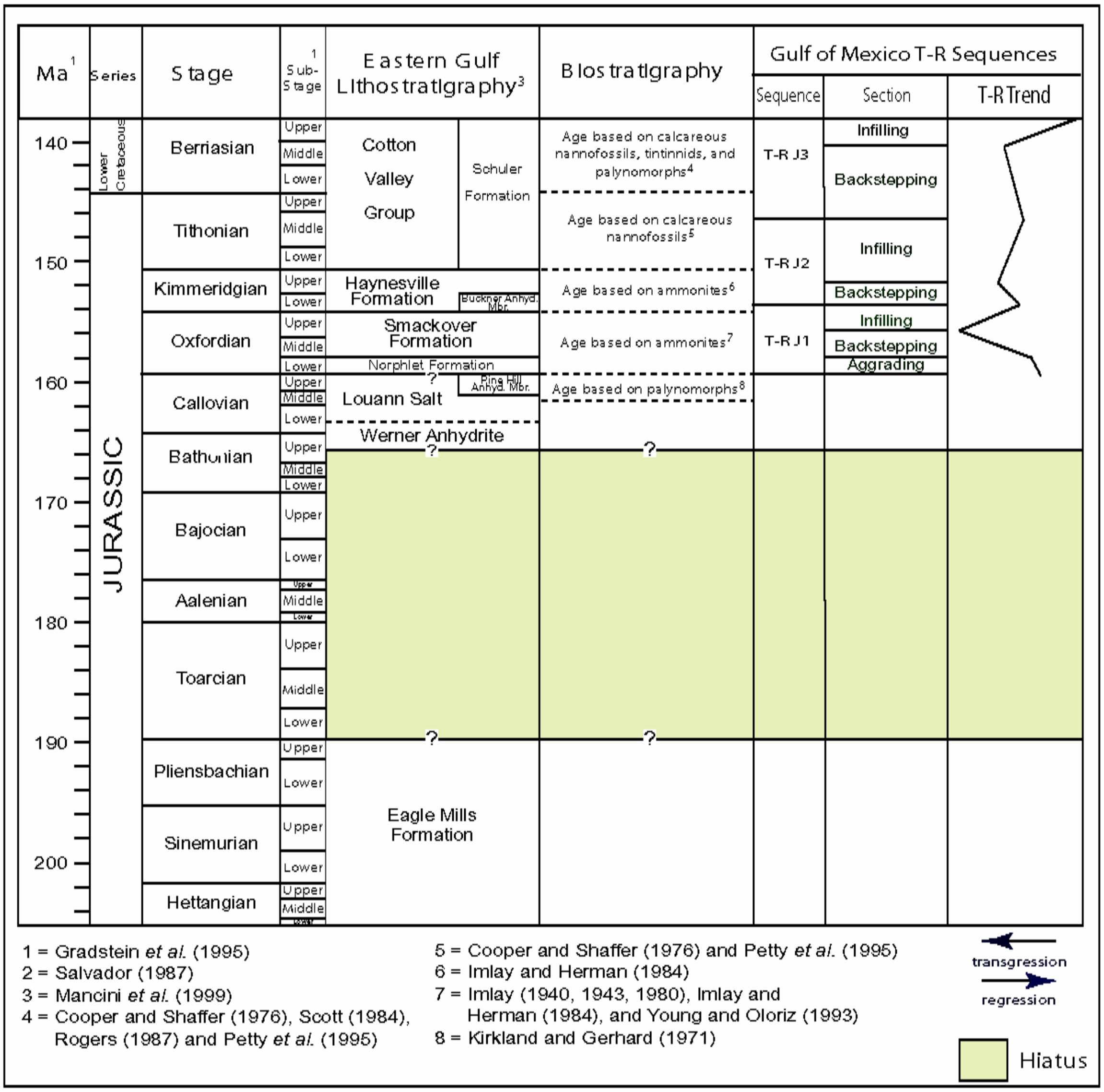


Figure 40. Absolute ages, chronostratigraphic units, lithostratigraphic units, biological units, and transgressive-regressive sequences of the Upper Jurassic section, onshore northeastern Gulf of Mexico.

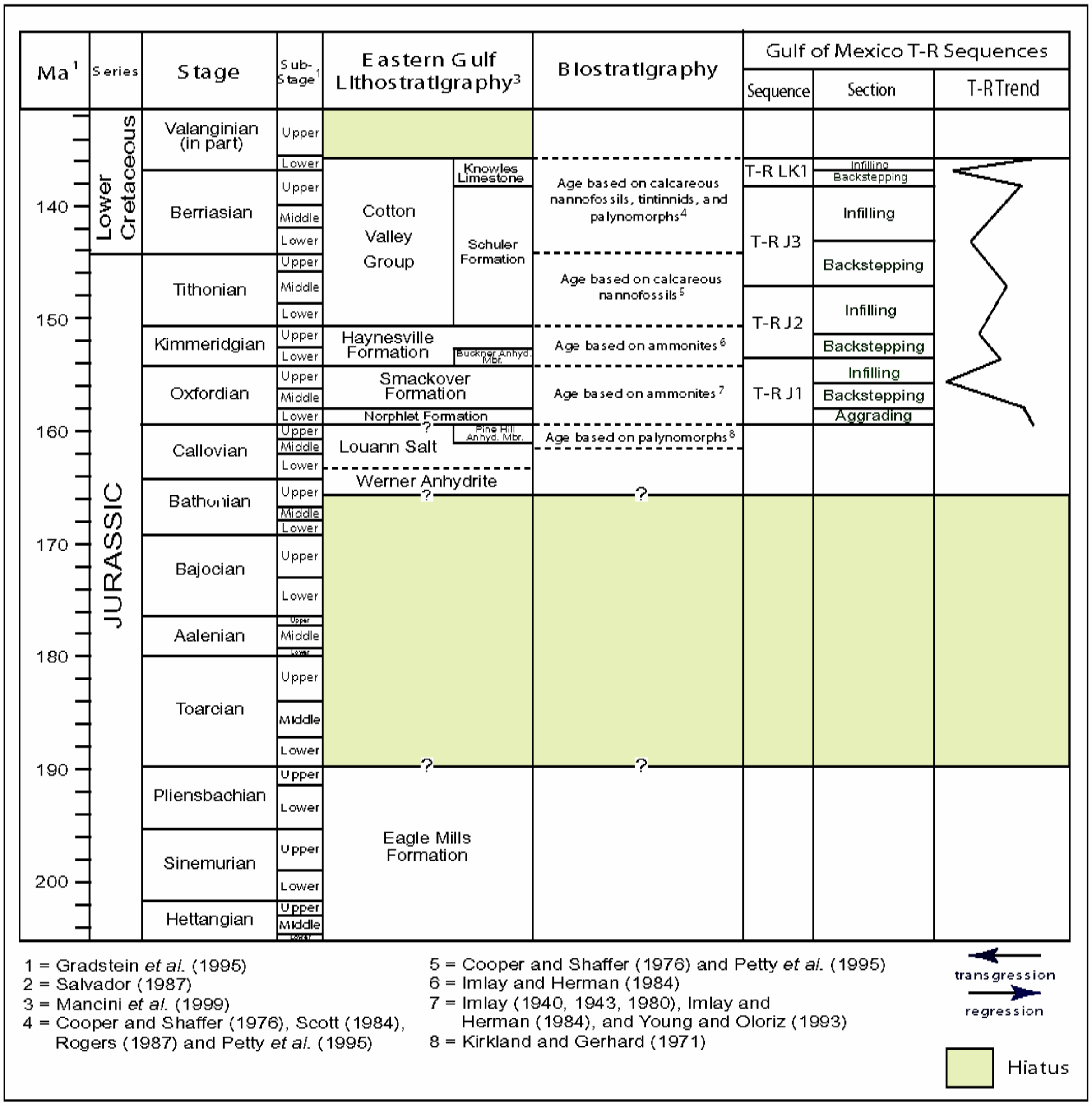


Figure 41. Absolute ages, chronostratigraphic units, lithostratigraphic units, biological units, and transgressive-regressive sequences of the Upper Jurassic section, offshore northeastern Gulf of Mexico.

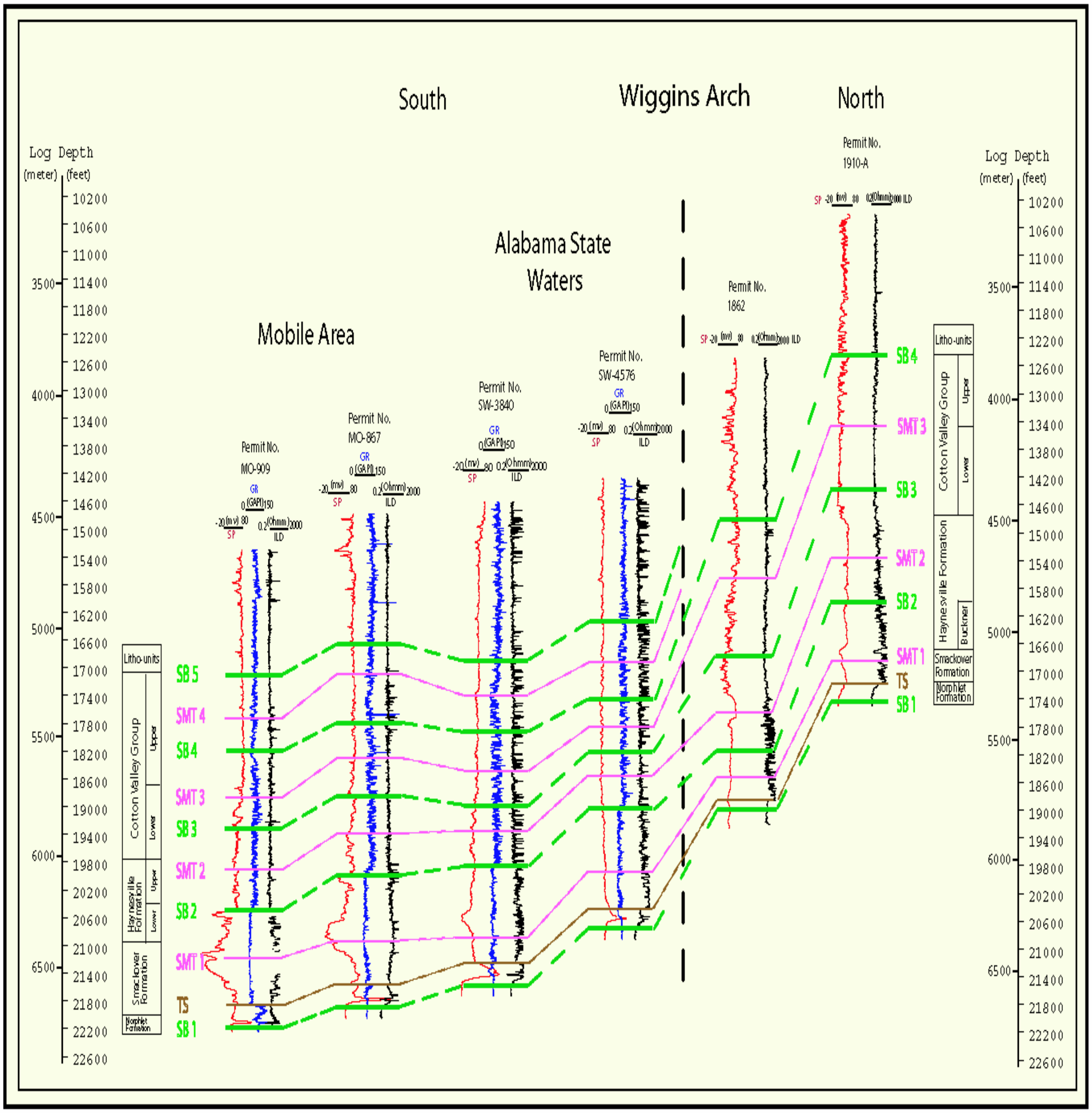


Figure 42. A well log cross section of the selected wells in the study area. Transgressive-regressive sequences, and their associated stratigraphic surfaces, are shown as recognized on well log responses. SB=sequence boundary, SMT=surface of maximum transgression, TS=transgressive surface.

		1910-A	1862	SW-4576	SW-3840	MO-867	MO-909
Sequence 4	R			LS*, Sh, SS*	LS, Sh, Si, SS*	LS, Do*, Sh, SS	LS, Do, Sh, SS*
	T			SS, Si*, Sh, LS*	SS, Si, Sh, LS	SS, Si, Do*, LS	SS, Sh, Do
Sequence 3	R	Sh, SS	Sh, Si, SS	LS*, Sh, Si, SS	LS, Sh, Si*	LS, Sh, Si, SS	LS, Sh, Si, SS
	T	SS, Sh	SS, Si, Sh, LS*	SS, Si, Sh	SS, Si, Sh*, LS*	SS, Si, Do*, LS	SS, Sh, LS
Sequence 2	R	LS, Sh, SS	LS, SS	LS, Sh, Si, SS	LS, Sh, Si*, SS	LS*, Do	LS*, Sh, SS
	T	An, SS*, Sh, LS	An, Sh*, LS	Sh, Si, LS	Si*, An*, LS	Si, Do, LS*	Do, Sh, LS*
Sequence 1	R	LS, Sh*, An	LS, Sh*, An	LS, Do, Sh	LS, Sh, Si*	LS, Si	LS, Do
	T	SS, LS	SS, An, Sh, LS	SS, An*, Do*, LS	SS, An*, Si*, LS	SS, LS	SS, LS

Figure 43. Lithology of the deposits, and associated T-R sequences, from mudogs and well cuttings for the six selected wells in the study area. SS=Sandstone, LS=Limestone, Do=Dolomite, Sh=Shale, Si=Silt, An=Anhydrite, T=Transgressive systems tract, R=Regressive systsms tract.

*** denotes small amounts**

The backstepping section of the transgressive systems tract of the T-R J2 sequence includes the bedded (subaqueous) anhydrite, the interbedded anhydrite and shale (lagoonal) deposits, and interbedded shale and limestone (shallow marine) deposits. The interbedded shale and limestone strata grade upward into interbedded shale and sandstone of the upper Haynesville (marginal marine) deposits. The upper Haynesville strata, along with the upper Cotton Valley sandstone (marginal marine and coastal plain) deposits, represent the infilling section of the regressive systems tract of this T-R sequence.

The infilling section of the sequence is separated from the underlying backstepping section by a surface of maximum transgression, which occurs in the interbedded shale and limestone of the lower Haynseville, and interbedded shale and sandstone of the upper Haynesville strata. The SMT separates the two systems tracts of this sequence, and represents a change from an upward deepening (dirtying) section to an upward shallowing (cleaning) section (Figs. 31, 32, 42 and 43). On well logs, the contact of the lower Cotton Valley sandstone deposits with the underlying interbedded shale and sandstone strata (upper Haynesville) is marked by a change in the resistivity log from a serrate signal for the interbedded shale and limestone of the upper Haynesville strata to a more continuous signal for the lower Cotton Valley sandstone strata. The Cotton Valley deposits also are characterized by a more blocky and negative SP and lower resistivity log responses than the Haynesville deposits (Fig. 31).

The onshore/offshore Tithonian to Berriasian T-R J3 sequence consists of the upper Cotton Valley Group sand and shale deposits (Figs. 40 and 41). On well logs, the contact between the upper Cotton Valley sandy shale strata with the underlying lower Cotton Valley sandstone deposits is recognized by a discontinuity, recorded in a lower resistivity, and more positive SP for the upper Cotton Valley strata, and represents a transgressive surface (Figs. 31 and 32). The backstepping section of the transgressive systems tract of this sequence comprises the upper Cotton Valley sandy shale (marine shelf) deposits. The infilling section of the regressive systems tract of this sequence is represented by the sandstone and conglomeratic (nearshore marine and fluvial) deposits of the upper Cotton Valley strata.

The SMT of this sequence occurs in the upper Cotton Valley strata, and is marked by a shift from higher to lower resistivity and from negative to positive SP, and by a higher gamma log responses (Figs. 31 and 32). The SMT separates the two systems tracts of this sequence, and represents a change from an upward deepening section to an upward shallowing section (Figs. 31, 32, 42 and 43).

In the offshore area, south of the Wiggins Arch, a fourth sequence, T-R LK1, which is Berriasian-Lower Valanginian, was recognized (Figs. 32, 41 and 42). This sequence is absent north of the arch, and includes the Knowles Limestone (marine shelf, shoal and reef complex) deposits. The contact of the Knowles with the underlying upper Cotton Valley sandy shale deposits is recognized as a discontinuity on well log pattern. It is marked by a shift from higher to lower gamma ray, and from positive to more negative SP, and a higher resistivity log responses for the Knowles Limestone (Figs. 32 and 42).

The Knowles marine shelf shale and limestone beds represent the backstepping transgressive section of this sequence. The shoal and reef complex deposits of the Knowles Limestone represent the infilling regressive section. A SMT occurs in the shale and limestone beds of the

Knowles, and is recognized as a shift from lower to higher gamma ray, and more positive SP log responses (Figs. 32 and 42). It separates the two systems tracts of this sequence, and represents a change from an upward deepening section to an upward shallowing section (Figs. 32, 41, 42 and 43).

6. North vs. South of the Wiggins Arch Correlation

The Norphlet Formation is a distinctive stratigraphic unit recognized as the first siliciclastic (mainly sandstone deposits) unit below the limestone of the overlying Smackover Formation. It lies unconformably on the salt in relatively downdip locales, and overlie basal black shale, the Pine Hill Anhydrite Member, the Louann Salt, Werner Anhydrite, the Eagle Mills Formation, Mesozoic volcanic rocks, or Paleozoic rocks in updip areas. The uppermost part of the Norphlet section is often massive, indicating marine reworking during the subsequent marine transgression at the end of the Norphlet deposition (Mancini et al., 1999).

The Norphlet Formation in the Mississippi Interior Salt Basin consists of four lithofacies: a basal black shale lithofacies, which occurs in Mississippi and Alabama as well as in the offshore regions of Alabama; a red bed lithofacies, which includes sandstones (subarkose and arkose), siltstones and shales; a cross-bedded sandstone (i.e. Denkman Member), which is also present in Mississippi and Alabama; and a conglomeratic sandstone, occurring in the extreme updip areas of the Norphlet Formation in Mississippi and Alabama (Mancini et al., 1999). In areas adjacent to the Wiggins Arch, Rhodes and Maxwell (1993) examined granite wash in the Norphlet Formation, and suggested a source within the granitic basement of the arch.

The Norphlet Formation thickens noticeably in the Mississippi Interior Salt Basin of Mississippi and Alabama. The Norphlet is about 1000 feet thick in Mississippi, and about 800 feet in southwestern Alabama. On the Wiggins Arch itself, the Norphlet is missing. South of the Wiggins Arch, the Norphlet is over 500 feet thick just offshore from Mobile Bay (Mancini et al., 1999). Further offshore, the Norphlet thickness ranges between 600-800 feet and could reach 1000 feet (Mink et al., 1990).

The Smackover Formation in the Mississippi Interior Salt Basin conformably overlies the Norphlet Formation. The Buckner Member (anhydrite beds) of the Haynesville Formation also conformably overlies it. The upper contact of the Smackover Formation, however, can be difficult to recognize in areas south of the Wiggins Arch where the overlying Haynesville Formation is largely carbonate (Mancini et al., 1999). The Smackover Formation in Alabama has been subdivided into lower, middle and upper members (Benson, 1988).

The lower member consists of algal laminate, intraclastic wackestone and packstone, and peloidal-oncoidal packstone and wackestone. The middle member consists of brown to gray skeletal peloidal wackstone interbedded with laminated mudstone. The upper member consists of complex lithologies mainly containing peloidal, oncoidal and oolitic packstone and grainstone (Benson, 1988).

The Smackover Formation in Mississippi differs considerably from the one in Alabama. In Mississippi the Smackover is subdivided only into two members: upper and lower. The upper member is in general coarse grained and quite sandy in certain areas, while the the lower member is typically more micritic in lithology, and sandstone is also common (Benson, 1988). South of the Wiggins Arch, the Smackover Formation is little studied. However, the lithology is thought to be more open marine and consists of low-energy, dark gray and dense limestone and of high-energy oolitic and peloidal grainstone shoal deposits (Rhodes and Maxwell, 1993; and Tew et al., 1993).

The thickness and facies distribution of the Smackover Formation is influenced by the configuration of the antecedent topography. This is evident in the relatively great thickness of the Smackover in the Mississippi Interior Salt Basin. In contrast, the Smackover thins dramatically, or is missing, over paleotopographic highs such as the Wiggins Arch. The thickness of the Smackover Formation ranges from few hundred feet (onshore and coastal areas of northeastern Gulf of Mexico) to over a thousand feet (south-southwest of coastal areas). It averages around 550-700 feet thick (Mancini et al., 1999; and Tew et al., 1993).

The Haynesville Formation in the Mississippi Interior Salt Basin is lithologically variable, and includes shale, anhydrite, sand, conglomerate, and carbonate in varying amounts. The Haynesville is characterized as a mixed siliciclastic-carbonate-evaporitic unit between the Smackover carbonates and the Cotton Valley siliciclastics.

The anhydrite deposits of the Haynesville Formation are often prevailing in the Mississippi Interior Salt Basin and in areas north of the Wiggins Arch, while they are absent in areas south of the arch (Mancini et al., 1999). The Buckner Anhydrite Member of the Haynesville is considered to be the massive anhydrite at the base of the Haynesville Formation, representing deposition in a restricted paleoenvironment landward of a significant barrier, i.e. the Wiggins Arch. It is present in Mississippi as well as in southwest Alabama, except in extreme updip and downdip regions (Tolson et al., 1983). The uppermost part of the Haynesville section is mainly shaley, particularly in southwest Alabama. On paleotopographic highs, the Haynesville sections are often conglomeratic and/or dolomitic in composition. South of the Wiggins Arch, the Buckner anhydrite is absent, and is replaced by interbedded sandstone, limestone, anhydrite and shale deposits of the lower Haynesville (Mancini et al., 1999).

The Wiggins Arch affected the distribution of the various Haynesville lithofacies. During the Jurassic, the arch could have probably defined a platform margin, or steepened ramp, separating dense, dark, micritic limestones offshore from siliciclastic, evaporitic, and carbonate sediments onshore (Cagle and Khan, 1983; and Ericksen and Thieling, 1993). The Haynesville equivalent beds south of the Wiggins Arch are chiefly dark gray, micritic limestones (Mancini et al., 1999)

The thickness of the Haynesville Formation varies significantly, but averages around 1200-1400 feet. Tolson et al. (1983) suggested that the Haynesville represents a transition between the underlying carbonate deposits of the Smackover Formation and the overlying Cotton Valley Group, with its coarser, continental, siliciclastic deposits.

The Jurassic/partly Lower Cretaceous Cotton Valley Group is mainly paralic deposits between the evaporite, carbonate and siliciclastic sediments of the Jurassic Haynesville Formation below, and the coarse, continental, siliciclastic sediments of the Lower Cretaceous Hosston Formation above (Mancini et al., 1999). Moore (1983) characterized the Cotton Valley Group in Mississippi as predominantly siliciclastic beds. Moore also divided the Cotton Valley Group into three intervals, lower (sandy), middle (less sandy) and upper (the least amount of sandstone, and more limestone) informal members. The updip limit of limestone occurrence in the upper Cotton Valley was mapped by Moore (1983), and was termed the Knowles

Limestone. Moore (1983) interpreted the Cotton Valley as being deposited in fluvial, deltaic, strandplain and nearshore marine environments.

The Cotton Valley Group in southern Mississippi was subdivided into three intervals by Ericksen and Thieling (1993). The lower consists of shale, siltstone, and sandstone. The middle consists of shale, limestone, and sandstone. The upper interval consists of sandstone with interbedded limestone. Tolson et al. (1983) described the Cotton Valley Group as consisting of moderate to pale red, light gray and white, fine to very coarse grained sand to conglomeratic sandstone.

In general, in the Mississippi Interior Salt Basin, the Cotton Valley Group is comprised of the Schuler Formation, which consists of coarse siliciclastic sediments that become more conglomeratic updip. The Schuler Formation in onshore northeastern Gulf of Mexico (i.e. in the Mississippi Interior Salt Basin, north of the Wiggins Arch) can be subdivided into two members, a lower Shongaloo Member and an upper Dorcheat Member. The Shongaloo Member consists of red and red-green shale of a darker color than the Dorcheat shale, and of red and white sandstone and conglomerate. The Dorcheat Member, which is partly Lower Cretaceous (Berriasian), is composed of pastel, varicolored shale or claystone, siltstone, and white sandstone (Mancini et al., 1999).

Offshore, south of the Wiggins Arch, the Cotton Valley Group consists of the Schuler Formation (Tithonian to Berriasian) and the Knowles Limestone (lower Valanginian). Unlike the Schuler Formation in the Mississippi Interior Salt Basin, north of the Wiggins Arch, the Schuler Formation south of the arch is undifferentiated (i.e. no Shongaloo or Dorcheat members). The Knowles Limestone is comprised of gray to dark brown dolomitic mudstone and wackestone (Moore, 1983).

7. Conclusions

In using the concepts of transgressive-regressive sequences, three onshore, and four offshore T-R sequences (T-R J1, T-R J2, T-R J3 and T-R LK1) were recognized in the Upper Jurassic-Lower Cretaceous strata of the northeastern Gulf of Mexico. Each of these T-R sequences consists of a transgressive systems tract, with its backstepping section, and a regressive systems tract, with its infilling section. Recognition of three T-R sequences north of the Wiggins Arch, and four south of the Wiggins Arch, implies that the depositional history of these two areas differ in their geohistories.

Four to five major unconformities/sequence boundaries, identified on reflection seismic data as toplap and erosional truncation surfaces and in well log patterns as discontinuities, and three to four surfaces of maximum transgression, identified on reflection seismic sections as downlap surfaces and in well log patterns as shifts in GR and SP signatures, were recognized as key stratigraphic seismic surfaces representing significant depositional episodes in the geohistory of northeastern Gulf of Mexico. These stratigraphic surfaces were traceable in the study area.

Four seismic facies (A, B, C, and D) were identified on seismic reflection sections in the Mobile Area. Seismic facies D boundaries correspond to sequence boundaries SB3 and SB4 for the T-R LK1 sequence, which implies change in sea level was the major factor influencing the character of seismic facies D. Conversely, the T-R J1 and T-R J2 sequence boundaries do not correspond to seismic facies boundaries, suggesting both tectonic and eustatic influences on the character of seismic facies A, B and C.

Work Planned

Sequence Stratigraphy Model—The development and testing of the sequence stratigraphy model will continue (Tables 1 and 2).

Discovered Reservoir Classification—The known petroleum reservoirs of the Mississippi Interior Salt Basin area will be classified into the phases of the T-R cycles.

Exploration Strategy Development—Exploration strategies will be developed using the results from the development and testing of the sequence stratigraphy model and the classification of the discovered reservoirs in the Mississippi Interior Salt Basin area.

Identification of Underdeveloped and Undiscovered Resources—The developed exploration strategies will be used for identifying and defining specific facies that have high reservoir potential and for identifying and delineating stratigraphic traps in the Mississippi Interior Salt Basin area.

Results and Discussion

Wichita State University (William Parcell) has applied T-R cycle models to describe middle Jurassic continental and marginal marine units as observed in outcrops in Wyoming and Montana. A T-R cycle method to characterize stratal architecture and the nature of bounding surfaces of these units has been developed. In addition, well log data were used to facilitate the correlation of the outcrop information.

McGill University (Bruce Hart) has demonstrated that traditional seismic stratigraphic analyses, involving the identification of key surfaces and stratal terminations to define unconformities, flooding surfaces, and maximum flooding surfaces, can be used to identify T-R cycles and depositional sequences in passive margin settings such as the Gulf Coast and offshore Atlantic (Scotian shelf). However, subaerial erosion surfaces associated with lowstands of relateive sea level have not been observed in seismic, well logs, or outcrop sections from foreland basins, and therefore, appear to be not developed in foreland basin settings. Reflection geometries, such as onlap and downlap, associated with T-R cycles, were not commonly visible in seismic data because the sections were too thin in thickness. Seismic attributes, in particular instantaneous phase, is useful in recognizing key surfaces because it is an indicator of reflection continuity.

University of Alabama (Kaiyu Liu) has shown that an integrated sequence stratigraphic framework was established for correlating Upper Cretaceous strata in the northeastern Gulf of Mexico area from updip areas to downdip areas and for interpreting the depositional history of these strata. Surfaces that have chronostratigraphic significance, such as maximum flooding surfaces and sequence boundaries, were used in conjunction with biostratigraphic data for correlation. Sequence stratigraphic interpretations from seismic studies were found to be in

Table 1
Milestone Chart—Year 2

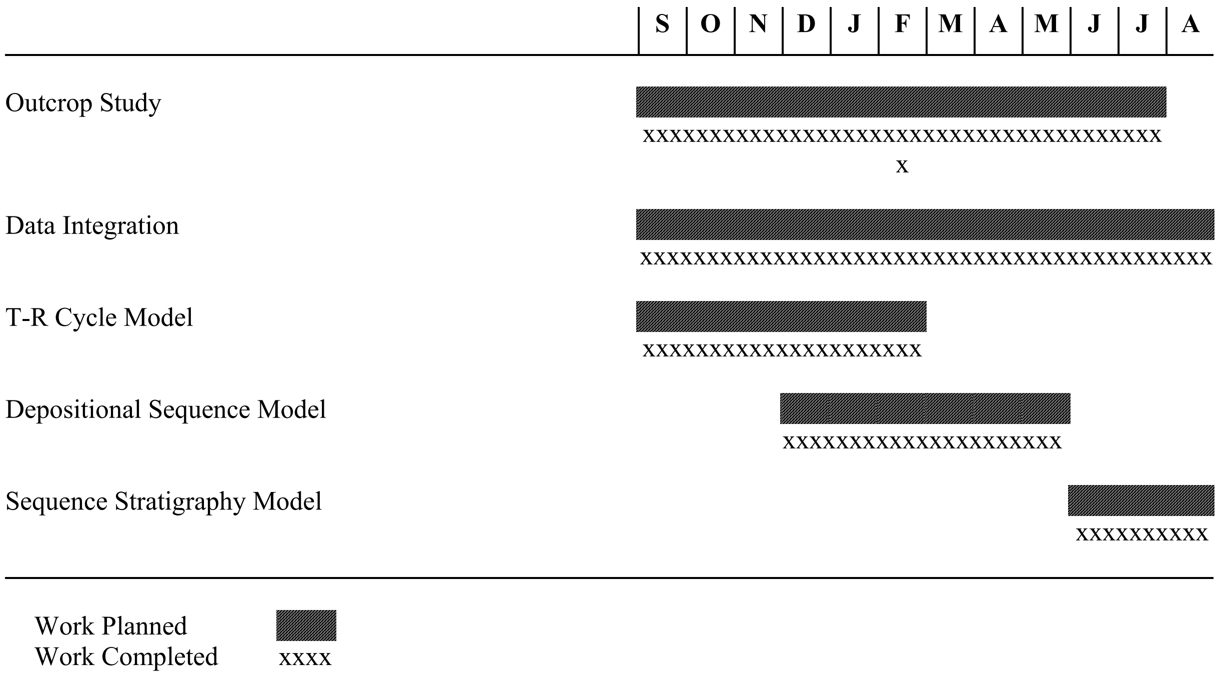
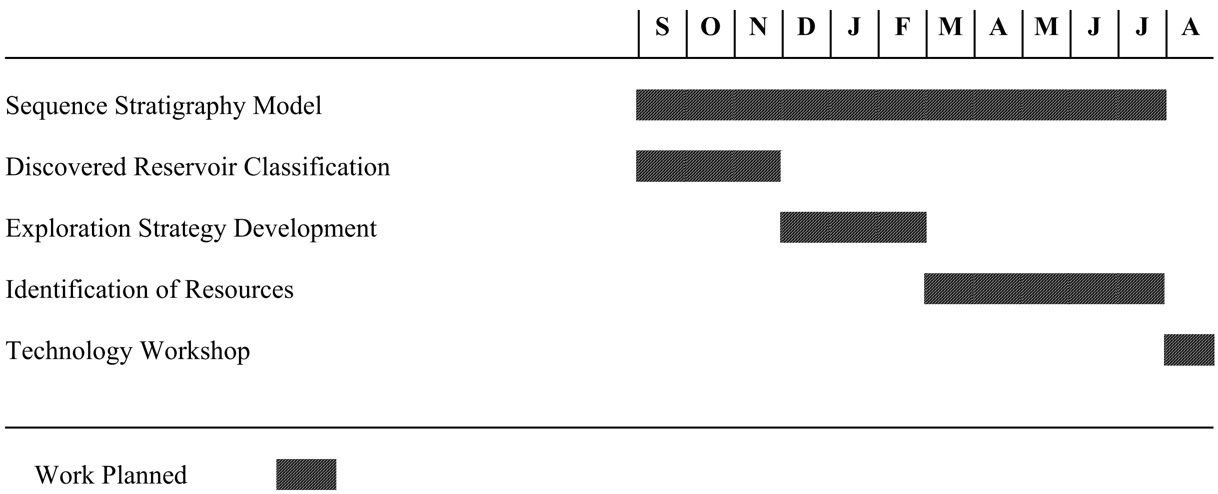


Table 2
Milestone Chart—Year 3



general agreement with interpretations from outcrop studies. Sequence boundaries identified as onlap surfaces from seismic sections were found to correspond to prominent unconformities observed from outcrop studies. Maximum flooding surfaces recognized as downlap surfaces on seismic sections in the downdip area were found to correlate with transgressive surfaces in marginal marine areas and with sediment starvation surfaces in pelagic areas. Strata of transgressive systems tracts were recognized as reflectors that onlap against sequence boundaries. These strata exhibit a retrogradational and backstepping geometry in well log patterns and in surface deposits. Strata of highstand systems tracts were recognized as reflectors that downlap on maximum flooding surfaces. These strata were observed to be progradational in well logs patterns and in surface deposits. Facies changes in a dip-oriented direction were determined in the established stratigraphic framework. The depositional history and relative sea-level changes in Upper Cretaceous deposits in the northeastern Gulf of Mexico area were interpreted from stratal geometry and facies stacking patterns. Differences in interpretations of changes in relative sea level based on outcrop studies versus seismic studies were attributed to variations in sedimentation rates in a strike orientation.

Univeristy of Alabama (Jamal Obid) has demonstrated that the Upper Jurassic-Lower Cretaceous mixed siliciclastic and carbonate section in the northeastern Gulf of Mexico includes three to four T-R sequences. Using selected onshore (north of the Wiggins Arch) and offshore (south of the Wiggins Arch) well log data, three T-R sequences were recognized in the Upper Jurassic-Lower Cretaceous onshore and offshore sections. A fourth sequence was recognized only in the offshore section, south of the Wiggins Arch. Three T-R sequences have been recognized on two dimensional reflection seismic data in the Mobile Area, offshore Alabama, northeastern Gulf of Mexico. The three T-R sequences (T-R J1, T-R J2, and T-R LK1) are of Upper Jurassic (Oxfordian) to Lower Cretaceous (Lower Valanginian) in age, averaging about 3-12 million years in duration. These sequences represent continental, coastal, marginal marine and marine strata of the shelfal areas of the Gulf of Mexico basin, in which low frequency, tectonic-eustatic events are the main driver behind such stratal patterns. Each sequence consists of a backstepping transgressive section and an infilling regressive section. A surface of maximum transgression (SMT) separates the two systems tracts. Four sequence boundaries and three surfaces of maximum transgression were recognized on seismic sections. These Upper Jurassic to Lower Cretaceous T-R sequences and their associated sequence boundaries and surfaces of maximum transgression (downlap surfaces) have utility for regional correlation across the northeastern Gulf of Mexico.

Conclusions

The principal research effort for Year 2 of the project is on stratigraphic model assessment and development. The research focus for the first six (6) months of Year 2 is on T-R cycle model development. The emphasis for the remainder of the year is on assessing the depositional model and developing and testing a sequence stratigraphy model. The development and testing of the sequence stratigraphy model was accomplished by studies by Wichita State University, McGill University and the University of Alabama. This work was achieved through integrated outcrop, well log, and seismic studies of Mesozoic strata in the onshore and offshore Gulf of Mexico, offshore North Atlantic, and onshore Rocky Mountain areas.

References

Addy, S. K., and Buffler, R. T., 1984, Seismic Stratigraphy of Shelf and Slope, Northeastern Gulf of Mexico, American Association of Petroleum Geologists Bulletin, v. 68, p. 1782-1789.

Asquith, G.B., and Gibson, C.R., 1982, Basic Well Log Analysis for Geologists, American Association of Petroleum Geologists Methods in Exploration Series, no. 3, p. 91-96.

Banerjee, I., and S.M. Kidwell, 1991, Significance of molluscan shell beds in sequence stratigraphy: an example from the Lower Cretaceous Mannville Group of Canada, Sedimentology, v. 38, p. 913-934.

Baria, L. R., Heydari, E., and Stephenson, M. A., 1997, A Proposed Basin-wide, Middle Smackover Lowstand and Its Effect on Mixed Carbonate/Siliciclastic Facies and Carbonate Diagenesis in the Eastern Gulf Basin (abs.), American Association of Petroleum Geologists Annual Convention.

Benson, D.J., 1988, Depositional history of the Smackover Formation in southwest Alabama, Gulf Coast Association of Geological Societies Transactions, v.38, p.197-205.

Berg, R.R. and B.C. Cook, 1968, Petrography and origin of Lower Tuscaloosa sandstones, Mallalieu Field, Lincoln County, Mississippi, Gulf Coast Geological Societies Transactions, v. 18, p. 242-255.

Buffler, R.T., and Sawyer, D.S., 1985, Distribution of Crust and Early History, Gulf of Mexico Basin, Gulf Coast Association of Geological Societies Transactions, v.35, p. 333-344.

Cagle, J.W. and Khan, M.A., 1983, Smackover-Norphlet Stratigraphy, South Wiggins Arch, Mississippi and Alabama, Gulf Coast Association of Geological Societies Transactions, v. 33, p. 23-29.

Catuneanu, O., A.J. Willis, and A.D. Miall, 1998, Temporal significance of sequence boundaries: Sedimentary Geology, v. 121, p. 157-178.

Catuneanu, O., 2002, Sequence stratigraphy of clastic systems: concepts, merits, and pitfalls, Journal of African Earth Sciences, v. 35, p. 1-43.

Conant, L. S., 1967, The pre-Selma Cretaceous strata, in D. E. Jones, ed., Geology of the Coastal Plain of Alabama, Guidebook for the 80th annual meeting of the Geological Society of Alabama, Alabama Geological Society, p. 4-11.

Cook, M.R., 1993, The Eutaw aquifer in Alabama: Geological Survey of Alabama Bulletin, v. 156, p. 1-105.

Cooper, W.W., and Shaffer, B.L., 1976, Nannofossil Biostratigraphy of the Bossier Shale and the Jurassic-Cretaceous Boundary, Gulf Coast Association of Geological Societies Transactions, v. 26, p. 178-184.

Copeland, C.W., 1968, Geology of the Alabama coastal plain, a guidebook, Geological Survey of Alabama Circular, v. 47, p. 1-97.

Corcoran, M.K., C.P. Cameron, and M.A. Meylan, 1993, The lower Tuscaloosa Formation in the Greensburg Field and Joseph Branch Field areas, St. Helena Parish, Louisiana, Gulf Coast Association of Geological Societies Transactions, v. 43, p. 87-96.

Cummings, D.I., Hart, B.S., and Arnott, R.W.C., Sedimentology and stratigraphy of a thick, areally extensive fluvial-marine transition, offshore Nova Scotia, Canada, and correlation with shelf margin and slope strata. Bulletin of Canadian Petroleum Geology.

Dickinson, K. A., 1962, The Upper Jurassic Stratigraphy of Mississippi and Southwestern Alabama, Unpublished Ph.D. Dissertation Thesis, University of Minnesota, 165p.

Dobson, L.M., 1990, Seismic Stratigraphy and Geologic History of Jurassic Rocks, Northeastern Gulf of Mexico, Master's Thesis, University of Texas at Austin, Austin, Texas, 165 p.

Dobson, L. M. and Buffler, R.T., 1991, Basement rocks and structure, northeast Gulf of Mexico. Gulf Coast Association of Geological Societies Transactions, v. 41, p.191-206.

Dobson, L.M., and Buffler, R.T., 1997, Seismic stratigraphy and geologic history of Jurassic rocks, Northeastern Gulf of Mexico, American Association of Petroleum Geologists Bulletin, v. 81, p. 100-120.

Donovan, A.D., G.R. Baum, G.L. Blechschmidt, T.S. Loutit, C.E. Pflum, and P.R. Vail, 1988, Sequence stratigraphic setting of the Cretaceous-Tertiary boundary in central Alabama, C.K. Wilgus, B.S. Hastings, C.G.St.C. Kendall, H.W. Posamentier, C.A. Ross, and J.C. Van Wagoner, eds., Sea-level Changes: An Integrated Approach, SEPM Special Publication No. 42, p. 299-307.

Dowsett, H.J., 1989, Documentation of the Santonian-Campanian and Austinian-Tayloran stage boundaries in Mississippi and Alabama using calcareous microfossils, United States Geological Survey Bulletin, v. 1884, p. 1-20.

Embry, A.F., 1993, Transgressive-Regressive (T-R) Sequence Analysis of the Jurassic Succession of the Sverdrup Basin, Canadian Arctic Archipelago, Geological Survey of Canada Contribution 46191, p. 301-320.

Embry, A. F., 2002, Transgressive-Regressive (T-R) Sequence Stratigraphy, *in* Armentrout, J.M., and Rosen, N.C., eds., Sequence Stratigraphic Models for Exploration and Production: Evolving Methodology, Emerging Models and Application Histories, 22nd Annual Gulf Coast Section SEPM Foundation, Bob F. Perkins Research Conference: Houston, Gulf Coast Section, SEPM, p. 151-172.

Emery, D., and Myers, K.J., 1996, Sequence Stratigraphy, Blackwell Science, Cambridge, MA, 297 p.

Faust, M.J., 1990, Seismic stratigraphy of the mid-Cretaceous unconformity (MCU) in the central Gulf of Mexico basin, Geophysics, v. 55, p. 868-884.

Galloway, W. E., 1989, Genetic stratigraphic sequences in basin analysis I: architecture and genesis of flooding-surface bounded depositional units, American Association of Petroleum Geologists Bulletin, v.73, no.2, p. 125-142.

Galloway, W. E., 1989, Genetic stratigraphic sequences in basin analysis II: application to Northwest Gulf of Mexico Cenozoic Basin, American Association of Petroleum Geologists Bulletin, v. 73, no. 2, p. 143-154.

Gan, X., 1996, Foraminifer biostratigraphy, paleoecology and sequence stratigraphy of the Mooreville Chalk in eastern Mississippi and western Alabama, unpublished M.S. thesis, University of Alabama, p. 1-103.

Gibson, T.G., 1989, Planktonic benthonic foraminiferal ratios: modern patterns and Tertiary applicability, Marine Micropaleontology, v. 15, p. 29-52.

Gradstein, F.M., Agterberg, F.P., Ogg, J.G., Hardenbol, J., van Veen, P., Thierry, J., and Huang, Z., 1995, A Triassic, Jurassic and Cretaceous Time Scale, in Berggren, W.A., Kent, D.V., Aubry, M.P., and Hardenbol, J., eds, Geochronology, Time Scales and Global Stratigraphic Correlation: Tulsa, SEPM (Society of Sedimentary Geology) Special Publications No. 54, p. 95-126.

Hancock, J.M., 1990, Sea-level changes in the British region during the Late Cretaceous, Proceeding of the Geologists' Association, v. 100, p. 565-594.

Hancock, J.M., 1993, Transatlantic correlations in the Campanian-Maastrichtian stages by eustatic changes of sea level, in Hailwood, E.A. and R.B. Kidd (eds.), High Resolution Stratigraphy, Geological Society Special Publication No. 70, the Geological Society, London, p. 241-256.

Haq, B.U., Hardenbol, J., and Vail, P.R., 1987, Chronology of fluctuating sea levels since the Triassic, Science, v. 235, p. 1156-1167.

Hardenbol, J., J. Thierry, M.B. Farley, T. Jacquin, P.-C. de Graciansky, and P.R. Vail, 1998, Mesozoic and Cenozoic sequence chronostratigraphic framework of European Basins, In P.-C. de Graciansky, J. Hardenbol, T. Jacquin, and P.R. Vail, eds., Mesozoic and Cenozoic Sequence Stratigraphy of European Basins: SEPM Special Publication 60, Tulsa, Society for Sedimentary Geology p. 3-13.

Hart, B.S. and Plint, A.G., 1993, Tectonic influence on deposition and erosion in a ramp setting: Upper Cretaceous Cardium Formation, Alberta Foreland Basin, American Association of Petroleum Geologists Bulletin, v. 77, p. 2092-2107.

Hayes, B.R., Christopher, J.E., Rosenthal, L., Los, G., McKercher, B., Minken, D., Tremblay, Y.M., and Fennell, J., 1994 Cretaceous Mannville Group of the Western Canada Sedimentary

Basin, *in*, Geological Atlas of the Western Canada Sedimentary Basin, Alberta Geological Survey, p. 317-334.

Hettinger, R.D., P.J. McCabe, and K.W. Shanley, 1994, Detailed facies anatomy of transgressive and highstand systems tracts from the Upper Cretaceous of southern Utah, U.S.A., in H.W. Posamentier, and P. Weimer, eds., Recent advances in siliciclastic sequence stratigraphy, American Association of Petroleum Geologists Memoir 58, p. 235-257.

Hollenshead, C. T. and R.L. Pritchard, 1961, Geometry of producing Mesaverde sandstones, San Juan Basin, in Peterson, J. A., Osmond, J. C., eds, Geometry of sandstone bodies, American Association of Petroleum Geologists, 1960 Symposium, p 98-118.

Imlay, R.W., 1940, Lower Cretaceous and Jurassic Formations of Southern Arkansas and their Oil and Gas Possibilities, Arkansas Division of Geology Information Circular 12, 64 p.

Imlay, R.W., 1943, Jurassic Formations of Gulf Region [of North America including United States, Mexico, and Cuba], American Association of Petroleum Geologists Bulletin, v. 27, p.1407-1533.

Imlay, R.W., L.S.Gardner, C.P. Jr. Rogers, H.D. Hadley, 1948, Marine Jurassic formations of Montana, US Geological Survey Oil and Gas Investigative Series, Preliminary Chart OC-32.

Imlay, R.W., 1956. Marine Jurassic exposed in Bighorn Basin, Pryor Mountains, and northern Bighorn Mountains, Wyoming and Montana, American Association of Petroleum Geologists Bulletin 40, p. 562-599.

Imlay, R.W., 1980, Jurassic Paleobiogeography of the Conterminous United States in its Continental Setting, U.S. Geological Survey Professional Paper 1062, 134 p.

Imlay, R.W., and Herman, G., 1984, Upper Jurassic Ammonites of the Subsurface of Texas, Louisiana, and Mississippi; *in* Ventress, W.P.S., Bebout, D.G., Perkins, B.F., and Moore, C.H., (eds.), The Jurassic of the Gulf Rim, 3rd Annual Gulf Coast Section SEPM Foundation Research Conference: Houston, Gulf Coast Section, SEPM, p. 149-170.

Jacquin, T., and de Graciansky, P.C., 1998, Major Transgressive-Regressive (second order) Facies Cycles: the Effects of Tectono-Eustasy, in de Graciansky, P.C., Hardenbol, J., Jacquin, T., and Vail, P.R., eds., Mesozoic and Cenozoic Sequence Stratigraphy of European Basins: Tulsa, SEPM (Society of Sedimentary Geology) Special Publication No. 60, p. 31-42.

Johnson, J.G., G. Klapper, and C.A. Sandberg, 1985, Devonian eustatic fluctuations in Euramerica, Geological Society of America Bulletin, v. 96, p. 567-587.

Jones, D.E., 1967, The Selma Group in west Alabama, in D.E. Jones, ed., Geology of the Coastal Plain of Alabama, A Guidebook for the 80th Annual Meeting of the Geological Society of America, Alabama Geological Society, p. 26-32.

Kerans, C., and Tinker, S.W., 1997, Sequence Stratigraphy and characterization of Carbonate Reservoirs, SEPM Short Course Notes, no. 40, 130 p.

Kidwell, S.M., 1991, Condensed deposits in siliciclastic sequences: Expected and observed features, in G. Einsele, W. Ricken and A. Seilacher, eds., Cycles and Events in Stratigraphy, Berlin, Springer-Verlag, p. 682-695.

Kirkland, D.W., and Gerhardt, J.E., 1971, Jurassic Salt, Central Gulf of Mexico, and it Temporal Relation to Circum-Gulf Evaporites, American Association of Petroleum Geologists Bulletin, v. 55, p. 680-686.

Kvale, E., G. Johnson, D. Mickelson, K. Keller, L. Furer, and A. Archer, 2001, Middle Jurassic (Bajocian and Bathonian) dinosaur megatracksites, Bighorn Basin, Wyoming, U.S.A., Palaios 16, p. 233-254.

Leckie, D.A., Bhattacharya, J.P., Bloch, J., Gilboy, C.F., and Norris, B., 1994, Cretaceous Colorado/Alberta Group of the Western Canada Sedimentary Basin, *in*, Geological Atlas of the Western Canada Sedimentary Basin, Alberta Geological Survey, p. 335-352.

Liu, K., 2004, Seismic and sequence stratigraphy of Upper Cretaceous strata, offshore Alabama and Mississippi area, Gulf Coast Association of Geological Societies Transactions, v. 54, p. 347-360.

Liu, K., 2005, Updip-downdip facies changes of the Eutaw Formation (Coniacian-Santonian), northeastern Gulf of Mexico area, Gulf Coast Association of Geological Societies Transactions, v. 55.

Loutit, T.S., J. Hardenbol, P.R. Vail, and G.R. Baum, 1988, Condensed sections: the key to age determination and correlation of continental margin sequences, in C.K. Wilgus, B.S. Hastings, C.A. Ross, H.W. Posamentier, J.C. Van Wagoner, and C.G.St.C. Kendall, eds., Sea-Level Changes: An Integrated Approach: SEPM Special Publication, v. 42, p. 183-213.

Mancini, E.A., and Smith, C.C., 1980, Geological age and depositional environment of the “Pilot Sand” and “Marine Shale” Tuscaloosa Group, South Carlton field, South Alabama, in Geology of the Woodbine and Tuscaloosa Formations, Society of Economic Paleontologists and Mineralogists First Annual Research Conference, v. 1, p. 24-25.

Mancini, E.A., and J.W. Payton, 1981, Petroleum geology of South Carlton field, Lower Tuscaloosa “Pilot Sand”, Clarke and Baldwin Counties, Alabama, Gulf Coast Association of Geological Societies Transactions, v. 31, p. 139-147.

Mancini, E. A., Mink, R. M., Bearden, B. L., and Wilkerson, R. P., 1985, Norphlet Formation (Upper Jurassic) of Southwestern Offshore Alabama: Environments of Deposition and Petroleum Geology, American Association of Petroleum Geologists Bulletin, v. 69, No. 6, p. 881-898.

Mancini, E.A., R.M. Mink, J.W. Payton, and B.L. Bearden, 1987, Environments of deposition and petroleum geology of Tuscaloosa Group (Upper Cretaceous), South Carlton and Pollard fields, southwestern Alabama, American Association of Petroleum Geologists Bulletin, v. 71, p. 1128-1142.

Mancini, Ernest A., and Tew, Berry H., 1988, Paleocene sequence stratigraphy of southwestern Alabama, Gulf Coast Associations of Geological Societies Transactions, v. 38, p. 453-460.

Mancini, E.A., B.H. Tew, and C.C. Smith, 1989, Cretaceous-Tertiary contact, Mississippi and Alabama, Journal of Foraminiferal Research, v. 19, p. 93-104.

Mancini, Ernest A., and Tew, Berry H., 1990, Relationships of Paleogene stage boundaries to group and unconformity-bounded depositional sequence contacts in Alabama and Mississippi, *in* Sequence Stratigraphy as an Exploration Tool: Concepts and Practices in the Gulf Coast, Proceedings of the 11th Ann. GCS-SEPM Research Conf., p. 221-228.

Mancini, E. A., Tew, B. H., and Mink, R. M., 1990a, Jurassic Sequence Stratigraphy in The Mississippi Interior Salt Basin of Alabama, Gulf Coast Association of Geological Societies Transactions, v. 40, p. 521-529.

Mancini, E. A., Mink, R. M., Bearden, B. L.., Mann, S. D., and Bolin, D. E., 1990b, Desert Environments and Petroleum Geology of the Norphlet Formation, Hatter's Pond Field, Alabama, Sprlinger-Verlag, New York, p. 153-180

Mancini, E. A., Mink, R. M., Tew, B. H., and Bearden, B. L., 1990c, Natural gas plays in Jurassic reservoirs of Southwestern Alabama, and the Florida Panhandle area, Gulf Coast Association of Geological Societies Transactions, v. 40, p. 513-519.

Mancini, Ernest A., and Tew, Berry H., 1991, Relationships of Paleogene stage and planktonic foraminiferal zone boundaries to lithostratigraphic and allostratigraphic contacts in the eastern Gulf Coastal Plain, Jour. Foraminiferal Research, v. 21, p. 48-66.

Mancini, Ernest A., and Tew, Berry H., 1993, Eustasy versus subsidence: Lower Paleocene depositional sequences from southern Alabama, eastern Gulf Coastal Plain, Geological Society of America Bulletin, v. 105, p. 3-17.

Mancini, Ernest A., Tew, Berry H., and Mink, Robert M., 1993, Petroleum source rock potential of Mesozoic condensed section deposits of southwest Alabama, *in* Source Rocks in a Sequence Stratigraphic Framework, American Association of Petroleum Geologists Studies in Geology No. 37, p. 147-162.

Mancini, E.A., and D.D. Soens, 1994, Paleoenvironments of the Tombigbee Sand Member of the Eutaw Formation (Upper Cretaceous) of eastern Mississippi and western Alabama, Gulf Coast Association of Geological Societies Transactions, v. 44, p. 421-430.

Mancini, Ernest A., and Tew, Berry H., 1994, Integrated biostratigraphic and sequence stratigraphic approach for intrabasin and interbasin correlations: Upper Cretaceous and Paleogene strata of the eastern Gulf Coastal Plain, USA, *in* Application of Sequence Stratigraphy to Oil Field Development, AAPG Hedberg Research Conference, p. M1-M5.

Mancini, Ernest A., and Tew, Berry H., 1995, Geochronology, biostratigraphy and sequence stratigraphy of a marginal marine to marine shelf stratigraphic succession: upper Paleocene and lower Eocene, Wilcox Group, eastern Gulf Coastal Plain, USA, SEPM Special Publication 54, p. 281-293.

Mancini, Ernest A., Puckett, T. Markham, Tew, Berry H., and Smith, Charles C., 1995, Upper Cretaceous sequence stratigraphy of the Mississippi-Alabama area, Gulf Coast Association of Geological Societies Transactions, v. 45, p. 377-384.

Mancini, E.A., T.M. Puckett, and B.H. Tew, 1996, Integrated biostratigraphic and sequence stratigraphic framework for Upper Cretaceous strata of the eastern Gulf Coastal Plain, USA, Cretaceous Research, v. 17, p. 645-669.

Mancini, Ernest A., Tew, Berry H. and Puckett, T. Markham, 1996, Comparison of Upper Cretaceous and Paleogene depositional sequences, Gulf Coast Association of Geological Societies Transactions, v. 46, p. 281-286.

Mancini, E. A., and Tew, B. H., 1997, Recognition of Maximum Flooding Events in Mixed Siliciclastic-Carbonate Systems, Key to Global Chronostratigraphic Correlation, Geology, v. 25, p. 351-354.

Mancini, E.A., Puckett, T.M., Parcell, W.C., and Panetta, B.J., 1999, Basin Analysis of the Mississippi Interior Salt Basin and Petroleum Systems Modeling of the Jurassic Smackover Formation, Eastern Gulf Coastal Plain: Topical Reports 1 and 2, DOE contract no. DE-FG22-96BC14946, p. 425.

Mancini, Ernest A., 2000, Sequence stratigraphy and chronostratigraphy of Upper Eocene and Lower Oligocene strata, eastern Gulf Coastal Plain, Gulf Coast Association of Geological Societies Transactions, v. 50, p. 379-388.

Mancini, Ernest A., and Puckett, T.M., 2000, Sequence stratigraphy and petroleum potential of Lower Cretaceous strata, Mississippi Interior Salt Basin, Gulf Coast Association of Geological Societies Transactions, v. 50, p. 351-360.

Mancini, Ernest A., and Parcell, W.C., 2001, Outcrop analogs for reservoir characterization and modeling of Smackover microbial reefs in the northeastern Gulf of Mexico area, Gulf Coast Association of Geological Societies Transactions, v. 51, p. 207-228.

Mancini, Ernest A., and Puckett, T.M., 2002, Transgressive-regressive cycles in Lower Cretaceous strata, Mississippi Interior Salt Basin area of the northeastern Gulf of Mexico, Cretaceous Research, v. 23, p. 409-438.

Mancini, E.A., and T.M. Puckett, 2002, Transgressive-regressive cycles: application to petroleum exploration for hydrocarbons associated with Cretaceous shelf carbonates and coastal and fluvial-deltaic siliciclastics, northeastern Gulf of Mexico, in J.M. Armentrout, ed., Sequence Stratigraphic Models for Exploration and Production: Evolving Methodology, Emerging Models and Application Case Histories: Proceedings of the 22nd Annual Bob F. Perkins Research Conference, Gulf Coast Section, SEPM Foundation, p. 173-199.

Mancini, E.A., and T.M. Puckett, 2003, Integrated biostratigraphic and sequence stratigraphic approach for correlation and basin interpretation, Gulf Coast Association of Geological Societies Transactions, v. 53, p. 517-526.

Mann, S. D., 1988, Subaqueous Evaporites of The Buckner Member, Haynesville Formation, Northeastern Mobile County, Alabama, Gulf Coast Association of Geological Societies Transactions, v. 37, p. 187-196.

Marzano, M. S., Pense, G. M., and Andronaco, P., 1988, A comparison of the Jurassic Norphlet Formation in Mary Ann Field, Mobile Bay, Alabama to onshore regional Norphlet trends, Gulf Coast Association of Geological Societies Transactions, v. 38, p. 85-100.

Mial, A.D., 2000, Principles of Sedimentary Basin Analysis, 3rd Edition, Springer-Verlag, New York, 616 p.

Mills, N.K., 1956, Subsurface stratigraphy of the pre-Niobrara formations in the Bighorn Basin, Wyoming, Wyoming Geological Association Guidebook, p. 98.

Mink, R.M., Tew, B.H., Mann, S.D., Bearden, B.L., and Mancini, E.A., 1990, Norphlet and pre-Norphlet Geologic Framework of Alabama and Panhandle Florida Coastal Waters Area and Adjacent Federal Waters Area: Alabama Geological Survey, Minerals Management Service Cooperative Agreement No. 14-12-0001-30387 through the University of Texas, Austin, Bureau of Economic Geology, Draft Report, 81 p.

Mitchum, R.M.Jr., Vail, P.R., and Sangree, J.B., 1977, Stratigraphic Interpretation of Seismic Reflection Patterns in Depsoitional Sequences, *in* Payton, C.E., ed., Seismic Stratigraphy – Applications to Hydrocarbon Exploration, p. 117-134.

Mitchum, R.M., Jr., Vail, P.R., and Thompson, S., III, 1977, Seismic Stratigraphy and Global Changes of Sea Level, part two, the Depositional Sequence as a Basin Unit for Stratigraphic Analysis, *in* C.E. Payton, ed., Seismic Stratigraphy-Applications to Hydrocarbon Exploration, Tulsa, American Association of Petroleum Geologists Memoir, v. 26, p. 53-62.

Mitchum, R.M., Jr., 1978, Seismic stratigraphic investigation of west Florida slope, Gulf of Mexico, in A.H. Bouma, G.T. Moore, J.M. Coleman, eds., Framework, Facies and Oil-trapping Characteristics of Upper Continental Margin, American Association of Petroleum Geologists Studies in Geology, v. 7, p. 193-223.

Monroe, W.H., 1964, General description of cores of pre-Selma Cretaceous strata in western Alabama, United States Geological Survey Bulletin, v. 1160-B, p. 1-8.

Montgomery, S.L., 2000, Wiggins Arch Southern Mississippi: New Exploratory Data from 3-D Seismic, American Association of Petroleum Geologists Bulletin, v. 84, no. 3, p. 299-313.

Moore, T., 1983, Cotton Valley depositional systems of Mississippi, Gulf Coast Association of Geological Societies Transactions, v. 33, p. 163-167

Moore, C.H., 2001, Carbonate Reservoirs: Porosity Evolution and Diagenesis in Sequence Stratigraphic Framework: Developments in Sedimentology, No. 55, Elsevier, New York, 444 p.

Naish, T., and P.J. Kamp, 1997, Foraminiferal depth palaeoecology of Late Pliocene shelf sequences and systems tracts, Wanganui Basin, New Zealand, Sedimentary Geology, v. 110, p. 237-255.

Nordquist, J.W., 1955, Pre-Rierdon Jurassic stratigraphy in northern Montana and Williston Basin. Billings Geological Society Guidebook, 6th Annual Field Conference, p. 96-106.

Nunn, J.A., 1984, Subsidence Histoires for the Jurassic Sediments of the Northern Gulf Coast: Thermal-Mechanical Model, *in* Ventress, W.P.S., Bebout, D.G., Perkins, B.F., Moore, C.H., eds., The Jurassic of the Gulf Rim, 3rd Annual Gulf Coast Section SEPM Foundation Research Conference: Houston, Gulf Coast Section, SEPM, p. 309-322.

Pashin, J.C., D.E. Raymond, G.G. Alabi, R.H. Groshong, Jr., and G. Jin, 2000, Revitalizing Gilbertown oil field: characterization of fractured chalk and glauconitic sandstone reservoirs in an extensional fault system, Geological Survey of Alabama Bulletin, v. 168, p. 1-81.

Perch-Nielsen, K., 1985, Mesozoic calcareous nannofossils, in H.M. Bolli, J.B. Saunders, and K. Perch-Nielsen, eds., Plankton Stratigraphy: Cambridge University Press, Cambridge, London, p. 329-426.

Petty, A.J., Thieling, S., and Friedman, T., 1995, Mesozoic Stratigraphy of Near Shelf-Edge Deposits, Southern Mississippi, Adjacent State and Federal Waters, *in* Batchelder, E., Larre, G.H., and Shepard, B., eds., Geologize, New Orleans, Minerals Management Service Office, v. 2, p. 9-10.

Posamentier, H.W., and Vail, P.R., 1988, Eustatic Controls on Clastic Deposition II: Sequence and Systems Tracts Models, in Sea-Level change-An Integrated Approach, SEPM Special Publication, No. 42, p. 125-153.

Posamentier, H. W., M. T. Jervey, and P. R. Vail, 1988, Eustatic controls on clastic depositionI— conceptual framework, in C.K. Wilgus, B.S. Hastings, C.G.St.C. Kendall, H.W. Posamentier, C.A. Ross, and J.C. Van Wagoner, eds., Sea-level Changes: An Integrated Approach, SEPM Special Publication No. 42, p. 109-124.

Posamentier, H.W., and Allen, G.P., 1999, Siliciclastic Sequence Stratigraphy: Concepts and Applications, SEPM (Society of Sedimentary Geology) Concepts in Sedimentology and Paleontology Series 7, Tulsa, 204 p.

Prather, B. E., 1992, Evolution of a Late Jurassic Carbonate/Evaporite Platform, Conecuh Embayment, Northeastern Gulf Coast, U.S.A., American Association of Petroleum Geologists Bulletin, v. 76, no. 2, p. 164-190.

Puckett, T.M., 1992, Distribution of ostracodes in the Upper Cretaceous (late Santonian through middle Maastrichtian) of Alabama and Mississippi, Gulf Coast Association of Geological Societies Transactions, v. 42, p. 613-632.

Puckett, T.M. and E.A. Mancini, 2000, Microfossil characteristics of deposits of systems tracts in the Upper Cretaceous strata of Mississippi and Alabama, Gulf Coast Association of Geological Societies Transactions, v. 50, p. 389-398.

Puckett, T.M., and E.A. Mancini, 2001, Asymmetry in Upper Cretaceous depositional sequences of the northeastern Gulf Coastal Plain, Alabama, Mississippi and Tennessee, Geological Society of America Abstracts with Programs, v. 33, p. 100.

Raymond, D.E., W.E. Osborne, C.W. Copeland, and T.L. Neathery, 1988, Alabama Stratigraphy, Geological Survey of Alabama Circular, v. 140, p. 1-97.

Rhodes. J.A., and Maxwell, G.B., 1993, Jurassic Stratigraphy of the Wiggins Arch, Mississippi, Gulf Coast Association of Geological Societies Transactions, v. 43, p. 333-344.

Rider, M.H., 1996, The Geological Interpretation of Well Logs, Gulf Publishing Company, Houston, 280p.

Rogers, R., 1987, A Palynological Age Determination for the Dorcheat and Hosston Formations: the Jurassic-Cretaceous Boundary in Northern Louisiana: Gulf Coast Association of Geological Societies Transactions, v. 37, p. 447-456.

Russell, E.E., 1967, The Selma equivalent in Mississippi, Tennessee and Kentucky, in D. E. Jones, ed., Geology of the Coastal Plain of Alabama: Guidebook for the 80th annual meeting of the Geological Society of Alabama, Alabama Geological Society, p. 12-17.

Russell, E.E., and D.M. Keady, 1983, Notes on Upper Cretaceous lithostratigraphy of the eastern Mississippi Embayment, in E.E. Russell, D.M. Keady, E.A. Mancini, and C.C. Smith, eds., Upper Cretaceous lithostratigraphy and biostratigraphy in northeast Mississippi, southwest Tennessee and northwest Alabama, shelf chalks and coastal clastics: The Geological Survey of Alabama Spring Field Trip, p. 1-15.

Salvador, A., 1987, Late Triassic-Jurassic paleogeography and origin of the Gulf of Mexico Basin, American Association of Petroleum Geologists Bulletin, v. 71, p. 419-451.

Salvador, A., 1991, Origin and Development of the Gulf of Mexico Basin, *in* Salvador, A., ed., the Gulf of Mexico Basin: the Geology of North America, v. J, Geological Society of America, Boulder, p. 389-444.

Sangree, J.B., and Widmier, J.M., 1977, Seismic Stratigraphy and Global Changes of Sea-level, Part 9: Seismic Stratigraphic Interpretation of Clastic Depositional Facies, i*n* Payton, C. E., ed., Seismic Stratigraphy- Applications to Hydrocarbon Exploration, American Association of Petroleum Geologists Memoir 26, Tulsa, p. 1165-1184.

Sarg, J.F., 1988, Carbonate Sequence Stratigraphy, *in* Wilgus et al., eds, Seal-Level Change: An Integrated Approach, SEPM Special Publication 42, p. 155-180.

Sawyer, D.S., Buffler, R.T., and Pilger, R.H., Jr., 1991, The Crust Under the Gulf of Mexico, in Salvador, A., ed., The Gulf of Mexico Basin, Decade of North American Geology, Boulder, GSA, v. J, p.53-72.

Schmidt, G.A., and Pemberton, S.G., 2003, Stratigraphy and Paleogeography of a Conglomeratic shoreline: the Notikewin Member of the Spirit River Formation in the Wapiti area of west-central Alberta, Bulletin of Canadian Petroleum Geology, v. 51, p. 519-538.

Scott, R.W., 1984, Significant Fossils of the Knowles Limestone, Lower Cretaceous, Texas, *in* Ventress, W.P.S., Bebout, D.G., Perkins, B.F., and Moore, C.H., eds., The Jurassic of the Gulf Rim, 3rd Annual Gulf Coast SEPM Foundation Annual Research Conference: Houston, Gulf Cost Section SEPM, p. 333-346.

Shanley, K. W., and McCabe, P. J., 1994, Perspectives on the Sequence Stratigraphy of Continental Strata, American Association of Petroleum Geologists Bulletin, v. 78, no. 4, p. 544-588.

Shaub, F.J., R.T. Buffler, and J.G. Parsons, 1984, Seismic stratigraphic framework of deep central Gulf of Mexico Basin, American Association of Petroleum Geologists Bulletin, v. 68, p. 1790-1802.

Sheriff, R.E., and Gldart, L.P., 1995, Exploration Seismology, 2nd edition, Cambridge University Press, 592 p.

Shipboard Scientific Party, 1998, Explanatory notes, in R.D. Norris, D. Kroon, A. Klaus, et al., eds., Proceedings of the Ocean Drilling Program, Initial Reports, v. 171b, Washington, U.S. Government Printing Office, p. 11-44.

Sissingh, W., 1977, Biostratigraphy of Cretaceous calcareous nannoplankton, Geologie En Mijnbouw, v. 56, p. 37-65.

Smith, C.C., and E.A. Pessagno, 1973, Planktonic foraminifera and stratigraphy of the Corsicana Formation (Maestrichtian), north-central Texas, Cushman Foundation for Foraminiferal Research Special Publication No. 12, p. 1-68.

Smith, C.C., 1975, Upper Cretaceous nannoplankton zonation and stage boundaries, Gulf Coast Association of Geological Societies Transactions, v. 25, p. 263-278.

Smith, C.C., and E.A. Mancini, 1983, Calcareous nannofossil and planktonic foraminiferal biostratigraphy, in E.E. Russell, D.M. Keady, E.A. Mancini, and C.C. Smith, eds., Upper Cretaceous lithostratigraphy and biostratigraphy in northeast Mississippi, southwest Tennessee and northwest Alabama, shelf chalks and coastal clastics: The Geological Survey of Alabama Spring Field Trip, p. 15-28.

Smith, C.C., 1995, Regional lithostratigraphy and calcareous nannofossil biostratigraphy of the Arcola Limestone Member, Mooreville Chalk, of Eastern Mississippi and Alabama, Gulf Coast Association of Geological Societies Transactions, v. 45, p. 529-535.

Smith, C.C., 1997, The Cretaceous-Tertiary boundary at Moscow landing, west-central Alabama, Gulf Coast Association of Geological Societies Transactions, v. 47, p. 533-539.

Sprinkel, D.A., 1982, Twin Creek Limestone - Arapien Shale relationships in central Utah, *in* Overthrust Belt of Utah, Utah Geological Association Publication 10, p. 169-179.

Stephenson, L.W., and W.H. Monroe, 1940, The Upper Cretaceous deposits, Mississippi State Geological Survey Bulletin, v. 40, p. 1-296.

Swann, C.T., 1997, Geology of the Chalybeate topographic quadrangle, Tippah and Alcorn Counties, Mississippi, Journal of the Mississippi Academy of Sciences, v. 42, p. 142-150.

Swann, C.T., 1999, Geology of the Falkner topographic quadrangle, Tippah County, Mississippi, Journal of the Mississippi Academy of Sciences, v. 44, p. 206-215.

Swann, C.T., 2003, Geology of the Walnut Miss.-Tenn. 7.5 minute topographic quadrangle, Journal of the Mississippi Academy of Sciences, v. 48, p. 181-192.

Tew, Berry H., and Mancini, Ernest A., 1992, An integrated lithostratigraphic, biostratigraphic, and sequence stratigraphic approach to paleogeographic reconstruction: examples from the Upper Eocene and lower Oligocene of Alabama and Mississippi, Gulf Coast Association of Geological Societies Transactions, v. 42, p. 735-756.

Tew, B.H., Mink, R.M., Mancini, E.A., Mann, S.D., and Kopaksa-Merkel, D.C., 1993, Regional Geologic Framework and Petroleum Geology of the Smackover Formation, Alabama and Panhandle Florida Coastal Waters Area and Adjacent Federal Waters Area, Bulletin-Geological Survey of Alabama, v. B-164: Tuscaloosa, Alabama, Geological Survey of Alabama, 60 p.

Tew, B.H., 2000, Depositional setting of the Arcola Limestone Member (Campanian) of the Mooreville Chalk, Eastern Gulf Coastal Plain, Gulf Coast Association of Geological Societies Transactions, v. 50, p. 157-166.

Tolson, J.S., Copeland, C.W., and Bearden, B.L., 1983, Stratigraphic Profiles of Jurassic Strata in the Western Part of the Alabama Coastal Plain: Bulletin – Geological Survey of Alabama, v. B 122, Tuscaloosa, Alabama, Geological Survey of Alabama, 425p.

Vail, P. R., and Mitchum, R. M. Jr., 1977, Seismic Stratigraphy and Global Changes of Sea Level, Part 1: Overview, *in* Payton, C.E., ed., Seismic Stratigraphy – Application to Hydrocarbon Exploration, p. 83-97.

Vail, P.R., R.M. Mitchum, Jr, and S. Thompson, 1977, Seismic stratigraphy and global changes of sea level, part 3: relative changes of sea level from coastal onlap, in C. E. Payton, ed., Seismic Stratigraphy — Applications to Hydrocarbon Exploration, American Association of Petroleum Geologists Memoir 26, Tulsa, Oklahoma, p. 63-81.

Vail, P. R., Todd, R. G., and Sangree, J. B., 1977, Seismic Stratigraphy and Global Changes of Sea Level, Part 5: Chronostratigraphic Significance of Seismic Reflections, *in* Payton, C. E., ed., Seismic Stratigraphy – Application to Hydrocarbon Exploration, p. 99-116.

Vail, P. R., Mitchum, R. M., Jr., Todd, R. G., Widmier, J. M., Thompson, S., III, Sangree, J. B., Bubb, J. N., and Hatelid, W. G., 1977, Seismic Stratigraphy and Global Changes of Sea Level, *in* Clayton, C. E., ed., Seismic Stratigraphy-Applications to Hydrocarbon Exploration, American Association of Petroleum Geologists Memoir 26, p. 49-212.

Vail, P.R., 1987, Seismic stratigraphy interpretation procedure, in A.W. Bally, ed., Atlas of Seismic Stratigraphy, Studies in Geology No. 27, v. 1, American Association of Petroleum Geologists, Tulsa, Oklahoma, p. 1-10.

Van der Zwaan, G. J., F.J. Jorissen, and H.C. de Stigter, 1990, The depth dependency of planktonic/benthic foraminiferal ratios, Constraints and applications: Marine Geology, v. 95, p. 1-16.

Van der Zwaan, G.J., I.A.P. Duijnstee, M. den Dulk, S.R. Ernst, N.T. Jannink, and T.J. Kouwenhoven, 1999, Benthic foraminifers: proxies or problems? A review of paleoecological concepts, Earth-Science Reviews, v. 46, p. 213-236.

Wade, J.A. and B.C. MacLean. 1990. Aspects of the geology of the Scotian Basin from recent seismic and well data *in* Geology of the Continental Margin of Eastern Canada, Keen, M.J. and G.L. Williams (eds), Geological Survey of Canada Series, p. 190-238.

Wade, W. J., and Moore, C. H., 1993, Jurassic Sequence Stratigraphy of Southwest Alabama, Gulf Coast Association of Geological Societies Transactions, v. 43, p. 431-443.

Wilson, G.V., 1975, Early Differential Subsidence and Configuration of the Northern Gulf Coast Basin in Southwest Alabama and Northwest Florida, Gulf Coast Association of Geological Societies Transactions, v. 25, p. 196-206.

Winter, C.V., Jr., 1954, Pollard field, Escambia County, Alabama: Gulf Coast Association of Geological Societies Transactions, v. 4, p. 121-142.

Wood, M.L. and Walper, J.L., 1974, The Evolution of the Interior Mesozoic Basin and the Gulf of Mexico, Gulf Coast Association of Geological Societies Transactions, v. 24, p. 31-41.

Young, K., and Oloriz, F., 1993, Ammonites from the Smackover Limestone, Cotton Valley Field, Webster Parish, Louisiana, U.S.A., Geobios, v. 15, p. 401-409.