Oil & Natural Gas Technology

DOE Award No.: DE-FC26-03NT15395

Final Report

Basin Analysis and Petroleum System Characterization and Modeling, Interior Salt Basins, Central and Eastern Gulf of Mexico

Submitted by:
Department of Geological Sciences
Box 870338
University of Alabama
Tuscaloosa, AL 35487-0338

Prepared for:
United States Department of Energy
National Energy Technology Laboratory

January 16, 2009

Office of Fossil Energy

Report Title

Basin Analysis and Petroleum System Characterization and Modeling, Interior Salt Basins,
Central and Eastern Gulf of Mexico

Type of Report

Final Report

Reporting Period Start Date

May 1, 2003

Reporting Period End Date

April 30, 2008

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

June 30, 2008

DOE Award Number

DE-FC26-03NT15395

Name and Address of Participants

Ernest A. Mancini	Donald A. Goddard
Paul Aharon	Marty Horn
Dept. of Geological Sciences	Roger Barnaby
Box 870338	Center for Energy Studies
Univ. of Alabama	Louisiana State Univ.
Tuscaloosa, AL 35487-0338	Baton Rouge, LA 70803

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.

EXECUTIVE SUMMARY

The central and eastern Gulf Coastal Plain areas remain an under explored region containing sedimentary basins, such as the North Louisiana Salt Basin and Mississippi Interior Salt Basin, filled with a thick section of Mesozoic siliciclastic and carbonate deposits having a high potential for oil and gas accumulations in intermediate underdeveloped and deep (below 15,000 feet) undiscovered hydrocarbon reservoirs. In the U. S. Geological Survey study of the world's oil and gas provinces, the hydrocarbon volume of the North Louisiana and the Mississippi Interior Salt Basins ranked in the top 8% (33 out of 406) of the most petroliferous sedimentary basins in the world. Based on the USGS resource estimates and the production from these basins of over 5 billion barrels of oil and 43 trillion cubic feet of gas, billions of barrels of oil and trillions of cubic feet of gas remain to be recovered. The assessment of these undiscovered and underdeveloped resources and the design of effective exploration strategies to reduce the risks and costs associated with finding these domestic resources require sedimentary basin analysis and petroleum system characterization and modeling. Presently, a high percent of the hydrocarbon production in the Mississippi Interior Salt Basin is from deeply buried reservoirs below 15,000 feet; however, to date there is little production in the North Louisiana Salt Basin below 15,000 feet.

Therefore, The University of Alabama and Louisiana State University proposed to DOE this long-term, fundamental, regional research project to assist companies searching for oil and gas in the central Gulf Coastal Plain area. This is a cooperative 5-year project involving sedimentary basin analysis of the North Louisiana Salt Basin and petroleum system modeling of the Upper Jurassic Smackover lime mudstone petroleum source rock and related reservoirs.

The project consisted of two phases: Concept Development and Concept Demonstration. The principal research effort for Phase 1 (Concept Development) of the project was data compilation; determination of the tectonic, depositional, geohistory (burial history), and thermal maturation history of the North Louisiana Salt Basin; basin modeling (geohistory and hydrocarbon expulsion and hydrocarbon flow pathway modeling); petroleum system identification; comparative basin evaluation; and initial assessment of the undiscovered and undeveloped reservoirs and associated resources in the North Louisiana Salt Basin. The principal research effort for Phase 2 (Concept Demonstration) of the project was characterization of the Smackover petroleum system in the North Louisiana Salt Basin, characterization of the Upper Jurassic to Lower Cretaceous Bossier petroleum system, and refined assessment of the undiscovered and underdeveloped reservoirs and associated resources in the North Louisiana Salt Basin. Presentations of the results of this work have been made at the annual meetings of the American Association of Petroleum Geologists and Gulf Coast Association of Geological Societies. Technology transfer workshops have been conducted in Shreveport, Louisiana; Jackson, Mississippi; and Tuscaloosa, Alabama.

Existing information and new data resulting from this study on the North Louisiana Salt Basin have been integrated into an electronic database, and regional cross sections have been developed. Structure, isopach, erosional thickness, and formation lithology maps have been constructed, and geohistory (burial history), thermal maturation history, and hydrocarbon expulsion profiles have been prepared. Seismic data, cross sections, subsurface maps, and geohistory (burial history), thermal maturation history, hydrocarbon expulsion profiles, hydrocarbon flow pathway modeling, and organic geochemical data have been used in evaluating the tectonic, depositional, burial and thermal maturation histories of the basin.

The origin of the North Louisiana Salt Basin is comparable to the origin of the Mississippi Interior Salt Basin. The geohistory of these basins is directly linked to the evolution of the Gulf of Mexico. The timing of tectonic events and the nature of the structural styles control the type and size of petroleum traps formed and the volume of hydrocarbons contained within these traps. The dominant structural styles include salt-supported pillows, diapirs, anticlines, extensional faults, and half grabens and large regional Paleozoic domal basement structures, such as the Sabine and Monroe uplifts. These structural styles produced structural, combination structural and stratigraphic, and stratigraphic petroleum traps.

The main difference in the geohistories of the North Louisiana Salt Basin and the Mississippi Interior Salt Basin is the elevated heat flow the strata in the North Louisiana Salt Basin experienced in the Cretaceous due primarily to reactivation of basement faults resulting in upward movement, igneous activity, and erosion associated with the Monroe and Sabine uplifts. The Jackson Dome in the Mississippi Interior Salt Basin is a similar phenomenon, but the effects of this igneous intrusion are on a much lower level geographically.

The Upper Jurassic Smackover petroleum system is the principal petroleum system in these basins. The underburden, source, overburden, reservoir, and seal rocks associated with this petroleum system are a result of its rift-related geohistory. The Smackover lime mudstone generated hydrocarbons from Type IIS kerogen starting in the Early Cretaceous in the southern part of the North Louisiana Salt Basin and continuing into the Paleogene. Hydrocarbon expulsion and migration commenced during the Early Cretaceous and continued into the Paleogene. Vertical migration along faults and lateral migration along bedding planes, physical surfaces, and sequence boundaries are important to the productivity

of these basins. In the North Louisiana Salt Basin, petroleum reservoirs include continental, coastal, and marine sandstone facies and nearshore marine, shelf, ramp, and reef carbonate facies. Seal rocks include Upper Jurassic and Lower Cretaceous anhydrite and shale, Upper Cretaceous chalk and shale, and lower Paleogene shale.

The Upper Jurassic to Lower Cretaceous Bossier shale generated thermogenic gas from Type III kerogen. Siliceous beds in the Bossier serve as the reservoir rocks making the Bossier an unconventional petroleum system.

Potential undiscovered reservoirs in the North Louisiana Salt Basin are pre-rift subsalt Triassic Eagle Mills nonmarine sandstone and deeply buried Upper Jurassic to Lower Cretaceous transgressive aggrading and regressive infilling sandstone, shale, and limestone. Potential underdeveloped reservoirs include Lower Cretaceous regressive infilling sandstone and limestone and Upper Cretaceous transgressive backstepping sandstone.

Knowledge of basin geohistory and of the concepts of petroleum systems and sequence stratigraphy (transgressive-regressive sequences) facilitates the design of new exploration strategies for the targeting of potential combination structural and stratigraphic traps, potential stratigraphic traps, and specific facies with reservoir potential in a transgressive-regressive sequence. The Lower Cretaceous (Valanginian) and Upper Cretaceous (Cenomanian) unconformities and sequence boundaries have potential as stratigraphic traps throughout the North Louisiana Salt Basin area. In this basin, Upper Cretaceous sandstone reservoirs are recognized as transgressive backstepping facies in transgressive-regressive sequences that onlap onto the Monroe Uplift that serves as a combination structural and stratigraphic trap. Thermogenic gas is predicted to occur in Upper Jurassic to Lower Cretaceous transgressive aggrading sandstone facies and regressive infilling sandstone and carbonate facies that are deeply buried and exhibit depositional and diagenetic porosity. The

Bossier shale is identified as a potential unconventional gas reservoir as a result of petroleum system study.

The utilization of an integrated sequence stratigraphic framework, in conjunction with sedimentary basin analysis and petroleum systems study, has resulted in a refined assessment of potential petroleum reservoirs and associated resources in the North Louisiana Salt Basin. Potentially 67-115 trillion cubic feet of in-place thermogenic gas remains to be recovered in this basin from undiscovered and underdeveloped reservoirs, assuming a gas expulsion, migration, and trapping efficiency of 2-3%.

ABSTRACT

The University of Alabama and Louisiana State University have undertaken a long-term, fundamental, regional research project to assist companies searching for oil and gas in the central Gulf Coastal Plain area. This project was a cooperative 5-year effort involving sedimentary basin analysis of the North Louisiana Salt Basin and petroleum system modeling of the Upper Jurassic Smackover lime mudstone petroleum source rock and related reservoirs. The project consisted of two phases: Concept Development and Concept Demonstration. The principal research effort for Phase 1 (Concept Development) of the project was data compilation; determination of the tectonic history, depositional history, geohistory (burial history), and thermal maturation history of the North Louisiana Salt Basin; basin modeling (geohistory and hydrocarbon expulsion and hydrocarbon flow pathway modeling); petroleum system identification; comparative basin evaluation; and initial assessment of the undiscovered and undeveloped reservoirs and associated resources in the North Louisiana Salt Basin. Existing information and new data resulting from this project on the North Louisiana Salt Basin have been evaluated, an electronic database has been developed, and regional cross sections have been prepared. Structure, isopach, erosion thickness, and formation lithology maps have been constructed, and geohistory (burial history), thermal maturation history, hydrocarbon expulsion profiles, and hydrocarbon flow pathway models have been prepared. Seismic data, cross sections, subsurface maps and geohistory (burial history), thermal maturation history, hydrocarbon expulsion profiles, hydrocarbon flow pathway models, and organic geochemical data have been used in evaluating the tectonic, depositional, burial and thermal maturation histories of the basin. The principal research effort for Phase 2 (Concept Demonstration) of the project was characterization of the Smackover petroleum system in the North Louisiana Salt Basin,

characterization of the Upper Jurassic to Lower Cretaceous Bossier unconventional petroleum system, and refined assessment of the undiscovered and underdeveloped reservoirs and associated resources in the North Louisiana Salt Basin. Presentations of the results of this work have been made at the annual meetings of the American Association of Petroleum Geologists and Gulf Coast Association of Geological Societies. Technology transfer workshops have been conducted in Shreveport, Louisiana; Jackson, Mississippi; and Tuscaloosa, Alabama.

TABLE OF CONTENTS

	Page
Title	i
Disclaimer	ii
Executive Summary	iii
Abstract	viii
Table of Contents	x
Introduction & Background	1
Project Objectives	4
Data & Methodology	5
Results	19
Discussion	112
Conclusions	119
References	122
Appendix	143

**Basin Analysis and Petroleum System Characterization and Modeling,
Interior Salt Basins, Central and Eastern Gulf of Mexico
Final Report
May 1, 2003—April 30, 2008**

INTRODUCTION & BACKGROUND

The central and eastern Gulf Coastal Plain areas remain an under explored region containing sedimentary basins, such as the North Louisiana Salt Basin and Mississippi Interior Salt Basin, filled with a thick section of Mesozoic siliciclastic and carbonate deposits having a high potential for oil and gas accumulations in intermediate underdeveloped and deep (below 15,000 feet) undiscovered hydrocarbon reservoirs. In the U. S. Geological Survey study of the world's oil and gas provinces, the hydrocarbon volume of the North Louisiana and the Mississippi Interior Salt Basins ranked in the top 8% (33 out of 406) of the most petroliferous sedimentary basins in the world. Based on the USGS resource estimates and production from these basins of over 5 billion barrels of oil and 43 trillion cubic feet of gas, billions of barrels of oil and trillions of cubic feet of gas remain to be recovered. The assessment of these undiscovered and underdeveloped resources and the design of effective exploration strategies to reduce the risks and costs associated with finding these domestic resources require sedimentary basin analysis and petroleum system characterization and modeling. Presently, a high percent of the hydrocarbon production in the Mississippi Interior Salt Basin is from deeply buried reservoirs below 15,000 feet; however, to date there is little production in the North Louisiana Salt Basin below 15,000 feet.

Independent oil and gas companies, who account for some 50% of domestic oil production and some 65% of gas production, have developed into major players in

drilling new exploration wells, particularly in the onshore northern Gulf of Mexico. These companies do not have the research staffs or financial resources to conduct long-term, fundamental research, such as sedimentary basin analysis and petroleum system characterization and modeling in support of their exploration efforts. They realize, however, that the information and analysis resulting from these studies is beneficial in the design of effective exploration strategies. In addition, prior to 1996, no published reports on sedimentary basin analysis or petroleum system modeling studies were available on these basins. In 1996, DOE funded a 5-year study consisting of sedimentary basin analysis of the Mississippi Interior Salt Basin and petroleum system modeling of the Upper Jurassic Smackover lime mudstone source rock and related reservoirs. The data and analysis resulting from this work by The University of Alabama have been widely accepted and integrated into the exploration thinking of the producers operating in the eastern Gulf Coastal Plain area.

Therefore, The University of Alabama and Louisiana State University proposed to DOE this long-term, fundamental, regional research project to assist companies searching for oil and gas in the central Gulf Coastal Plain area. This cooperative 5-year project involving sedimentary basin analysis of the North Louisiana Salt Basin and petroleum system modeling of the Upper Jurassic Smackover lime mudstone petroleum source rock and related reservoirs will serve as a companion study to the study of the Mississippi Interior Salt Basin. The North Louisiana Salt Basin is bounded on the west by the Sabine Uplift and on the northeast by the Monroe Uplift (Fig. 1). The North Louisiana Salt Basin has a maximum sediment filled depth of 27,000 feet (Scardina, 1982).

A.

B.

Figure 1. Location of salt basins and index for wells for North Louisiana Salt Basin maps.

PROJECT OBJECTIVES

The principal objectives of the project, within a sequence stratigraphic framework, were to develop the concept that petroleum systems acting in a basin can be identified through basin analysis and to demonstrate that the information and analysis resulting from characterizing and modeling of the petroleum systems inherent to the North Louisiana Salt Basin and the Mississippi Interior Salt Basin can be used in providing a more reliable and advanced approach for targeting stratigraphic traps and potential reservoir facies and in providing a refined assessment of undiscovered and underdeveloped reservoirs and associated oil and gas resources. The project was designed to demonstrate the usefulness of using the concepts of sequence stratigraphy and petroleum systems in the formulation of exploration strategies, particularly in the identification of potential hydrocarbon reservoir facies and potential stratigraphic traps. Completion of this project has resulted in an increase of the amount of geoscientific information and analysis available on the interior salt basins of the northern Gulf of Mexico and the petroleum systems inherent to these basins. The data and analysis from this research has been made available to the petroleum companies operating in these basins and to the public through information dissemination and technology transfer. The results of this project have the potential to contribute to national and state economies and to national security by increasing the domestic supplies of oil and gas through more discoveries.

DATA & METHODOLOGY

Data Compilation

Existing data and new information and analysis resulting from the completion of this project on the North Louisiana Salt Basin have been integrated into an electronic database that is available to the petroleum industry, government agencies, and the public. All figures and tables generated by the researchers on this project from existing data and from new information and analysis resulting from this project, are included in the Appendix, and certain figures and tables are included in the text. Selective seismic reflection data (Fig. 2) have been studied as part of this project. Representative oil and gas well logs (141) were digitized as a task of this project and were utilized in the construction of 11 regional stratigraphic cross sections for the North Louisiana Salt Basin (Fig. 1). The digitized well logs, which are available to the industry and public, have been used, in combination with the seismic data, to construct these cross sections (Figs. 3-13) for the basin using PETRA software. Subsurface (structure, isopach, erosion thickness, and formation lithology) maps (Figs. 14-40) have also been prepared using these well logs. Samples taken from cores from wells drilled in this basin were used in the characterization of the petroleum source rocks to assist with the determination as to the source rocks that generated the oil and gas occurring in the North Louisiana Salt Basin (Table 1).

Seismic profiles and well log data have been used in constructing the cross sections and geohistory (burial history) (Figs. 41-82) profiles. Present day heat flow values (Fig. 83), lithospheric stretching beta factors (Fig. 84), measured and calculated vitrinite reflectance values (Figs. 85-86), and a transient heat flow model were used in preparing

the thermal maturation profiles (Figs. 87-128) and hydrocarbon expulsion profiles (Figs. 129-170). Geohistory (burial history) (Figs. 171-219), thermal maturation history (Figs. 220-267), and hydrocarbon expulsion profiles (Figs. 268-312) were prepared for strata in the Mississippi Interior Salt Basin using the same methodologies as was used for strata in the North Louisiana Salt Basin, and geohistory (burial history) (Figs. 313-316), thermal maturation history (Figs. 317-320), and hydrocarbon expulsion profiles (Figs. 321-324) were prepared for the North Louisiana Salt Basin using a rift heat flow model for comparison purposes.

Tectonic History

Researchers on this project used the 141 digitized well logs, 11 cross sections, and selective seismic profiles in making interpretations regarding the tectonic history of the North Louisiana Salt Basin and the structural styles and nature of the petroleum traps inherent to this basin. Also, structure maps (Figs. 14-16), isopach maps (Figs. 17-19), an erosional thickness map for the Lower Cretaceous section (Fig. 20), formation lithology maps (Figs. 21-40), and geohistory (burial history) profiles (Figs. 41-82) have been constructed to assist with the reconstruction of the tectonic history of this basin.

Depositional History

Researchers on this project used the digitized well logs, cross sections, and selective seismic profiles in making interpretations regarding the depositional history of the North Louisiana Salt Basin and the depositional systems, facies associations, and unconformities inherent to this basin. Also, isopach maps, an erosional thickness map for the Lower Cretaceous section, formation lithology maps, and geohistory (burial history) profiles have been constructed to assist with the reconstruction of the depositional history

of this basin. Cores from wells that penetrated Jurassic strata have been studied to assist with the interpretations of the geohistory of the basin. An integrated biostratigraphic and sequence stratigraphic classification was used as a framework for this interpretation (Fig. 325).

Geohistory (Burial History)

Researchers on this project used the 141 digitized well logs in making interpretations regarding the geohistory of the North Louisiana Salt Basin and assisting with the identification of the potential petroleum systems that are active in this basin. Geohistory (burial history) profiles were constructed for each of the 141 wells using Platte River BasinMod[®] 1D software and representative geohistory (burial history) profiles (Figs. 41-82) have been included in the Appendix.

Critical to interpreting the geohistory of a basin is establishing a stratigraphic framework. For this project, we constructed an integrated biostatigraphic and sequence stratigraphic framework, based on transgressive-regressive sequences (Figure 325). Other crucial factors in developing geohistory (burial history) profiles involve knowledge of the geologic age, thickness, lithology, and petrophysical properties of the stratigraphic units studied, stratigraphic unit tops, the water depth at the time of unit deposition, the amount of sediment compaction, and the stratigraphic level of unconformities and duration of associated hiatuses.

The Mesozoic to Cenozoic stratigraphic section in the North Louisiana Salt Basin ranges in age from Triassic through Neogene. The section was subdivided into unit intervals, including depositional events represented by stratigraphic units, depositional hiatuses (Middle Jurassic, 195-176 Ma, and Early Cretaceous, 136-133 Ma), and

sediment erosion surfaces or unconformities (three in the Late Cretaceous, 97-95 Ma, 90-88 Ma, and 72-70 Ma, and one in the early Paleogene, 58-52 Ma). The geological time scale of Gradstein et al. (1995) was used with formation ages being compiled from Mancini and Tew (1991), Mancini and Puckett (2002, 2003a), and Mancini et al. (2004). Surfaces that represent the base and top of each of the unit intervals were correlated throughout the study area for the 141 wells. These stratigraphic picks were based on accepted industry correlations and modified according to our interpretations based on extrapolations from subsurface and surface data.

Basin analysis requires reconstructing the thickness of sediments that were deposited and subsequently uplifted and eroded. In the North Louisiana Salt Basin area, adjustments needed to be made regarding reactivation of the Sabine and Monroe uplifts. The Sabine and Monroe uplifts were first reactivated in the Early Cretaceous and again in the Cenomanian due to tectonic compression during Cordilleran thrust faulting in Western North America (Jackson and Laubach 1988; Laubach and Jackson 1990). Uplift and erosion persisted throughout the Late Cretaceous and early Paleogene (Jackson and Laubach 1988; Laubach and Jackson 1990; Ewing 1991). On the Sabine Uplift, movement occurred as recently as the early Eocene due to arching associated with the Laramide orogeny (Jackson and Laubach 1988; Laubach and Jackson 1990). Significant erosion due to uplift in the Cenomanian through Maastrichtian is indicated by updip stratal truncation of Cretaceous strata on the Monroe Uplift. Erosion incised down to the lower part of the Lower Cretaceous section on this uplift. On the Sabine Uplift, updip stratal truncation is more subtle, and maximum erosion incised into the upper part of the Lower Cretaceous section.

To estimate the original depositional thickness of the Lower Cretaceous prior to Cenomanian erosion, we projected thickness trends of the truncated Lower Cretaceous units across the Sabine and Monroe uplifts. Our estimation of erosion of Lower Cretaceous strata of 200-600 feet compares favorably with that of Zimmerman (1999).

Updip thinning of Upper Cretaceous strata onto the Monroe Uplift is interpreted to reflect as much as 7,200 feet of episodic post mid-Cenomanian erosion, and this interpretation is consistent with the estimates of Zimmerman (1999). The youngest erosional event recorded on this uplift is early Paleogene. Updip stratal thinning of up to 600 feet as a result of erosion is interpreted for this area. This estimation is consistent with previous interpretations by Zimmerman (1999). Although erosion in the Middle Jurassic and Lower Cretaceous (Valanginian) is significant, a lack of well control precluded mapping of the extent of erosional incision. Therefore, these events were included as depositional hiatuses rather than as an unconformity or sediment erosion surface in this study.

Geohistory (burial history) profiles were reconstructed from present-day sediment thickness after correcting for the effects of compaction. Modeled compaction is mechanical and resulted from sediment loading. The maximum estimated water depths in north Louisiana during the Jurassic through Paleogene were approximately 300 to 450 feet (Zimmerman 1998), so the effects of water loading on burial were not significant. The sediment column was corrected for compaction using BasinMod[®] 1D software. Because the lithology of stratigraphic units is generally not uniform but rather exhibits spatial variation due to lateral facies changes, reconstruction of the geohistory (burial history) requires knowledge of the lithology for each stratigraphic unit at each well

location. For the siliciclastic units, the digitized SP log curve was used to quantitatively calculate V_{shale} . The SP curve was normalized for baseline drift, and V_{shale} was calculated from the normalized SP curve by assuming that maximum SP deflection is 0 percent shale (100 percent sandstone) and that minimum SP deflection was 100 percent shale. For the carbonate and evaporite units, the lithology at each well location was based on qualitative interpretation of the SP and resistivity log response, supplemented by published lithology maps, such as those of Zimmerman (1999).

Sediment accumulation rates and subsidence rates were determined using BasinMod[®] 1D software.

Thermal Maturation History

Researchers on this project used the digitized well logs in making interpretations regarding the thermal maturation history of the North Louisiana Salt Basin and in assisting with the identification of the potential petroleum systems that are active in this basin. Thermal maturation history profiles were constructed for each of the 141 wells using BasinMod[®] 1D software and representative thermal maturation history profiles based on a transient heat flow method (Figs. 87-128) and based on a rift heat flow method (Figs. 313-316). These profiles are included in the Appendix. Data and information utilized in this characterization include: corrected bottom hole temperature (BHT), thermal conductivities of rock units, geothermal gradient values, present-day heat flow values, paleoheat flow values, vitrinite reflectance values, thermal alteration index (TAI) values, Rock-Eval pyrolysis data, measured and original total organic carbon (TOC) contents, and kerogen types. Core samples in potential source rock facies were

used for organic geochemical analysis (Table 1) to be used in source rock evaluation and in thermal maturation characterization and modeling.

For each well, the bottom hole temperatures were recorded from the log header. Because logging companies keep the logging tool at the bottom of the well bore for an insufficient period of time after circulation is stopped, the measured bottom hole temperatures typically underestimate true formation temperatures. Because data are not available to apply Horner-type analysis, an empirical depth-based correction factor for Louisiana Gulf Coast wells was applied after Bebout (1978). The surface temperature was held constant at 20° C., based on shallow groundwater temperatures in north Louisiana. These corrected bottom hole temperatures were consistent with those published by Eversull (1984) for the wells studied.

The corrected bottom hole temperatures were used to determine the present-day geothermal gradients. The calculated geothermal gradients show a range of 11 to 43° C /km with an average geothermal gradient of 31° C /km. These values are in agreement with those reported by Smith et al. (1981) for the north Louisiana area.

The in-situ thermal conductivity of each stratigraphic unit was calculated at each well location using the equation:

$$k_{\text{in-situ}} = k_w^{\phi} \cdot k_{mT}^{1-\phi}$$

of Deming and Chapman (1989), where ϕ is porosity calculated using lithology-dependent compaction curves; k_w is thermal conductivity of the pore water calculated by assuming that the pore fluid is seawater using the methodology of Deming and Chapman (1989); T is the in-situ temperature (°K); and k_{mT} is the matrix conductivity calculated for the in-situ temperature using the relation:

$$k_{mT} = k_m^0 - \exp(C/T - C/T_0),$$

where T_0 = standard temperature (273° K); T = calculated temperature; k_m^0 = initial matrix thermal conductivity at T_0 ; and C = matrix thermal conductivity temperature correction factor.

The initial matrix thermal conductivities of pure end-member lithologies (sandstone, shale, limestone, evaporite) are from the BasinMod® 1D default values. The initial matrix thermal conductivity of each mixed lithology was calculated from the harmonic average of the pure end-member lithologies. The matrix thermal conductivity temperature correction factors for pure end-member lithologies are from the BasinMod® 1D default values, and for mixed lithologies, they are calculated using a weighted arithmetic average.

Modeled heat flow was determined assuming 1-D steady state heat flow at the model base with heat transfer from thermal conduction. Calculated heat flow values range from 37-62 mW/m². Spatial variability is expressed with higher heat flows in the area of the North Louisiana Salt Basin and to the adjacent areas to the north and west (Fig. 83). The lowest heat flow values occur in the southeast part of the study area where the youngest sediments were deposited. It is difficult to directly compare the heat flow values calculated in this study with those published by Smith et al. (1981) and Smith and Dees (1982) because of the different methodology used (based on precise measurement of temperature and thermal conductivity values from shallow boreholes) and because they present data from only 15 wells in north Louisiana. Their reported values tend to be somewhat higher than the values we determined, ranging from 46-83 mW/m² (Smith et al. 1981; Smith and Dees 1982).

The higher heat flow values in the North Louisiana Salt Basin and adjacent areas probably reflect the presence of salt intrusions, given that salt has a higher thermal conductivity compared to sediments. The lower heat flow values in the southeast part of the study area indicate suppression of heat flow values by more recent sedimentation. The calculated heat flow and the calculated in situ thermal conductivity values were used to model the present-day thermal gradient for each well. The geothermal gradient is the change in temperature with change in depth. Comparison of the modeled temperature profile with measured bottom hole temperatures allows assessment of the internal consistency of the calculated thermal conductivity and heat flow. A sensitivity analysis of compaction and thermal conductivity parameters was performed to optimize fit between measured and calculated temperatures.

To evaluate the thermal history, it is necessary to consider not only the present-day heat flow but also to evaluate paleoheat flow. In a passive margin setting such as the present-day Gulf Coast of Louisiana, a minimum estimate of paleoheat flow can be derived by assuming constant heat flow through time and projecting the present-day heat flow throughout the geological past. An upper limit on paleoheat flow can be estimated using the BasinMod[®] 1D rift heat flow option, which is a modification of the model of Jarvis and McKenzie (1980). According to this model, attenuation of the lithosphere during rifting results in increased heat flow, followed by a subsidence phase with exponential decay of heat flow.

Paleoheat flow in the rifting model is impacted by the timing and duration of rifting, the amount of lithospheric attenuation, and present-day heat flow. Rifting of continental crust began in the Late Triassic and continued through Early Jurassic, and stretching of

the thick transitional crust to form the North Louisiana Salt Basin probably extended into the Middle Jurassic (Buffler, 1991). The modeled timing of rifting is 210 to 170 Ma. The lithosphere beneath north Louisiana was moderately attenuated during rifting, the rift beta factor in north Louisiana is approximately 1.25-1.50, increasing to 2.00 in central Louisiana (Fig. 84) (Dunbar and Sawyer 1987). For modeling, the original lithospheric thickness is assumed to have been 120 km, typical of unrifted continental values.

Different rift beta factors have an impact on paleoheat flow and impacted the thermal history of the Smackover source rocks. Comparing the temperature profile for a beta factor of 1.0 (no rifting) with other beta factors, the temperature varies by as much as 15°C in the early part of the burial history although the starting and end points remain the same. Because organic maturation depends on the temperature to which the source rock was heated and the duration of the heating, different heat flow regimes may impact both final organic maturity and the timing of maturation.

Thermal maturity is based on the analysis of the thermal alteration index (TAI) and vitrinite reflectance (%R₀) values. TAI values were converted to %R₀ values using the relationship of Dow (1977) and conversion relationships in the BasinMod[®] 1D software. A plot of the %R₀ values versus depth shows no well-defined relationship due to the different sample ages and burial histories of the wells (Fig. 85).

Thermal maturity expressed as %R₀ was calculated from the kinetic model for standard Type IIS marine kerogen with the default kinetic parameters. Measured TAI data, converted to %R₀, were compared with modeled values. Comparison of the modeled %R₀ with measured values indicates considerable scatter (Fig. 86). A least

squares fit, however, indicates a 1:1 relationship demonstrating that the overall model is reasonable and does not consistently overestimate or underestimate thermal maturity.

Although the modeling demonstrates that there is little difference in the final thermal maturity determined using various heat flow models, a major difference in the timing of organic maturation results using different heat flow models. The rift heat flow model (Figs. 313-316) predicts thermal maturation up to 20 to 30 my before thermal maturation based on a transient heat flow model (Figs. 108 and 112). A transient heat flow method of modeling was used in this study.

Total organic carbon (TOC) values for the potential source rocks analysed were highly variable ranging from <0.1 to 4.09%. For samples that experienced advanced levels of thermal maturity based on their kerogen type (amorphous, microbial, herbaceous, and woody) and TAI or % R_0 factors, the method of Daly and Edman (1987) for thermal maturation modeling was used to adjust for the loss of total organic carbon due to the thermal maturation process. The results show that the original TOC was reduced by 1.5 to 1.8 times for Smackover lime mudstone samples.

Rock-Eval pyrolysis analysis indicates that the hydrogen index for the samples ranges from 0 to 942 mg HC/g TOC, and S_2 values range between 0 and 2.71 mg HC/g of the rock. Most samples, however, have values that reflect an advanced level of thermal maturation. T^{max} is not a useful indicator for thermal maturity for those samples with low S_2 values.

Basin Modeling & Petroleum System Identification

Researchers on this project used the digitized well logs, cross sections, selective seismic sections, structure maps, isopach maps, geohistory (burial history) profiles,

thermal maturation history profiles, organic geochemical analyses for potential source rocks, hydrocarbon expulsion profiles (Figs. 129-170 and 321-324), and hydrocarbon flow modeling (Figs. 326-328) to assist with the basin modeling and petroleum system identification in the North Louisiana Salt Basin. Hydrocarbon flow pathways were modeled using IES PetroMod[®] 2D software. We included the information from figures from Buffler (1991) (Fig. 329) and MacRae and Watkins (1996) (Fig. 330) for reference in this study.

Comparative Basin Geohistory Evaluation

Researchers on this project used the data and information (well logs, cross sections, selective seismic sections, and organic geochemical analyses) resulting from our previous study of the Mississippi Interior Salt Basin in comparing the North Louisiana Salt Basin to this basin (Table 2). We did, however, prepare new geohistory (burial history) profiles (Figs. 171-219), new thermal maturation history profiles (Figs. 220-267), and new hydrocarbon expulsion profiles (Figs. 268-312) using the methodology employed in this study of the North Louisiana Salt Basin to insure consistency of comparison of these two basins. We also prepared thermal maturity profiles for these basins (Fig. 331).

Reservoir and Resource Assessment

Researchers on this project compiled the historical production by oil and gas reservoirs for the North Louisiana and Mississippi Interior Salt Basins from state regulatory agencies and other sources (Table 3). We also made a compilation of the physical and petrophysical properties of these reservoirs (Table 4). Based on a comparison of the producing reservoirs and their characteristics for each of these basins,

we made interpretations as to prospective reservoirs and associated resources for the North Louisiana and Mississippi Interior Salt Basins.

Upper Jurassic Smackover Petroleum System

Researchers on this project used the digitized well logs, cross sections, selective seismic sections, structure maps, isopach maps, geohistory (burial history) profiles, thermal maturation history profiles, hydrocarbon expulsion profiles, hydrocarbon flow pathway modeling, additional organic geochemical analyses (Table 5), the results from the basin modeling in the North Louisiana Salt Basin, and the results from the comparative basin geohistory evaluation for the North Louisiana and Mississippi Interior Salt Basins to characterize and model the Upper Jurassic Smackover petroleum system (Fig. 332).

Lower Cretaceous/Upper Jurassic Bossier Petroleum System

Researchers on this project used the digitized well logs, cross sections, selective seismic sections, additional organic geochemical analyses for Bossier and Cotton Valley shale units, geochemical comparative study, a geohistory (burial history) profile, a thermal maturation history profile, a hydrocarbon expulsion profile, hydrocarbon flow pathway modeling, the results from the basin modeling in the North Louisiana Salt Basin, and the results from the comparative basin geohistory evaluation for the North Louisiana and Mississippi Interior Salt Basins to characterize and model the Lower Cretaceous/Upper Jurassic Bossier petroleum system (Tables 6-10 and Figs. 333-354).

Refined Reservoir and Resource Assessment

Researchers on this project used the compilation of the historical production by oil and gas reservoirs for the North Louisiana and Mississippi Interior Salt Basins from state

regulatory agencies and other sources and the compilation of the physical and petrophysical properties of these reservoirs, in combination with the results from the characterization and modeling of the Smackover and Bossier petroleum systems, in making additional interpretations as to prospective reservoirs and associated resources for the North Louisiana and Mississippi Interior Salt Basins. We used Platte River BasinMod 1D[®] and BasinView[®] software applications to estimate the in-place thermogenic gas resource available for recovery from potential reservoirs in the North Louisiana Salt Basin. This method of resource assessment is discussed in our 2006 DOE report. This refined reservoir and resource assessment is presented in a sequence stratigraphic framework (Tables 11-12).

Technology Transfer Workshops

Researchers on this project presented technology workshops on the results of this research to the industry and the public in the central and eastern Gulf Coastal Plain areas (Shreveport, Louisiana; Jackson, Mississippi; and Tuscaloosa, Alabama) and at regional (Gulf Coast Association of Geological Societies) and national (American Association of American Petroleum Geologists) geoscientific meetings.

Technical Reports

Researchers on this project submitted the required DOE technical reports and published papers on the results of this research in regional (Transactions of the Gulf Coast Association of Geological Societies and national journals (Bulletin of the American Association of American Petroleum Geologists).

RESULTS

Tectonic History

In using information and data resulting from this study, such as digitized well logs, cross sections, selective seismic profiles, structural maps, isopach maps, an erosional thickness map for the Lower Cretaceous section, formation lithology maps, geohistory (burial history) profiles, and core data, in combination with the published literature on the North Louisiana Salt Basin, researchers on this project have determined that the origin of the North Louisiana Salt Basin is directly linked to the evolution of the Gulf of Mexico. The Gulf of Mexico is a divergent margin basin characterized by extensional rift tectonics and wrench faulting (Pilger, 1981; Miller, 1982; Klitgord, et al., 1984; Van Siclen, 1984; Pindell, 1985; Salvador, 1987; Winker and Buffler, 1988; Buffler, 1991). The history of the basin includes a phase of crustal extension and thinning, a phase of rifting and sea-floor spreading, and a phase of thermal subsidence (Nunn, 1984). Rifting was in a northwest-southeast direction; however, early rifting may have been north-south (Pilger, 1981; MacRae and Watkins, 1996). The Gulf has been interpreted as opening by right lateral translation and with movement of the Yucatan block playing a major role in the opening (Van Siclen, 1984; Buffler and Sawyer, 1985). The structural and stratigraphic framework of the region was established during the Triassic and Jurassic (Salvador, 1987).

Two periods can be recognized in the evolution of the region: active rifting lasting from the Late Triassic to Middle Jurassic represented by the deposition of nonmarine siliciclastic sediments (red beds) and associated volcanics in rapidly subsiding grabens and the accumulation of thick salt deposits and prolonged crustal cooling and subsidence

from the Late Jurassic into the Cretaceous (Salvador, 1991a). In the Gulf, oceanic crust is surrounded by attenuated continental crust (Winker and Buffler, 1988) (Fig. 329). The transition from continental crust (predated the formation of the Gulf of Mexico and has not been significantly modified) to thick transitional crust (extended, thinned and/or intruded as a result of rifting) corresponds to a regional hinge zone or flexure in the basement and approximates the updip limit of Louann Salt deposition (Sawyer et al., 1991). The boundary is defined as a series of faults, including the Bahamas Fracture Zone offshore and regional peripheral fault trend onshore (Winker and Buffler, 1988; Sawyer et al., 1991). Alignment of these fault systems indicates a large-scale, left-slip series of transform and wrench faults that were active during the Late Triassic to Early Jurassic rift phase and the Middle Jurassic to Late Jurassic opening of the Gulf of Mexico (Sawyer et al., 1991). The transition from thick transitional crust to thin transitional crust corresponds to a major tectonic hinge zone in the basement and approximates the Lower Cretaceous shelf margin (Sawyer et al., 1991). The boundary is defined by the Cuba Fracture Zone and Pearl River Transfer Fault (Dobson and Buffler, 1991; MacRae and Watkins, 1996). Within the zone of thick transitional crust, a pattern of alternating relict basement highs and lows occurs which represents areas of greater or lesser attenuation (Winker and Buffler, 1988) (Fig. 330). The paleotopographic highs are interpreted to be continental blocks that are relicts of rifting that have rotated counterclockwise and have not experienced much extension or internal deformation (Sawyer et al., 1991). The lows would be depressions in the basement that formed due to greater crustal extension between these continental blocks (Sawyer et al., 1991). An example of a relict high is the

Figure 329. Distribution of crustal types and depth to basement in the Gulf of Mexico basin. Depth to basement is in kilometers (modified from Buffler, 1991).

Figure 330. Tectonic framework of part of the northern Gulf of Mexico region (modified from MacRae and Watkins, 1996).

Wiggins Arch and examples of basement lows that acted as depocenters are the Mississippi Interior Salt Basin and North Louisiana Salt Basin.

Based on the distribution of crust type, Sawyer et al. (1991) proposed the following as a model for the evolution of the Gulf of Mexico and related Mississippi Interior Salt Basin and North Louisiana Salt Basin. A Late Triassic-Early Jurassic early rifting phase is characterized by large and small half-grabens bounded by listric normal faults and filled with nonmarine siliciclastic sediments (red beds) and volcanics. A Middle Jurassic phase of rifting, crustal attenuation and the formation of transitional crust is characterized by the evolution of a pattern of alternating basement highs and lows and the accumulation of thick salt deposits. A Late Jurassic phase of sea-floor spreading and oceanic crust formation in the deep central Gulf of Mexico is characterized by a regional marine transgression as a result of crustal cooling and subsidence. Subsidence continued into the Early Cretaceous and a carbonate shelf margin developed along the tectonic hinge zone of differential subsidence between thick and thin transitional crust. This pattern of deposition was broken by a period of igneous activity and global sea-level fall during the Late Cretaceous (mid-Cenomanian) that produced a major lowering of sea level in the region and resulted in the exposure of the shallow Cretaceous platform margin that rimmed the Gulf (Salvador, 1991b). This mid-Cenomanian unconformity is most pronounced in the northern Gulf of Mexico area.

The Mesozoic and Cenozoic strata of the northeastern Gulf of Mexico were deposited as part of a seaward-dipping wedge of sediment that accumulated in differentially subsiding basins on the passive margin of the North American continent. Basement cooling and subsidence resulted in a progressive infilling of the

accommodation space throughout the Jurassic, Cretaceous, and Paleogene. Structural elements that affected the general orientation of these strata include basement features associated with plate movement and features formed due to halokinesis of Jurassic salt. The basement surface is dissected by the regional basement rift system that consists of a rift-related trend of divergent wrench-type basement faults and associated grabens and half grabens (Mink et al., 1990; Tew et al., 1991). The major basement faults are the northwest-southeast trending Florida-Bahamas and Pearl River transfer faults. The graben system is a result of rifting and its geometry is a reflection of the direction of plate separation (MacRae and Watkins, 1996). The Lower Cretaceous shelf margin that corresponds to a major basement hinge dominated carbonate deposition throughout the Early Cretaceous.

The major positive basement features that influenced the distribution and nature of Mesozoic deposits in the northern Gulf of Mexico are the Sabine Uplift, Monroe Uplift, Wiggins Arch, Middle Ground Arch-Southern Platform, Choctaw Ridge, the Conecuh Ridge, the Pensacola Arch, and the Decatur Ridge. These structural elements, such as the Choctaw, Conecuh, Pensacola, and Decatur Ridge complexes, are associated with the Appalachian fold and thrust structural trend that was formed in the late Paleozoic by tectonic events resulting from convergence of the North American and African-South American continental plates. The Sabine Uplift, Monroe Uplift, Wiggins Arch and Middle Ground Arch-Southern Platform are associated with crustal extensional and rifting (Miller, 1982; Sawyer et al., 1991). These basement features may be remnants of the rifted continental margin of North America. The Wiggins Arch consists of pre-rift

Paleozoic metamorphic and granitic rocks (Cagle and Khan, 1983) and the Middle Ground Arch includes pre-rift Paleozoic and Triassic rocks (Dobson, 1990). The Middle Ground Arch is a broad structural nose that plunges southwest toward the Southern Platform (Dobson, 1990). Paleotopography had a significant impact on the distribution of sediment, and positive areas within basins and along basin margins provided sources for Mesozoic terrigenous sediments (Mancini et al., 1985). The East Texas Salt Basin, North Louisiana Salt Basin, Mississippi Interior Salt Basin and the Apalachicola-De Soto Canyon Salt Basin, which are major negative structural features in the northern Gulf of Mexico, are classified as the interior fracture portion of a margin sag basin using the classification of Kingston et al. (1983). These extensional basins were associated with early rifting linked with wrench faulting and were actively subsiding depocenters throughout the Mesozoic and into the Cenozoic.

Most, but not all, of the salt movement related structural features recognized in the North Louisiana Salt Basin today developed during the Late Jurassic to Late Cretaceous. However, rejuvenated movements of the Louann Salt occurred in some parts of the basin in the early part of the Paleogene. In general, following the deposition of the Louann Salt, the basin underwent a prolonged gradual subsidence and loading that was only interrupted occasionally by episodes of sub-regional uplift and erosion.

The tectonic history of the North Louisiana and Mississippi Interior Salt Basins records two major events characterized by unique dominant structural styles. These include extensional rift tectonics and wrench faulting and halokinesis. These structural styles produce the majority of the known petroleum traps inherent to these interior salt basins. Reactivation of Paleozoic basement faults along pre-rift horst blocks, such as the

Wiggins, Sabine, and Monroe uplifts, and related igneous activity, such as that associated with the Monroe Uplift and Jackson Dome, have produced paleohighs, which serve as combination stratigraphic and structural petroleum traps. Reservoirs associated with these traps are commonly fractured. Salt movement produced an array of petroleum traps, including pillows, diapirs, anticlines, and extensional faults and half graben systems, such as the State Line fault system along the northern rim of the North Louisiana Salt Basin. The State Line fault system occurs near the updip limit of thick salt and generally defines the northern boundary of the basin. Fault systems, such as this, are regional features and are developed along the northern periphery of the thick salt basins in the eastern Gulf (Mancini et al., 1999). The Pickens and Gilbertown fault systems are two of these extensional fault systems found in the eastern Gulf. These normal faults are characterized as listric, down to the basin features. In addition, potential pre-salt petroleum traps may consist of half grabens and grabens bounded by listric faults. These half grabens and grabens are filled with Late Triassic to Early Jurassic nonmarine siliclastic deposits, which have potential as undiscovered reservoirs.

Salt tectonics became an early integral part of the basin during the Late Jurassic with both lateral and vertical salt movement occurring. The evolution of salt structures originating from bedded salt (Louann) into vertical salt stocks involved pillow, diaper, and piercement structures with their associated concomitant concentric structural lows being filled with sediments (Kupfer et al., 1976; Lobao and Pilger, 1985). Kupfer et al. (1976) and Lobao and Pilger (1985) concluded that the major time of salt dome growth occurred during the Late Jurassic and continued into the Early Cretaceous with lesser movement in the Late Cretaceous and early Paleogene. Further, we (Fig. 2) and Lobao

Figure 2. Cross sections from seismic data.

and Pilger (1985) have found that there was a greater intensity and more rapid growth in diapirs located in the southern and central parts of the basin when compared to the intensity and growth of diapirs located in the north during their major development in the Early Cretaceous. Along with the initiation of vertical (and lateral) salt movement, major extensional faults formed on the northern rim of the basin.

Depositional History

In using an integrated biostratigraphic and sequence stratigraphic framework (Fig. 325) and information and data resulting from this study, such as digitized well logs, cross sections, selective seismic profiles, isopach maps, an erosional thickness map for the Lower Cretaceous section, formation lithology maps, geohistory (burial history) profiles, and core data, in combination with the published literature on the North Louisiana Salt Basin, researchers on this project have prepared a tabulation of the environments of deposition of the hydrocarbon producing units in the north Louisiana Salt Basin (Table 4). This table also includes the petrophysical properties of these units. Figure 325 shows the transgressive-regressive systems tract and facies association assignments of these units. This figure also depicts the potential petroleum source and seal rock units.

Sedimentation in the northern Gulf of Mexico was associated with rifted continental margin tectonics resulting from the breakup of Pangea and the opening of the Gulf of Mexico according to the researchers on this project. Triassic graben-fill red beds were deposited locally as the oldest Mesozoic strata above pre-rift Paleozoic basement during the early stages of extension and rifting (Tolson et al., 1983; Dobson, 1990); and therefore, the starting point for sediment accumulation in the North Louisiana Salt Basin begins with Late Triassic terrestrial deposition in a structural crustal extensional setting.

Figure 325. Sequence stratigraphy of the North Louisiana Salt Basin.

Table 4. Sedimentary and petrophysical characteristics of the reservoirs in the onshore interior salt basins and subbasins, central and eastern Gulf Coastal Plain

Reservoir	Lithology ¹	Environment ²	Porosity (%) ³	Permeability (md)
Wilcox	SS	FD	15–35	200–600
Arkadelphia/Monroe Gas Rock	CK	NS, MS	5–25	1–500
Selma/Jackson Gas Rock	CK	MS	5–18	1–500
Nacatoch	SS	NS	20–28	200–2,500
Ozan	SS	NS	20–33	100–1,000
Tokio	SS	NS	20–35	200–450
Eutaw	SS	T, NS, MS	13–39	1–5,470
Tuscaloosa	SS	FD, C, MS	25–30	200–2,000
Dantzler	SS	FD	25–30	50–150
Fredericksburg	SS, LS	NS, MS, R	10–30	1–150
Paluxy	SS	F, NS, MS	24–30	150–600
Mooringsport	SS, LS	NS, MS, R	10–20	10–500
Rodessa	SS, LS	NS, MS, R	10–26	10–650
James	LS	NS, MS, R	10–15	1–100
Pine Island	SS	NS	10–15	10–200
Sligo	SS, LS	NS, MS, R	16–20	9–100
Hosston	SS	FD, NS, DM	10–26	10–250
Cotton Valley	SS, LS	FD, NS, R	9–18	1–300
Haynesville	SS, LS	F, NS, R	9–16	50–400
Smackover	LS	CR, R	11–22	1–100
Norphlet	SS	E, F	3–20	1–890

¹ Lithology: SS = sandstone, LS = limestone, CK = chalk.

² Environment: E = eolian, F = fluvial, FD = fluvial-deltaic, C = coastal, T = tidal, NS = nearshore marine, MS = marine shelf, DM = deep marine, CR = carbonate ramp, R = reef.

³ Reservoir porosity and permeability data are from published field studies files of the regulatory agencies and geological surveys, and Goddard (2006), Quick look handbook onshore Louisiana petroleum producing formations (unpublished).

Evolving grabens were filled with red bed sequences of fluvial and freshwater lake sediments and deposition remained active during the early part of the Early Jurassic. This initial cycle of deposition culminated with the Upper Triassic-Lower Jurassic Eagle Mills Formation (Salvador, 1987). The Eagle Mills red bed deposits contain conglomeratic sandstones and red shales with diabase pebbles (Scott et al., 1961). These Eagle Mills terrestrial strata are positioned as the pre-rift deposits of the overlying Middle Jurassic Werner and Louann evaporites that were laid down on the rifted, trailing plate margin of North America (Zimmerman, 1992). Following the deposition of the Eagle Mills in the Early Jurassic, the North Louisiana Salt Basin underwent continental crust attenuation. Subsequently, Middle Jurassic rifting occurred in central north Louisiana. The rifting provided a 19 million year period in which a hiatus in the depositional record developed as a result of non-deposition and/or erosion across the area.

In southern Arkansas, northern Louisiana, and adjacent parts of Texas and Mississippi, the Werner Anhydrite predominantly composed of anhydrite, commonly associated with conglomerates and red siliciclastics at the base, underlies the Louann Salt. This underlying Werner-Louann sequence unconformably overlies the Eagle Mills Formation or Paleozoic basement rocks, and it is in turn, overlain by the basal siltstone and sandstone unit (Norphlet Formation) of the Upper Jurassic.

The Louann Salt forms an extremely incompetent and ductile layer, particularly where it has accumulated to mid-basin thicknesses in excess of several thousands of feet. This layer, after it had been overlain by several thousand feet of younger sediments, was generally deformed into extensive massifs, walls, ridges, domal features, and spines, or into pillows and swells in the core of salt-supported anticlines. The thick salt layer has

only been penetrated by wells along the northern rim of the basin. The top of the salt has also been reached by wells drilled on or around diapiric salt features.

Probably, as the North Louisiana Salt Basin and the Mississippi Interior Salt Basin were developing, the Werner, and more particularly, thick Louann Salt deposits were separated physically by a stranded transform-faulted relic segment of an attenuated high crustal block (LaSalle Arch of Zimmerman, 1995). Only thin (probably less than 500 ft thick) Louann Salt was deposited across the feature's crestal area. The physical separation between the East Texas Salt Basin and the North Louisiana Salt Basin was provided by the Sabine Uplift. Exploration wells on crestal areas of the uplift have encountered Paleozoic rocks beneath Oxfordian sediments with Louann, Werner, and Eagle Mills deposits missing because of non-deposition or erosion.

Seawater first invaded the North Louisiana Salt Basin during the late Bathonian or the Callovian (Salvador, 1987). This encroachment was then followed in the Oxfordian by a widespread and prolonged marine invasion. The initial Oxfordian influx created an increasingly larger and deeper body of water with unrestricted circulation and normal salinity—the ancestral Gulf of Mexico. Within the basin, Upper Jurassic Norphlet and Smackover sediments were deposited downdip directly on the Louann Salt, and updip on Werner Anhydrite or Eagle Mills siliciclastic red beds.

The Norphlet Formation, although deposited over most of the area, varies in thickness and lithology between a thin (0-50 ft thick) dolomitic or sandy siltstone and shale to a sandstone or conglomerate eolian-alluvial deposit (up to 50 ft thick). Eustatic rise in sea level occurred at the end of the Callovian to the beginning of the Oxfordian.

Such a sea-level rise would have inundated Norphlet deposits and set the stage for carbonate deposition throughout the basin.

The northern edge of the Smackover Formation is at the updip subcrop or truncated edge of the Jurassic marine section. The formation varies in thickness between the truncated edges to probably several thousands of feet in the downdip areas of the central basin area (Zimmerman, 1992). In general, the formation can be divided into 3 stratigraphic units: 1) an upper grayish to brown dolomitic grainstone with interbedded lime mudstone, dolomitic-quartzose siltstone, and sandstone; 2) a middle brown dense, laminated siliceous, dolomitic-lime mudstone with occasional thin sandstone interbeds; and 3) a lower dark gray to black fine-grained argillaceous limestone (Zimmerman, 1992). The maximum thickness of the basinal facies developed during the Oxfordian in the lower Smackover. Although there is no pronounced abrupt basinal thickening indicated from seismic profiles, the deepest penetrations through the Smackover are in a downdip prograded ramp setting. Backstripping of the Smackover and the overlying Kimmeridgian and Tithonian sequences (Haynesville and Cotton Valley) indicates there was gradual basinwide tectonic subsidence accompanied by compaction at this time (Zimmerman, 1999b).

The Lower Kimmeridgian (Haynesville/Buckner) strata indicate a general shallowing in depositional environment following the Oxfordian. Buckner evaporitic deposits and their associated red beds apparently resulted from deposition in hypersaline coastal lagoons or sabkhas. The Upper Kimmeridgian (Haynesville/Bossier) strata indicate that more marine conditions existed during the late Kimmeridgian in the southern (deeper) part of the basin. In the central and toward the northern (landward) part

of the basin, the section grades from a marine dark calcareous shale to a coarser grained, locally nonmarine siliciclastic sequence.

Cotton Valley units reflect a variation in depositional environments that extended southward in a deepening basin (Forgotson, 1954). These environments of deposition range from coastal plain and shelf to slope. Regional subsidence from the edge of the Mississippi River Embayment area and throughout the basin accommodated a broad progradation of thick Cotton Valley sediments. By the end of the Berriasian (end of Cotton Valley time, i.e., in the Early Cretaceous), the progradation had essentially filled the salt basin with Werner/Louann, Norphlet, Smackover, Buckner/Haynesville and Cotton Valley sediments, and formed the first greater Gulf Basin continental shelf edge across the southern area of central Louisiana (Zimmerman, 1999a and Zimmerman, 2000). An estimated 4,000 to 6,000 ft of combined Haynesville and Cotton Valley sediments filled the basin in the area of the shelf edge. These sediments were deposited on some 1,400 to 2,000 ft of Norphlet and Smackover deposits, which for the most part, rested on thin Werner/Louann Salt and/or probable Eagle Mills.

A hiatus in the sedimentary record occurred in the Valanginian reflecting non-deposition and/or erosion across the area. The hiatus essentially includes all of the Valanginian Stage of the Lower Cretaceous.

Sedimentary units of the Lower Cretaceous that were deposited in the basin are, from bottom to top, Hosston, Sligo, Trinity (Pine Island, James, Bexar, Rodessa, Ferry Lake, Mooringsport, Upper Glen Rose), Fredericksburg (Paluxy, Walnut, Goodland), and Washita. It is noted that because of the Comanchean/Gulfian erosional unconformity (mid-Cenomanian), the upper part of the Trinity Group, part of the Fredericksburg

Group, and/or part of the Washita Group have been removed in the northern part of the basin. It is also noted that some of the upper units of the Washita Group may be Late Cretaceous and preserved in the central part of the basin. The formation of the unconformity is probably a result of reactivation of upward movement of the Sabine and Monroe uplifts as well as uplifting on the north flank of the basin. Tectonic subsidence within the basin apparently slowed to a point of being halved after peaking in the Early Cretaceous (Lowrie et al., 1993).

The geologic time span for the deposition of the Early Cretaceous formations was Valanginian to Cenomanian. In that period of time, there was continued subsidence in the basin as indicated by shelf/slope deposition during Hosston time (Zimmerman and Goddard, 2001). These authors predicted a deep downdip slope environment with turbidite sandstone deposition in southern north Louisiana.

A shelfal environment of deposition persisted from Sligo to Washita time with the shelf edge migrating further south. Shelfal deposition culminated during the Washita (Lower Cretaceous barrier reef trend) across southernmost north Louisiana (Adams, 1985). In general, it is concluded that there were two cycles of progradation during the Early Cretaceous-Coahuilan (Hosston/Sligo) and Comanchean (Pine Island-Washita).

There are four groups of lithologic units within the Upper Cretaceous in the basin. From bottom to top, these are: Tuscaloosa, Austin, Taylor and Navarro. The geologic time span for Late Cretaceous deposition was mid-Cenomanian to Maastrichtian. The entire Upper Cretaceous section resulted from deposition in what undoubtedly was a slowly subsiding shallow shelf environment that, from time to time, changed to a deeper water shelf environment because of rises in sea level.

At the end of the Cretaceous, there was a reactivation of upward movement in the Monroe Uplift that was accompanied by erosional and igneous activity (Zimmerman and Sassen, 1993).

The Paleogene strata consist of seven stratigraphic units ranging in age from Paleocene (Midway and lower Wilcox), Eocene (upper Wilcox, Claiborne, and Jackson), and Oligocene (Vicksburg and Catahoula) (Andersen, 1993). For the most part, deposition occurred in a slowly subsiding shallow shelf environment that, from time to time, changed to a deeper water shelf environment because of rises in sea level. The range in depositional environments includes deep-shelf through shallow-shelf to paralic/deltaic and fluvial. Erosional conditions occurred, especially at the end of the Claiborne, Jackson, and Vicksburg deposition. A drop in sea level was the cause of this erosion.

Typically, 3D seismic data have been used to identify potential oil and gas reservoirs, such as thrombolite buildups, eolian dunes, and stacked coastal deposits associated with salt features and basement paleohighs. However, researchers in this study have found that thrombolite and associated higher energy grainstone reservoirs located updip near the Jurassic paleo-shoreline require extensive knowledge of the regional geology of the area and detailed subsurface mapping and coring to detect these updip depositional pinchouts that are characteristic of these stratigraphic traps and associated reservoirs (Mancini et al., 2008b). Further, additional stratigraphic and combination structural and stratigraphic traps associated with potential siliciclastic and carbonate reservoir facies can be identified in the areas of the Monroe and Sabine uplifts through the recognition of the major unconformities or sequence boundaries, such as the Lower Cretaceous (Valanginian) and

the multiple Upper Cretaceous (Cenomanian-Maastrichtian) transgressive-regressive sequence boundaries.

Geohistory (Burial History)

Understanding burial history is important to interpreting the geohistory of a basin. Burial history is critical to petroleum system identification and assists in determining the generation, expulsion and migration of hydrocarbons in the basin.

Study of the well log patterns, regional cross sections (Figs. 3-13), and geohistory (burial history) profiles (Figs. 41-82) indicates that there are differences in the geohistory for various areas of the North Louisiana Salt Basin. The structure maps constructed on top of the Cotton Valley (Fig. 14), on top of the Lower Cretaceous (Fig. 15), and on top of the Upper Cretaceous (Fig. 16) show the configuration of the basin. The cross sections and isopach maps of the interval from the top of the Smackover to the top of the Cotton Valley (Fig. 17) and of the interval from the top of the Cotton Valley to the top of the Lower Cretaceous (Fig. 18) show that the area updip or along the northern margin of the basin is characterized by a thinner stratigraphic section, and the area downdip or along the southern margin of the basin is characterized by a thicker stratigraphic section. The formation lithology maps illustrate lithologic changes in the various units (Figs. 21-40). Although an unconformity is present at the base of the Upper Cretaceous section throughout the basin (Figs. 3-13), this unconformity is particularly developed in Lower Cretaceous strata onlapping the Monroe Uplift as illustrated by the isopach map of the interval from the top of the Lower Cretaceous to the top of the Upper Cretaceous (Fig. 19), by the map that shows the erosional thickness of the total Lower Cretaceous section (Fig. 20), by the cross sections, and by the seismic data (Fig. 2).

We determined that tectonic subsidence was a significant component of total subsidence in the North Louisiana Basin, which represents 42-52% of the total subsidence or accommodation created for sediment accumulation in the basin. Tectonic subsidence was greatest (50-60% of total subsidence) during the Late Jurassic (135-157 ft/my). The Early Cretaceous was characterized by tectonic subsidence rates of 52-64 ft/my and the Late Cretaceous by rates of 5-17 ft/my. This pattern of tectonic subsidence is consistent with the rift related geohistory of this basin.

Accordingly, sediment accumulation rates in the North Louisiana Salt Basin were greatest for Upper Jurassic (196-264 ft/my) and Lower Cretaceous (161-233 ft/my) deposition. Upper Cretaceous deposition was characterized by slower sediment accumulation rates (58-80 ft/my). Sediment accumulation rates increased for Paleocene and lower Eocene deposition (68-148 ft/my) due to an influx of siliciclastics into the basin.

The geohistory (burial history) profiles for individual wells in the basin reflect these trends. For example, the burial histories of wells located updip (Figs. 3, 6, 43, and 62) and on the Monroe Uplift (Figs. 12, 80) record that rapid subsidence occurred in the Late Jurassic and Early Cretaceous. The profiles for wells located on the Monroe Uplift indicate that mid-Cenomanian tectonism resulted in significant uplift and erosion, which resulted in incisement into the Hosston Formation. The Tuscaloosa was deposited on top of the eroded Lower Cretaceous strata. Late Cretaceous subsidence rates were relatively lower due to several episodes of uplift and erosion during this period. Subsidence increased in the early Paleocene and continued into the early Eocene. By the middle

Figure 3. Cross section A-A' for the Sabine Uplift area. See Figure 1. VE:22X

Figure 43. Burial history for well 1701521099, Sabine Uplift area.

Figure 6. Cross section for the North Louisiana Salt Basin. See Figure 1. VE:32X

Figure 62. Burial history for well 1702701974, North Louisiana Salt Basin.

Figure 12. Cross section for the Monroe Uplift area. See Figure 1. VE:30X

Figure 80. Burial history for well 1706700008, Monroe Uplift area.

Eocene, subsidence due to sediment loading had ceased as sediment accommodation space was filled and deposition shifted basinward.

The geohistory (burial history) profiles for individual wells located downdip (Figs. 6 and 66) in the basin reflect these trends also. The profiles for these wells reflect rapid subsidence in the Late Jurassic and Early Cretaceous. Subsidence rates decreased in the Late Cretaceous due to regional tectonic compression. Subsidence increased during the early Paleocene and persisted through the Eocene. In this area of the basin, present-day burial depths represent maximum burial.

Thermal Maturation History

The thermal history of a basin is critical to petroleum identification and is a crucial element as to whether the basin has hydrocarbons in commercial quantities and as to whether these hydrocarbons are oil, natural gas or both. Thermal maturity modeling, which builds on burial history modeling, assists in this hydrocarbon determination. In the North Louisiana Salt Basin, Smackover oil has not been produced below 12,000 feet.

Our study of the thermal maturation history profiles (Figs. 87-128) indicates that in the North Louisiana Salt Basin hydrocarbon generation and maturation trends are evident. Maps of present day heat flow (Fig. 83), of lithospheric stretching beta factors (Fig. 84), and plots of vitrinite reflectance values (Figs. 85-86) were prepared to assist with this analysis.

Initial organic geochemical analysis of 74 core samples from Upper Jurassic (Smackover), Upper Jurassic-Lower Cretaceous (Cotton Valley and Bossier), Lower Cretaceous (Hosston, Sligo, Pine Island-James interval, Bexar-Rodessa interval, Mooringsport, and upper Glen Rose, and Upper Cretaceous (Austin) yielded a range of

Figure 6. Cross section for the North Louisiana Salt Basin. See Figure 1. VE:32X

Figure 66. Burial history for well 1706920079, North Louisiana Salt Basin

geochemical values (Table 1). Lower Cretaceous samples range from 0.10 to 4.09% in total organic carbon. The dominant kerogen type is herbaceous. These shale and lime mudstone beds exhibit vitrinite reflectance (R_0) values of 1.00 to 1.37%. These samples have hydrogen index (HI) values between 5 and 43 HC/g TOC, and S_2 values for these samples range from 0.00 to 0.20 mg HC/g of rock. The Upper Jurassic-Lower Cretaceous samples range from 0.11 to 1.80% in total organic carbon. The dominant kerogen types are herbaceous and woody. These shale and lime mudstone beds exhibit vitrinite reflectance (R_0) values of 0.74 to 1.89%. These beds have hydrogen index (HI) values between 2 and 151 HC/g TOC, and S_2 values ranging from 0.01 to 2.71 mg HC/g of rock.

The generation of oil and associated gas from Smackover lime mudstone was initiated at 6,000 to 8,500 feet during the Early Cretaceous and continued into the Paleogene (Figs. 89, 108, 112, and 126), using a transient heat flow model. Total organic carbon contents of up to 1.80% have been recorded from initial analyses of the Smackover for this basin (Table 1). The dominant kerogen types in the Smackover are primarily amorphous and microbial with some herbaceous. These Smackover lime mudstone beds exhibit thermal alteration indices of 2^+ to 3^+ and vitrinite reflectance (R_0) values of 1.00 to 1.89%. Smackover samples have hydrogen index (HI) values between 6 and 344 HC/g TOC reflecting that the Smackover has generated and expelled hydrocarbons. S_2 values for these samples range from 0.01 to 0.33 mg HC/g of rock. The $T^{\max}$ values for these samples cannot be used for interpreting thermal maturity of these samples because of the low TOC and S_2 values.

Figure 89. Thermal maturation profile for well 1701521099, Sabine Uplift area.

Figure 108. Thermal maturation profile for well 170270194, North Louisiana Salt Basin.

Figure 112. Thermal maturation profile for well 1706920079, North Louisiana Salt Basin.

Figure 126. Thermal maturation profile for well 170670008, Monroe Uplift area.

Basin Modeling & Petroleum System Identification

Basin modeling is crucial to petroleum system identification. In basin modeling, regional hydrocarbon flow patterns generally are discerned from two-dimensional models. Petroleum system characterization assists in the recreation of the history of the hydrocarbons within a specific geologic system in a basin. Knowledge of the petroleum system can greatly facilitate the development of improved exploration strategies for hydrocarbons in a basin. In this study, digitized well logs, cross sections, selective seismic sections, structure maps, isopach maps, an erosional thickness map for the Lower Cretaceous section, formation lithology maps, geohistory (burial history) profiles, thermal maturation history profiles, organic geochemical analyses for potential source rocks, hydrocarbon expulsion profiles, and hydrocarbon flow modeling was undertaken to assist with the basin modeling and petroleum system identification in the North Louisiana Salt Basin.

Researchers on this project have found from analysis of the literature that several active petroleum source rocks have been reported from the onshore northern Gulf of Mexico area. The Upper Jurassic (Oxfordian) Smackover lime mudstone beds have been described as serving as source rocks in the North Louisiana and Mississippi Interior Salt Basins (Sassen et al., 1987). Upper Jurassic (Tithonian) to Lower Cretaceous (Berriasian) Bossier shale beds have been reported as source rocks in the East Texas Salt Basin (Ridgley et al., 2006). The Lower Cretaceous (Albian) Sunniland lime mudstone beds have been described as serving as source rocks in south Florida (Palacas, 1978; Palacas et al., 1984). The Upper Cretaceous (Cenomanian-Turonian) Tuscaloosa marine shale beds have been reported as serving as source rocks in Mississippi (Koons et al., 1974).

Sassen (1990) reported that lower Paleogene (Paleocene/Eocene) Midway, Wilcox, and Sparta shale beds are source rocks in southern Louisiana and that Paleocene/Eocene Wilcox lignite beds may be a petroleum source in southwestern Mississippi.

From the source rock and oil characterization studies of Claypool and Mancini (1989), of Mancini et al. (1999), and of this work and from the geohistory, thermal maturity, and hydrocarbon expulsion and flow modeling completed in this study, we determined that the lime mudstone of the Upper Jurassic Smackover Formation served as an effective regional petroleum source rock in the North Louisiana Salt Basin. Upper Jurassic-Lower Cretaceous strata were effective source rocks in the East Texas Salt Basin, and we found in this study that these shale beds have high potential as probable source rocks for thermogenic gas in the North Louisiana Salt Basin given the proper organic facies. Although Lower Cretaceous lime mudstone was an effective local petroleum source rock in the South Florida Basin, we determined that these rocks are, at best, possible source beds in the North Louisiana Salt Basin given the proper organic facies. We concluded that the Upper Cretaceous marine shale probably is not a source bed in this basin given the thickness and organic facies of this unit although the Upper Cretaceous Tuscaloosa marine shale beds were an effective local petroleum source rock in parts of the Mississippi Interior Salt Basin. Lower Paleogene shale and lignite have been reported to be source beds in south Louisiana and southwestern Mississippi, but we found that these beds have not been subjected to favorable burial and thermal maturation histories required for petroleum generation in the North Louisiana Salt Basin.

Based on our assessment of potential petroleum source rocks, the Upper Jurassic Smackover organic rich and laminated lime mudstone beds were determined to be an

effective regional petroleum source rock in the interior salt basins. Organic geochemical analyses, including C₁₅₊ chromatograms and biomarker data of the oils produced from Upper Jurassic, Lower Cretaceous, and Upper Cretaceous reservoirs have shown that the oils produced from the Upper Jurassic, Lower Cretaceous, and many of the Upper Cretaceous reservoirs were generated from organic matter that accumulated and was preserved in association with the Smackover lime mudstone beds (Koons et al., 1974; Oehler, 1984; Sassen et al., 1987; Claypool and Mancini, 1989; Mancini et al., 2001; Mancini et al., 2003).

Hydrocarbon expulsion from Smackover source rocks commenced during the Early Cretaceous and continued into the Paleogene with peak expulsion chiefly in the Early to Late Cretaceous (Figs. 131, 150, 154, and 168). Oil migration started in the Early Cretaceous, and gas migration commenced in the Late Cretaceous and continued into the Paleogene in the North Louisiana Salt Basin (Figs. 326-328). Hydrocarbon flow pathway modeling supports an intermediate range migration process for Smackover crude oil and gas. Smackover hydrocarbon migration into overlying strata was facilitated by vertical migration along faults. Smackover hydrocarbons migrated into Upper Jurassic, Cretaceous, and Paleogene sandstone and carbonate reservoirs. Upper Jurassic and Lower Cretaceous anhydrite and shale, Upper Cretaceous chalk and shale, and lower Paleogene shale acted as effective petroleum seal rocks.

Comparative Basin Geohistory Evaluation

From a comparative study of the North Louisiana and Mississippi Interior Salt Basins (Table 2), the researchers on this project have determined that the evolution of the North Louisiana Salt Basin and Mississippi Interior Salt Basin are comparable and reflect their

Figure 130. Hydrocarbon expulsion plot for well 1701500464, Sabine Uplift area.

Figure 150. Hydrocarbon expulsion plot for well 1702701974, North Louisiana Salt Basin

Figure 154. Hydrocarbon expulsion plot for well 1706920079, North Louisiana Salt Basin.

Figure 168. Hydrocarbon expulsion plot for well 1706700008, Monroe Uplift area.

A.

B.

Figure 326. (A) Thermal-maturity and migration modeling at the initiation of oil expulsion during the Early Cretaceous in the southern part of the basin based on the geologic model constructed from cross section D-D'. (B) Thermal-maturity and migration modeling at peak dry-gas expulsion during the early Late Cretaceous in the southern part of the basin. See Figure 1 for the location of cross section D-D'.

A.

B.

Figure 327. (A) Thermal-maturity and migration modeling at the initiation of oil expulsion during the Early Cretaceous in the southern part of the basin based on the geologic model constructed from cross section J-J'. (B) Thermal-maturity and migration into the Monroe uplift area during the early Eocene from the southern part of the basin. See Figure 1 for location of the cross section J-J'.

Figure 328. (A) Thermal-maturity and migration modeling at the time of oil expulsion during the Early Cretaceous in the southern part of the basin based on the geologic model constructed from seismic cross section D-D'. (B) Thermal-maturity and migration modeling at peak dry-gas expulsion during the early Late Cretaceous in the southern part of the basin. See Figure 1 for location of seismic cross section D-D'.

Table 2. Comparison of North Louisiana Salt Basin and Mississippi Interior Salt Basin.

Petroleum system characteristics (Smackover)	North Louisiana Salt Basin				Mississippi Interior Salt Basin	
Thickness (m)	396				116	
Kerogen type	Type IIS (Microbial/Amorphous)				Type IIS (Microbial/Amorphous)	
TOC (wt%) range	0.06 – 8.42				0.24 – 4.55	
TOC (wt%) average	0.58 (measured) - 1.0 (calculated for modeling)				0.85 (measured) – 1.5 (calculated for modeling)	
Depth to generate oil, m (ft)	1829 – 2591 (6,000-8,500)				2438 – 3353 (8,000-11,000)	
Depth to generate gas, m (ft)	3658 – 4877 (12,000-16,000)				5029 – 6401 (16,500-21,000)	
	<u>Basin proper</u>		<u>Monroe Uplift</u>	<u>Sabine Uplift</u>	<u>Updip/Margin</u>	<u>Downdip/Center</u>
	<u>Updip/Margin</u>	<u>Downdip/Center</u>				
Maturity (R _o %)	0.8-1.3	1.3->2.6	<0.5-1.3	0.8-1.5	<0.5-1	1-2.5
Time to generate oil (Ma)	115-135	125-140	105-125	115-125	35-90	90-135
Time to generate gas (Ma)	Present-50	50-105	No gas	20-50	No gas	12-80
Time of expulsion (Ma)	50-110	100-125	<u>100-120*</u>	90-105	30-50	60-110
Time of peak expulsion (Ma)	40-105	80-120	<u>90-110*</u>	60-100	Present-45	50-100
Heat flow (HFU)	1.25				1.09	

* Only in the southwest portion of Monroe Uplift

common origin as interior salt basins (Figs. 329-330). This analysis employed the use of digitized well logs, cross sections, structure maps, isopach maps, geohistory (burial history) profiles (Figs. 171-219), thermal maturation history profiles (Figs. 220-267), hydrocarbon expulsion profiles (Figs. 268-312), and organic geochemical analyses for each basin.

We found that these rift-related basins are filled with Mesozoic nonmarine, coastal, and marine siliciclastic and carbonate deposits. The Upper Jurassic and Lower Cretaceous sections in the Mississippi Interior Salt Basin include more siliciclastic units than the equivalent sections in the North Louisiana Salt Basin (Fig. 325). The Upper Cretaceous and Paleogene sections in the North Louisiana Salt Basin include more siliciclastic units than the equivalent sections in the Mississippi Interior Salt Basin. These sedimentologic differences are a result of the high influx of siliciclastics entering the Gulf Coast area during the Late Jurassic to Early Cretaceous from the Appalachian highlands to the east of the Mississippi Interior Salt Basin, and the high influx of siliciclastics entering this area associated with the Laramide orogeny to the northwest of the North Louisiana Salt Basin. Tectonic subsidence rates are highest for the Upper Jurassic and Lower Cretaceous strata and lower for the Upper Cretaceous strata in each basin. For example in the Mississippi Interior salt Basin, tectonic subsidence rates for the Upper Jurassic section are 130 ft/my, for the Lower Cretaceous section are 72 ft/my, and for the Upper Cretaceous section are 46 ft/my (Mancini et al., 2003). In the North Louisiana salt Basin, tectonic subsidence rates for the Upper Jurassic section are 135-157 ft/my, for the Lower Cretaceous section are 52-64 ft/my, and for the Upper Cretaceous section are 5-17 ft/my. This pattern of tectonic subsidence is consistent with the rift-related geohistory of

this basin. With regard to sediment accumulation rates in the Mississippi Interior Salt Basin, rates for the Upper Jurassic section are 168 ft/my, for the Lower Cretaceous section are 311 ft/my, and for the Upper Cretaceous section are 108 ft/my (Mancini et al., 2003) . In the North Louisiana Salt Basin, sediment accumulation rates are 196-264 for the Upper Jurassic section, 161-233 for the Lower Cretaceous section, and 58-80 for the Upper Cretaceous section. This pattern of sediment accumulation rates is reflecting both the tectonic origin of these basins and the influence of the timing of high siliciclastic influxes into these basins.

Upper Jurassic Smackover lime mudstone beds are the main petroleum source rock in both of these basins; however, there is a significant difference in the thermal maturation history for these basins (Fig. 331). This difference is the elevated heat flow the strata in the North Louisiana Salt Basin experienced in the Cretaceous. This event is primarily due to reactivation of upward movement, igneous activity, and erosion associated with the Monroe and Sabine uplifts.

The difference is the heat flow values between the North Louisiana Salt Basin (1.25 HFU) and the Mississippi Interior Salt Basin (1.09 HFU) results in the generation of hydrocarbons being initiated at depths of 6,000 to 8,500 feet for the North Louisiana Salt Basin and hydrocarbon generation commencing at depths of 8,000 to 11,000 feet for the Mississippi Interior Salt Basin using a transient heat flow model (Table 2). This elevated heat flow results in thermogenic gas generation being initiated at a depth of 12,000 feet for the North Louisiana Salt Basin compared to a depth of 16,500 feet for the Mississippi Interior Salt Basin (Fig. 331).

Figure 331. Vitrinite reflectance profiles: A. North Louisiana Salt Basin B. Mississippi Interior Salt Basin.

We found that hydrocarbon flow pathway modeling supports an intermediate range migration process for Smackover crude oil and gas in the North Louisiana and Mississippi Interior Salt Basins. Our finding that Smackover hydrocarbon migration into overlying strata was facilitated by vertical migration along faults is consistent with the work of Evans (1987), Sassen (1990) and Zimmerman and Sassen (1993), who published information in support of combined intermediate range and vertical hydrocarbon migration in these basins.

Reservoir & Resource Assessment

The assessment of the undiscovered and underdeveloped reservoirs of the North Louisiana Salt Basin was made by us based on the historical oil and gas production reported by state regulatory agencies (Table 3) and other sources for these reservoirs, on a cataloging of the properties of the reservoirs in the North Louisiana Salt Basin, a tabulating of the physical and petrophysical properties of the reservoirs in the North Louisiana and Mississippi Interior Salt Basin (Table 4), and on the results from a comparative basin analysis study of these basins

Comparison of the geohistory, production history, and reservoir characteristics of the North Louisiana Salt Basin by us to those of the Mississippi Interior Salt Basin indicates that potential undiscovered and underdeveloped reservoirs are present in the North Louisiana Salt Basin. From an assessment of the undiscovered and underdeveloped reservoirs of the Mississippi Interior Salt Basin by Mancini et al. (2006a,b), the Norphlet, Smackover, Haynesville, Cotton Valley, Hosston-Sligo, Rodessa-Mooringsport-Paluxy, Dantzler-Andrew, Fredericksburg-Washita, Tuscaloosa and Eutaw reservoirs were characterized as being productive throughout most of this basin. Reservoirs with a limited

Table 3. Oil and gas production from the North Louisiana and Mississippi Interior Salt Basins.

Reservoir	North Louisiana Salt Basin				Mississippi Interior Salt Basin			
	Oil (bbls)	Gas (Mcf)	GOR (scf/bbl)	Reservoir Depth, m (ft)	Oil (bbls)	Gas (Mcf)	GOR (scf/bbl)	Formation Depth, m (ft)
Tertiary								
Wilcox	228,200	89,342	392	610-2134 (2,000-7,000)	273,753,647	198,084,956	724	398-1,177 (1,307-3,863)
Upper Cretaceous								
Selma/Jackson Gas Rock					39,205,424	224,393,889	5,724	921-1,570 (3,022-5,150)
Arkadelphia/Monroe Gas Rock	44,038	7,452,904,183	169,238,026	610-762 (2,000-2,500)				
Nacatoch (Navarro)	758,374,196	4,431,274,239	5,843	244-623 (800-2,700)				
Ozan/Buckrange (Taylor)	265,037,353	1,007,534,243	3,801	381-945 (1,250-3,100)				
Tokio/Blossom (Austin)	128,817,273	1,718,406,462	13,340	823-945 (2,700-3,100)				
Eutaw					301,449,711	1,754,506,272	5,820	945-2,448 (3,100-8,030)
Tuscaloosa/Eagle Ford	3,971,873	75,601,381	19,034	945-2,819 (3,100-9,250)				
Tuscaloosa					637,040,878	1,824,392,781	2,598	1,084-2,602 (3,558-8,537)
Lower Cretaceous								
Dantzler					783,201	72,450,931	92,506	943-2,955 (3,095-9,695)
Washita-Fredericksburg					56,943,318	255,821,157	4,493	1,446-2,955 (4,744-9,695)
Fredericksburg	1,643,190	34,409,159	20,940	914-1829 (3,000-6,000)				
Paluxy	6,206,760	88,408,279	14,244	762-2,591 (2,500-8,500)	56,544,588	568,991,732	10,063	1,730-3,706 (5,677-12,160)
Mooringsport/Ferry Lake	312,309	1,171,999	3,753	914-1,524 (3,000-5,000)	11,641,148	215,893,837	18,546	1,677-4,215 (5,502-13,830)
Rodessa	198,858,232	5,615,080,804	28,237	1,250-1,829 (4,100-6,000)	235,162,019	341,331,628	1,451	1,715-4,088 (5,628-13,413)
James	12,409	2,869,335	231,230	1,433-1,829 (4,700-6,000)	902,320	80,356,905	89,056	2,479-4,237 (8,133-13,900)
Pine Island	8,745,072	545,229,418	62,347	1,219-2,134 (4,000-7,000)	543,856	676,027	1,243	2,479-4,237 (8,133-13,900)
Sligo/Pettet	140,715,109	3,557,065,945	25,278	1,524-2,743 (5,000-9,000)				
Sligo					30,927,220	157,859,597	5,104	2,543-4,478 (8,343-14,692)
Hosston	12,896,970	1,641,948,296	127,313	1,524-3,658 (5,000-12,000)	54,887,990	995,065,210	18,129	2,664-4,640 (8,740-15,223)
Upper Jurassic								
Cotton Valley	114,348,835	2,223,486,076	19,445	2,195-4,420 (7,200-14,500)	106,461,276	146,163,240	1,373	1,437-5,502 (4,713-18,050)
Haynesville	13,923,298	152,081,744	10,923	2,957-3,200 (9,700-10,500)	6,421,491	349,786,844	54,471	1,990-6,367 (6,528-20,890)
Smackover	33,800,601	271,765,406	8,040	3,048-3,810 (10,000-12,500)	522,979,535	4,069,721,819	7,782	2,038-7,179 (6,685-23,553)
Norphlet					12,664,335	331,269,443	26,158	2,209-7,500 (7,247-24,606)
Others	25,388,311	130,564,541	5,143		872,883,419	1,277,775,162	1,464	
Total for Reservoirs	1,713,324,029	28,949,890,852	16,897		3,221,195,376	12,864,541,430	3,994	

Production data for Louisiana from the 2002 International Oil Scout Association Yearbook (unpublished), and production data for 2005 for Mississippi from Mississippi Oil and Gas Board. Reservoir depths for the North Louisiana Salt basin are from Goddard (2006), Quick look handbook onshore Louisiana petroleum producing formations (unpublished). Formation depths for the Mississippi Interior Salt basin are from well logs in Mancini et al. (1999).

areal extent of production included the Selma Chalk, Wilcox sandstone, and James Limestone. Potential reservoirs in this basin were identified as subsalt Triassic Eagle Mills sandstone and Lower Cretaceous carbonates. Lower Cretaceous Hosston/Sligo, Rodessa-Mooringsport-Paluxy, and Dantzler-Fredericksburg-Washita sandstone facies and Upper Cretaceous Tuscaloosa and Eutaw sandstone facies were determined to be underdeveloped reservoirs having high potential for hydrocarbon productivity.

In the North Louisiana Salt Basin, we determined that the subsalt Late Triassic-Early Jurassic Eagle Mills sandstone and deeply buried Upper Jurassic sandstone, shale, and limestone facies of the Smackover, Haynesville, Bossier, and Cotton Valley are identified as potential undiscovered reservoirs. Upper Jurassic units account for 20% of the current oil production and 38% of the current gas production in the Mississippi Interior Salt Basin. The depositional and diagenetic histories of these strata in the North Louisiana Salt Basin are interpreted to be similar to those in the Mississippi Interior Salt Basin. These units currently account for some 10% of the oil production and some 10% of the gas production in the North Louisiana Salt Basin. Potential underdeveloped reservoirs include Lower Cretaceous sandstone facies (Hosston, Paluxy) and limestone facies (Sligo, James, Rodessa, Mooringsport, and Fredericksburg) and Upper Cretaceous sandstone facies of the Austin (Tokio), Taylor (Ozan), and Navarro (Nacatoch) Groups.

Below we provide a catalog of the information resulting from this study and the literature for the stratigraphic units and oil and gas reservoirs in the North Louisiana Salt Basin.

Paleozoic (Pennsylvanian-Permian)

The oldest sediments drilled in the subsurface of north Louisiana are in the late Pennsylvanian-Permian carbonate section over on the Sabine Uplift (Lowrie et al., 1993). An example is found in a crestal area located in Sabine Parish, Louisiana (Zimmerman, 2000). In southern Arkansas and extending southward to the north side of the North Louisiana Salt Basin, folded Pennsylvanian-Mississippian sandstone and shale of the Ouachita are present. Imlay (1942) considered the Morehouse Formation as representing Paleozoic rocks in the deeper parts of the North Louisiana Salt Basin.

Morehouse Formation

One of the older sedimentary rocks drilled to date in the subsurface of north Louisiana is the gray shale with rare siltstone and limestone of the Morehouse Formation. It is found from 9,285 to 10,475 ft in depth in the Union Producing well (No. A-1 Tensas Delta), drilled in Morehouse Parish (Sec. 8, T. 22 N., R. 4 E) (Imlay, 1942; Bishop, 1967). Because this well was still in the Morehouse Formation at total depth and no other wells have penetrated it, the exact thickness of the formation is unknown. This well also indicated that the Morehouse is overlain directly by Werner red beds (Hazzard et al., 1947; Scott et al., 1961). According to these authors the Morehouse was deposited prior to the Eagle Mills, and later removed in south Arkansas by pre-Werner erosion. Other geologists define the Morehouse either as a marine wedge overlying the Eagle Mills or as a downdip marine facies of that formation.

According to Imlay (1942), a distinctive gastropod and assemblage of other pelecypods found in cores from the No. A-1 Tensas Delta well suggest a late Paleozoic age, probably not older than Pennsylvanian, for the Morehouse Formation. In a core from

the same well, Pennsylvanian plant spores were recovered, which allowed Imlay (1942) to assign a middle to late Pennsylvanian age to the formation.

Late Triassic-Early Jurassic (Eagle Mills)

Eagle Mills Formation

The Eagle Mills Formation extends in the subsurface from east Texas through south Arkansas into Alabama. However, it has not been penetrated by the drill in north Louisiana, and is absent in the Union No. A-1 Tensas Delta well (Bishop, 1967). According to Scott et al. (1961), the Eagle Mills unconformably overlies beds of Paleozoic age and is overlapped unconformably on the north by the Jurassic Werner. These authors were unable to establish the northern depositional limit in south Arkansas, and reported that the eroded edge has been fairly well defined in the subsurface where, the Eagle Mills was found to be approximately 7,000 ft thick in the Humble No. 1 Royston well in Hempstead County, Arkansas. Based on cores from this well, Scott et al. (1961) suggested a Late Triassic age for the Eagle Mills. These authors observed plant fossils, including *Macrotaeniopteris magnifolia*, and reported that the fossils are closely comparable with those of known Late Triassic rocks, particularly the Newark Group of the eastern seaboard and the Chinle Formation of Arizona.

More recent work by Dawson and Callendar (1991) and based on information from several deep wells (12,000-18,000 ft) in northeast Texas and southwest Arkansas, the Eagle Mills is considered to be of Triassic-Jurassic age. The lithology given is the following: green, red, and pink conglomeratic lithic arenite and fine- to coarse-grained, feldspathic arenite, interbedded with red and greenish gray shale and siltstone. Lithic arenite contains basalt, chert, quartzite, and dolomite rock fragments; plagioclase is the

predominant feldspar. The sandstone has low textural and mineralogic maturities. Eagle Mills red beds and associated intrusive igneous rocks (diabase and basalt dikes and sills) represent the fillings of grabens or rift basins that actively subsided during deposition in alluvial, fluvial-deltaic, and lacustrine paleoenvironments.

Middle Jurassic (Werner, Louann)

Werner Formation

The Werner Formation unconformably overlies both the Eagle Mills and Morehouse formations and grades into the overlying Louann Salt; north of the limit of the salt, the Werner is overlain unconformably by the Norphlet (Bishop, 1967). Hazzard et al. (1947) mentioned the Werner contains a lower red bed member consisting of red shale and sandstone, commonly conglomeratic at the base, and an upper anhydrite member of relatively pure, dense, granular anhydrite. They reported that the members are conformable, and that the Werner-Louann sequence represents a continuous cycle of deposition.

The Werner anhydrite underlies the greater part of south Arkansas and is present in north Louisiana. About 50 ft of red beds and sandstone between the Werner anhydrite and the dark shale of the Morehouse in the A-1 Tensas Delta well is probably the equivalent Werner red bed member. Several workers in the region have reported apparent excessive thickness of Louann Salt as compared to the average 50 to 100 ft of underlying Werner anhydrite (Andrews, 1960).

Louann Salt

The Louann Salt conformably overlies the Werner anhydrite, and is unconformably overlain by the Upper Jurassic Norphlet (Bishop, 1967). This unconformity of unknown magnitude and the undetermined age of the Eagle Mills make it difficult to determine the

exact age of the salt. However, most authors (Murray, 1961; Bishop, 1967) favored an Early to Middle Jurassic age for the Werner-Louann and gave the following reasons: (1) the evaporite sequence of the Sabinas basin of Mexico, which could be the sulfate concentrate of the Louann Salt, appears to be continuous with beds of the coastal province; (2) the formations underlie strata of known Late Jurassic age, and there is no positive evidence for a pre-Mesozoic age; (3) they are stratigraphically equivalent to evaporite and red shale in the Mexican portion of the coastal province which have been determined to be approximately of Middle Jurassic age and to overlie, at least in part, Lower Jurassic rocks (Murray, 1961); (4) thick (more than 2,000 ft) salt appears to occur only basinward from the Mexia-Talco, South Arkansas, and Pickens-Gilbertown fault system which also appears to be the approximate updip limit of thick Upper Jurassic sediments; and (5) spores of Mesozoic age have been identified from salt domes of northern Cuba which may be the same age as domes of the United States.

Andrews (1960) described undisturbed bedded Louann Salt as being coarsely crystalline, free of terrigenous siliciclastic material, and containing anhydrite streaks. A core taken in the Ohio No. H-1 Waller well (Sec. 3, T. 23 N., R. 8 W) in Claiborne Parish, Louisiana, showed the salt to be white to gray in color. Other salt cores are pale pinkish orange, a color attributed to meteoric water percolating through the Norphlet during deposition. The salt core from this well shows an absence of spores and pollen and the high iron content seems to support the existence of the pre-Norphlet unconformity. From subsurface control, it appears as though the salt is laterally continuous and underlies parts of Texas, Arkansas, Alabama, and Mississippi, and nearly all of Louisiana (Andrews, 1960). A maximum thickness of 1,300 ft was recorded in the Placid No. 3

Freeman-Smith (Sec. 14, T. 16 S., R. 13 W.), Calhoun County, Arkansas, and more than 3,300 ft (still in salt at total depth of 14,890 ft) in the C.V.O.C. No. 2 Banks well (Sec. 34, T. 21 N., R. 10 W.), Webster Parish, Louisiana. The thickness is believed to be associated with salt flowage, and may have been the result of basinward thickening of the salt. An original deposition of about 5,000 ft of bedded salt has been postulated but because of the topographically irregular floor of the basin, the thickness was not uniform (Parker and McDowell, 1955; Andrews, 1960). Bishop (1967) reported that precipitation of as much as 5,000 ft of Louann Salt was the result of concentrated marine waters flowing periodically into the basin, more or less isolated from the open sea by barrier bars. The CaCO_3 and CaSO_4 were precipitated, and the produced concentrated brines of NaCl were deposited in the basin.

Upper Jurassic Louark (Norphlet, Smackover, Haynesville-Buckner)

Norphlet Formation

The Norphlet unconformably overlies the Louann Salt and older units near the margins of the basin where the Louann was not deposited or has been removed by erosion. Based on the relation of the Norphlet to the overlying Smackover, it has been assigned to the Upper Jurassic (Hazzard et al., 1947; Bishop, 1967). The Norphlet of Arkansas, Louisiana, and Texas attains a maximum thickness of about 150 ft and is composed primarily of red and gray shale and sandstone. The northernmost area of Norphlet deposition, in southern Arkansas and northeastern Texas, is characterized by gravel with interbedded red and gray mudstone and is largely fluvial. Basinward, the Norphlet is believed to be composed of lagoonal deposits that are transitional with the

lower Smackover; a minor diastem may separate the fluvial equivalents of these rocks from the limestone of the Smackover.

Smackover Formation

Producing Parishes

Bossier, Webster, Claiborne, Lincoln, Union

The Smackover Formation conformably overlies the Norphlet. It consists mainly of carbonate mud with pyrite and carbonaceous material deposited in a quiet, toxic environment and non-skeletal carbonate grains deposited in a shallow water environment (Hazzard et al., 1947; Bishop, 1968, 1971). It is reported that the deposition of these non-skeletal particles in the late Smackover sea is similar to those of the present Bahama Banks. Likewise, pellet-mud was deposited in warm, quiet, shallow, water followed by slight differential uplift causing turbulence in local areas, and deposition of mixed facies.

Dickinson's (1969) work was used successfully in predicting productive trends, and for reconstructing the environment of deposition of the upper Smackover section (Late Jurassic) at North Haynesville field, Claiborne Parish, Louisiana. The oolitic limestone (mudstone, wackestone, packstone) and pelletoid "B" reservoir studied was thought to contain an estimated 16 million barrels of oil in place. Analysis of dry holes in North Haynesville field indicates that nondeposition or complete cementation of the reservoir facies is more important than present structure in limiting the productive area. However, only those wells favorably located with respect to present structure, as well as to structure during deposition and diagenesis, are productive.

According to Moore and Druckman (1981), the upper Smackover is a blanket ooid grainstone 300 to 400 ft thick and covering approximately 4,000 sq mi in east Texas,

southern Arkansas and northern Louisiana. Their work in burial diagenesis of the Smackover indicates that porosity is affected to a greater degree by burial diagenetic processes than by depositional environment processes. They indicate zones with porosity values ranging from 11 to 22%, and permeabilities of 1 to 100 millidarcys at the site of some of the larger upper Smackover discoveries of the 1960s, such as Walker Creek field, that eventually led to new exploration across the entire Smackover fairway.

Zimmerman's (1992) study of the sparsely drilled area in the northeast corner of Louisiana indicates that the extensively fractured intervals observed in Smackover conventional cores in the area can be attributed to wrench and normal faulting. Although located on the border of the North Louisiana Salt Basin, this area is an example of tectonic fracturing that may have future exploration and production potential in the Smackover interval.

In summary and regarding reservoir conditions of the Smackover in north Louisiana, depth to pay ranges from 8,600 to 11,600 ft with net pay of producing intervals ranging from 20 to 120 ft. The oolitic and pisolitic limestones tend to be tight with porosities of 11 to 22% and permeability less than 1 to 100 md. The hydrocarbons produced are generally 42° to 53° API gravity crudes and condensates

Haynesville-Buckner Formation

Producing Parishes

Bossier, Claiborne

Forgotson and Forgetson (1976) described the Haynesville in southern Arkansas and northern Louisiana, as red shales and pink to white sandstone that grade laterally into the Gilmer Limestone in East Texas and basinward into black shale lithologically similar to

the Bossier Shale. In some areas, the Haynesville or Gilmer Limestone (commonly called Cotton Valley Lime) rests unconformably on the Smackover Formation. The Buckner Member of the Haynesville (primarily red shale, sandstone, anhydrite, and limestone lenses) is transitional with the underlying Smackover limestone. According to Salvador (1987), the lower Buckner (Kimmeridgian) section reflects depositional environments that are less marine or shallower water marine than those of the underlying Oxfordian Smackover, because the Buckner consists of evaporitic deposits and associated red beds formed in hypersaline coastal lagoons or sabkhas. At North Haynesville field, most of the thick Buckner consists largely of red and greenish-gray mudstone and shale with varying amounts of nodular anhydrite and with a few thin beds of white to red, anhydritic sandstone (Bishop, 1971).

In Texas, Louisiana, and Arkansas, Dickinson (1968a, 1968b, 1969) divided the Buckner into two members, each of which is gradational with the Smackover in different areas. The lower is predominantly anhydrite and anhydritic mudstone, and was deposited in an evaporite basin north of a chain of salt-cored anticlines. The upper member consists largely of red and greenish-gray mudstone and shale with nodular anhydrite. Several zones of calcarenites similar to those of the Smackover are present in a general east-west trend area, and at least one of them, the "A" zone, extends regionally across most of northern Louisiana. Dickinson (1969) stated that the lower member of the Buckner is time-equivalent to part of the upper member of the Smackover, but the upper Buckner grades basinward into the Bossier Formation. The Buckner calcarenite zones coalesce at the south edge of the Haynesville field to form a bank up to 600 ft thick, which extends regionally along the basinward edge of the shelf slope, a zone of active subsidence.

Dickinson (1969) reported that the older zones of the Buckner calcarenite appear to be limited to the south flanks of Haynesville and Red Rock fields, and that the "A" zone is developed on a regional scale across north Louisiana and is known to extend from Texas nearly to Mississippi. The trends vary from east to west to northwest, with a beach deposit forming at the seaward edge of the shelf-slope break during the Buckner regression.

In summary, the Haynesville-Buckner consists of fine-grained sandstones, shales, bedded anhydrite, and oolitic limestone that were deposited in a shallow marine environment. Hydrocarbons were primarily sourced from the underlying Smackover Formation basinal deposits and are stratigraphically trapped in multiple, stacked, ooid shoal pinch-outs. With respect to the reservoirs, the depth to top of pay is from 9,400 to 10,750 ft. Porosity ranges from 9 to 16% and permeability from 50 to 400 md. Produced hydrocarbons consist of 42° API gravity oil, condensate, and gas.

Upper Jurassic (Cotton Valley)

Cotton Valley Group

Producing Parishes

Caddo, Bossier, Webster, Claiborne, Lincoln, Union, Ouachita, De Soto, Bienville, Winn, Natchitoches, Jackson, Morehouse

The Cotton Valley Group in southern Arkansas and northern Louisiana has been extensively studied (Crider, 1938; Imlay, 1943; Swain, 1944; Forgotson, 1954; Sloane, 1958; Mann and Thomas, 1964; Thomas and Mann, 1966; Collins, 1980; Coleman and Coleman, 1981; Eversull, 1985; Zimmerman, 2000). The Cotton Valley consists of the Schuler and Bossier formations and lies unconformably on the Louark Group. The uppermost Schuler Formation, predominantly composed of sandstone and siltstone, is

unconformable to and oversteps the Bossier Formation (mainly shale) near the basin margins. Continuous deposition occurred in the deeper parts of the basin. The basal Cretaceous Coahuilan Series rests unconformably on the Schuler Formation of the Upper Jurassic Cotton Valley Group. Swain and Anderson (1993), in ascending order, divided the Cotton Valley Group into the Millerton, Shongaloo, and Dorcheat formations. They defined the Millerton as dominantly a siliciclastic shelf unit that was deposited over the Haynesville Formation and used it in place of the Bossier Shale. These authors described the Shongaloo Formation as typical foreshelf and shelf edge silty shales and sandstones, in part, calcareous. They assigned the name Dorcheat Formation to the uppermost unit below the Hosston Formation and used it in reference to the Schuler.

Kornfeld (1985) described the sandstones of the upper Cotton Valley Group of Mississippi, northern Louisiana, and eastern Texas as being deposited on a stable but subsiding shelf. The quartz-rich regressive sandstones are described as being deposited in a complex of deltaic and marine systems. The sediments of the Cotton Valley fluvial-deltaic systems were derived from Paleozoic and younger highlands to the north and northwest. These sandstones accumulated on the shelf where they were subsequently reworked. Kornfeld (1985) stated that proximal destructive delta systems existed in northern Louisiana and northeastern Texas and that another system consisting of barrier beaches and bars was located centrally between them.

Environments of deposition located landward from the open Gulf to the south and paralleling the late Jurassic Gulf of Mexico coastline included a longshore barrier island in northern Louisiana and a coastal lagoon in southern Arkansas. Sands to the barrier island were supplied by a delta that was formed by the ancestral Mississippi River in

northeastern Louisiana and adjacent Mississippi (Thomas and Mann, 1966). The description by these authors and others of the open and shallow marine systems together with the nearshore coastal features typify the lithofacies of the formations within the Cotton Valley Group. Updip in southern Arkansas, the uppermost Schuler Formation pinches out. Of interest are the thick downdip marine deposits in northern Louisiana that include the following formations: Bossier Shale, Terryville Sandstone, Hicos Shale, Knowles Limestone, and Schuler Formation. The sedimentary characteristics of the formations that comprise the group in northern Louisiana are summarized below.

Bossier Shale (Millerton Formation)

The open marine basin deposits of the Bossier Shale are found in northern Louisiana and consist of dark-gray, fossiliferous, calcareous shale. A wedge of this marine shale pinches out updip in southernmost Arkansas. It attains a maximum thickness of 2,000 ft. The marine shale grades eastward into red shale and sandstone in northeastern Louisiana (Swain, 1944; Forgotson, 1954). The Haynesville Formation conformably underlies the Bossier; and where the Haynesville is absent, the Bossier rests on the Smackover limestone. The Bossier grades upward into the overlying Terryville Formation.

Terryville Sandstone

The Terryville, which consists of regressive massive white quartzose sandstone, extends from Ouachita Parish westward through southern Caddo Parish, Louisiana (Mann and Thomas, 1964). It was deposited as an offshore sand barrier island that separated the open sea on the south from a coastal lagoon on the north (Forgotson, 1954; Sloane, 1958). The Terryville attains a maximum thickness of about 1,400 ft. Only a few thin, dark gray shale beds occur in this sandstone sequence. The Terryville interval consists of five sandstone tongues; each of the tongues is composed of one to five regionally

extensive blanket sandstone beds, which are 10 to 50 ft thick. Oyster beds occur at the pinch-out edges of some of the sandstones. The Terryville Sandstone interfingers with and grades northward into the overlying and laterally equivalent Hico Shale.

Hico Shale

In northern Louisiana, the Hico Shale consists mainly of dark gray shale and a few thin beds of silty limestone, siltstone, and sandstone. Locally, thin beds of carbonaceous and pyritic sandstone and shale are present. The dark shale of the Hico is thought to be a lagoonal facies that accumulated adjacent to the Terryville barrier island (Forgotson, 1954).

Knowles Limestone

The Knowles Limestone in Louisiana, which consists of alternating dark gray, argillaceous limestone and gray shale, is 300 to 400 ft thick (Mann and Thomas, 1964). Thin lenses of sandstone occur within, and locally supplant, some of the limestone units. The limestone is 10 to 100 ft thick and is interbedded with shale that is 10 to 30 ft thick. Similar to the other underlying Cotton Valley units, the Knowles in Louisiana grades northward into terrestrial red beds of the Schuler Formation in Arkansas, and in some areas of Louisiana it is overlain conformably by the Cretaceous Hosston Formation.

Schuler Formation (Dorcheat Formation)

The Schuler Formation consists mainly of shale, but in Arkansas toward the pinch-out of the unit it contains increasing amounts of sandstone (Forgotson, 1954). In fact, near the pinch-out, the formation is entirely sandstone and pebble conglomerate. In southern Arkansas, there is a predominance of nearshore to nonmarine lenticular, fine-grained, red and gray sandstone and shale or mudstone. The lenticular red beds probably

accumulated as coastal plain deposits on the coastal side of a lagoon. The red terrigenous siliciclastic sediments extend south in northeastern Louisiana and western Mississippi, where the Schuler is almost totally sandstone. According to Forgotson (1954), a large delta was responsible for the thickness and distribution of the sandstone in northeastern Louisiana and western Mississippi. The Hosston Formation overlies the Schuler Formation disconformably.

Approximately 45 reservoirs exist within the Cotton Valley Group. The optimum producing reservoirs consist of fine- to medium-grained, massive barrier bar sandstone and shallow marine oolitic limestone of the Terryville and Knowles formations, respectively. In northern Louisiana, depth to the top of the pay zones range from 3,600 to 14,500 ft. Net pay of the reservoirs ranges from 10 to 60 ft with porosities of 9 to 18% and permeabilities of 1 to 300 md. The produced hydrocarbons are typically 41° API gravity oil, condensate, and gas.

Lower Cretaceous Coahuila (Hosston, Sligo)

The Sligo and Hosston Formations belong to the Lower Cretaceous Coahuilan Series. The Pearsall, the basal formation of the Trinity Group, conformably overlies the Sligo. The Sligo, consisting of gray to black shale and limestone, grades transitionally downward into the red sandstones and shales of the Hosston. Basinward, both units thicken and the base of the Sligo occurs stratigraphically lower.

Hosston Formation

Producing Parishes

Caddo, Bossier, Webster, Claiborne, Union, Lincoln, De Soto, Bienville, Red River, Natchitoches, Jackson, Ouachita, Caldwell

Deposition of predominantly fluvial-deltaic sediments continued during the early Cretaceous in the basin. During Hosston time this deposition included a large variety of lithologies from delta plain to shallow marine shelf environments. According to Rogers (1987), the Hosston Formation overlies the Dorcheat and is of early Cretaceous age. The Hosston Formation contains the early Cretaceous marker spore *Cicatricosisporites angicanalis*, and the Cretaceous dinoflagellate *Oligosphaeridium* complex. To the west in Texas, Blount et al. (1986) were able to identify the following five major lithofacies in the Hosston Formation of Trawick field, Nacogdoches County, Texas: (1) a clean, cross-bedded, tidal-channel facies; (2) a sandy, bioturbated, tidal-flat facies; (3) thin, rapidly deposited crevasse-splay deposits; (4) interdistributary bay sands, silts, and muds; and (5) partly reworked distal-deltaic sandstones. These workers observed distribution differences between the upper and lower Hosston. In the lower Hosston, the channel, crevasse splay, and interdistributary bay facies were common, and in the upper Hosston a marginal marine delta-fringe system existed.

The predominant arenaceous siliciclastics of the Hosston range from claystone/shale, siltstone, very fine-grained sandstone to conglomerate resulting in prolific hydrocarbon reservoirs that can be found from Texas, across northern Louisiana and into Mississippi (Beckman and Bloomer, 1953; Cullom et al., 1962; Gorrod, 1980; Saucier et al., 1985; Garner et al., 1987). The thickness of the Hosston varies from a few hundred ft to over 3,500 ft in Jackson Parish. Minor limestones and conglomerates, as well as some lignites, are also present in the Hosston (Granata, 1963; Saucier et al. 1985). In the Pine Island field, Caddo Parish, the non-marine beds of the Hosston are located between 3,900 and

5,900 ft in depth. Hosston reservoirs can be reached at drilling depths of less than 10,000 ft over most of the productive trend in Texas and Louisiana. The thickness of the Hosston ranges from a few hundred feet near the zone of truncation in south Arkansas to over 3,500 ft in southern Jackson Parish, Louisiana (Cullom et al., 1962). Accompanying the change in thickness there is also a change in character of the formation from predominantly coarse red sandstones, often cherty, interbedded with red shales in south Arkansas, to finer grained white sandstones and siltstones interbedded with gray, green and red shales and oolitic limestones in the deeper parts of the North Louisiana Salt Basin.

In Texas, the Travis Peak Formation (Hosston equivalent) was deposited as a complex of fluvial and deltaic systems that rapidly prograded over a broad, shallow shelf more than 100 miles wide. Aggradation resulted in braided stream deposits that were more than 2,000 ft thick. The entire complex is considered a fluvial-deltaic system that includes a variety of depositional environments associated with the transition from the continental braided stream deposits to shallow-marine carbonate shelf deposits of the overlying Sligo Formation.

Zimmerman and Goddard (2001), studying an area that includes parts of and extends to the south of the basin, reported there were four wells that completely penetrate the formation. The penetrations are located in a shallower shelf area along the eastern margin of the Sabine Uplift in Sabine and Natchitoches Parishes. These four wells provide facies control for the updip portion of the Hosston Formation. Farther downdip, deeper water facies were interpreted in the eight wells found to have penetrated the entire upper half of the Hosston interval. These eight wells, located in the deeper part of the study area, plus

one additional well that penetrated the lower Hosston Formation in extreme southwest Mississippi, provide the main control for understanding deeper water Hosston deposition. It is noted that there are no known conventional cores available from any of the downdip wells, and the depositional environments are based on well-log interpretations. However, two wells, one updip in Red River Parish and one in Zwolle field, located in Sabine Parish, just southeast of the Sabine Uplift, encountered a shaly facies with Bossier-like lithology. Based on that data and a detailed facies interpretation, Zimmerman and Goddard (2001) concluded that depositional environments in the downdip area were deeper water and quite different from those found in the shallower updip Hosston.

In the past, in order to evaluate the hydrocarbon potential of the Hosston in unexplored areas, an attempt was made to predict what sort of environment might have existed for this formation in the deeper, sparsely drilled parts of the basin (Cullom et al., 1962). It was determined from sandstone-limestone percentage maps that some of the better Hosston fields in north Louisiana were located in Bienville, Webster, Jackson, Caldwell, and Ouachita Parishes. The more favorable environments were then extrapolated to the southeast into Caldwell, Richland and Franklin Parishes, and with less certainty to the southwest into De Soto and Red River Parishes.

Based on these earlier studies, operators in north Louisiana and east Texas are now aware that the Hosston Formation has characteristically low porosity and permeability values and that both environment of deposition and diagenesis control variations in reservoir quality of these sandstones (Swain, 1944; Saucier, et al., 1985; Dutton and Finley, 1988). Late-stage diagenetic events include cementation by calcite and anhydrite as well as isolated occurrences of intergranular albite cementation. Channel sands of the

lower Hosston maintain the highest consistent reservoir qualities. The oil and gas accumulations discovered to date are found predominantly in fine- to medium-grained sandstone reservoirs (approximately 40) from alluvial, fluvial-deltaic, and shallow marine shelf depositional environments. The porosities (10 to 26%) and permeabilities (10 to 250 md) observed in the gas prone reservoirs of Bassfield field in Mississippi, and fields in east Texas and northern Louisiana are the result of excessive compaction and cementation (Dutton and Finley, 1988; Mitchell-Tapping, 1981).

The Lower Cretaceous Travis Peak Formation of east Texas as well as its equivalent, the Hosston Formation of northern Louisiana and Mississippi, is a gas-bearing sandstone that has low permeability and requires hydraulic fracture treatment to produce gas at economic rates (Dutton and Finley, 1988; Dutton et al., 1990, 1993; Davies et al., 1991). Although a few thin zones near the top of the Travis Peak in east Texas have permeability greater than 90 md, most of the Travis Peak has permeability of less than 0.1 md. Porosity in sandstones ranges from 3 to 17% but is mostly less than 8%.

Oil and gas accumulations in the Hosston are closely associated with salt-cored structures in east Texas and north Louisiana. It is an important source of oil and gas-distillate in many fields of north Louisiana and east Texas, with production generally coming from three zones, the upper 300 ft, the middle 300 ft and the basal 200 ft. The depths to the reservoirs in Caldwell, Richland and Franklin Parishes are estimated to range between 4,000 and 13,700 ft.

Sligo Formation

Producing Parishes

Caddo, Bossier, Webster, Ouachita, Claiborne, Lincoln, De Soto, Bienville, Natchitoches, Winn

The Hosston is transitional with the limestone and dark gray shale of the Sligo Formation. Early workers (Breedlove and Ogden, 1955; Nichols 1958; Murray, 1961) reported an early Cretaceous age for the Sligo and correlated this unit with the Nuevo Leon Stage of the Upper Coahuilan Series. These workers published thicknesses for the Sligo of less than 100 ft in south Arkansas and greater than 500 ft in central Louisiana. According to Hermann (1971), the Sligo in Rapides Parish of central Louisiana forms a large bioherm of least 450 ft thick. This main reef trends northerly through eastern Natchitoches, western Grant, and western Winn Parishes. The northern extent of the reef trend turns eastward through northern Winn, southern Jackson, and central Caldwell Parishes. The reef facies thins in Caldwell Parish.

Nichol's (1958) description for the Sligo in the "Ark-La-Tex" region is as follows: gray to brown shale, limy shale and limestone, locally contain lentils of dark gray oolitic argillaceous fossiliferous and sandy limestone and light to dark gray and brown fossiliferous shale. The oolitic to pseudo-oolitic limestone, where porous and well developed, are good petroleum reservoirs. Nichol (1958) considered the depositional sequence to be from a shallow water, neritic, or perhaps lagoonal, environment between a transitional, deltaic environment in south Arkansas and a biohermal reef trend in central Louisiana. There is some disagreement among petroleum geologists concerning the contact between the Sligo and overlying Pine Island Formation. Hermann (1971) picked the top of the Sligo at the top of the reef limestone.

Using paleontology, well data, and 2-D seismic, Forgotson and Forgotson (1975) considered the Sligo Formation a transgressive carbonate sequence with shelf edge and

dolomitic reef-crest zones, trending approximately east-west through Vernon, Rapides, and Avoyelles Parishes. This Sligo trend is considered a reef complex, consisting of reef, fore-reef, back-reef, and inter-reef deposits. Forgotson and Forgotson (1975) showed the back-reef and patch-reef zones extending from the northern boundary of these parishes to approximately the southern boundary of De Soto, Red River, Bienville, Jackson, Ouachita, and Franklin Parishes. The limestone may be oolitic or pseudo-oolitic, and is productive in many areas where porosity is present. The distribution of the Sligo extends across east Texas, Louisiana, and Arkansas where it is mainly calcareous, but grades into a predominantly arenaceous facies in Mississippi. It is sometimes referred to as the Pettet Limestone; a term that refers to a productive, porous, pelletal-oid limestone.

To date, the Sligo limestone has produced both gas and oil in Louisiana, Texas, Arkansas, and Mississippi. Throughout the region, the depth to top of limestone pay ranges from 3,000 to 8,000 ft. Net pay is generally between 10 and 160 ft. The Sligo contains approximately 13 producing reservoirs in northern Louisiana. Porosity ranges from 16 to 20% and permeability from 9 to 100 md. The produced hydrocarbons are typically 25° to 46° API gravity oils, condensate, and gas.

Bailey's (1978) brief historical account of early drilling activity at Black Lake field in Natchitoches Parish gives insight as to the rather slow pace of Sligo development. The first well to show the existence of Sligo reefs was Hunt's Goodpine Lumber Co. #F-24, drilled in 1942. Later, between 1947 and 1949, the limits of the hydrocarbon trap were defined by four additional wells. The first well discovered 160 ft of Sligo reef, with 80 ft of water-wet porosity. The second well found no reef facies and no porosity in the Sligo. The third well penetrated 52 ft of wet reefal limestone about two miles south of the field

and the fourth well found no reef and no porosity, only one mile north. Because of these rather poor results, it was not until 1958 that interest was renewed in the area and drilling began less than three miles west of the field. Again, no reef and no porosity were found. Then a well drilled some three miles east of original production, encountered almost 200 ft of Sligo reef, of which 130 ft was porous and water-wet. By this time, both downdip porosity and the updip permeability barriers were known to exist, and preliminary structure maps indicated the possibility of structural closure or nosing trend. In spite of the presence of the elements of a structural-stratigraphic trap, interest was again lost and Black Lake field remained undeveloped for several more years.

It was not until 1963 that a seismic survey, verified the existence of strong nosing in the Black Lake field area. The first drill test encountered water with a slight show of oil in the Sligo reef. The next well was lost because of drilling problems. At a distance of 100 ft away another hole was drilled and the perforated interval (7,990-8,000 ft) tested at 2.65-MMcf gas/day and 459 bbls of 45.8° API oil on an 11/64-inch choke, with a tubing pressure of 2,409 lb. and a gas/oil ratio of 5780 cf/bbl. Finally, in January 1966, commercial production in Black Lake field began after 24 years of drilling activity. Hermann (1971) mentions that after the successes of Black Lake field only minor production occurred in the Sligo in northern Louisiana.

Lower Cretaceous Comanche/Trinity (Pine Island, James, Bexar, Rodessa, Ferry Lake, Mooringsport, Upper Glen Rose)

Pearsall Formation

According to Forgotson (1963), the Pearsall Formation is the lowest of the units of the Lower Cretaceous Trinity Stage. In southern Arkansas, north Louisiana, and east

Texas, it is subdivided, in ascending order, into the basal Pine Island Shale, the James (Cow Creek) Limestone, and the Bexar Shale. In Louisiana, these members are nearshore, sandy facies along the updip margin of deposition and cannot be subdivided. The Rodessa, Ferry Lake, and Mooringsport formations overlie the Pearsall. The Rodessa and Mooringsport comprise separate platform sequences. Anhydrite beds occur throughout the Rodessa. The Ferry Lake Anhydrite reflects a regional episode and is used as a marker bed throughout the northern Gulf (Petty, 1995; Montgomery et al., 2002).

Pine Island Formation

Producing Parishes

Lincoln, Ouachita

The Pine Island consists predominantly of calcareous black shale with interbedded fine-grained sandstone and minor crystalline limestone layers associated with lagoonal to nearshore marine environments. The widespread nature of the marine shales of the Pine Island is interpreted by Yurewicz et al. (1993) as regional transgressive deposits. The Pine Island shale, averaging 250 ft in thickness, is widely distributed in Arkansas and Louisiana and located in the subsurface between 4,000 and 7,000 ft. Minor production has been reported from its basal Causey, Hogg and Woodruff sandstone reservoirs (Breedlove et al., 1953; Crump, 1953; Whitfield, 1963). The first well drilled in the Pine Island found gas and salt water in a sandstone from 5,315 to 5,340 ft at the base of the formation, but the second in the Causey sandstone was the first commercial gas producer. Net pay of the reservoir sandstone ranges from 30 to 60 ft with porosity of 10 to 15% and permeability from 10 to 200 md. Hydrocarbons produced are typically 24° to 30° API gravity oil, condensate, and gas.

James Formation

Producing Parishes

Bossier, Webster, Claiborne, Lincoln, De Soto, Bienville, Jackson

The James Formation (late Aptian age) overlies the Pine Island Shale and was deposited in a moderately low energy open shelf environment. The James consists of burrowed argillaceous miliolid lime mudstone, wackestone, and packstone (Yurewicz et al., 1993). According to Forgotson (1957), the term "James limestone" was first applied in the year 1926 to a section of calcareous sandstone that was cored in Union Parish, Louisiana, from 3,827 to 3,917 ft. Forgotson (1957) described the James as sandy and chalky, fossiliferous limestone, fine- to medium-grained, and calcareous sandstone with gray shale interbeds. However, its lithology is quite variable throughout the region, changing westward to black marl and shale in northwest Louisiana and northeast Texas. In southwest Arkansas, the James consists of a fossiliferous, dense limestone and red and gray shale. In southern North Louisiana and East Texas, it is characterized by porous, oolitic, and fossiliferous or fossiliferous-fragmental limestone.

Hermann (1976) described the James as reef-like deposits within an arcuate trend in Winn and Natchitoches Parishes, Louisiana. His description of the James is as follows: The principal limestone varieties within this trend are light-colored, pelletal-miliolid calcarenite, pelletal calcarenite, pelmicrite, and caprinid biosparite. On well logs the limestone is characterized by a leftward excursion of the spontaneous-potential curve giving the zone the massive look of a reef section as much as 300 ft (91 m) thick in one test well. However, the limestone appears to be nonreef in origin. Isopach studies have shown that the James is a detrital deposit that accumulated in low areas. The trend

probably contains local patch-reef developments as indicated by the presence of a few caprinid zones, but it does not appear to be a true reef trend as generally defined. Southwest, south, and east of the main trend the James consists principally of interbedded gray argillaceous micrite and gray shale, and on the north and northwest it consists of some combination of interbedded gray micrite, oomicrite, oosparite, quartz sandstone, and gray shale.

The James Limestone produces from numerous fields from east Texas, through Louisiana to southern Mississippi. Production is mainly from rudist-coral-stromatoporoid reef facies on salt-related structural highs in the interior salt basins of east Texas, north Louisiana (Chatham field), and Mississippi (Hermann, 1976). When Chatham field was discovered in 1960, original estimates were 400 million bbl oil in place, of which at least 230 million bbl are recoverable. The few test wells that have cored the James massive-limestone interval indicate that porosity ranges from 10 to 15%, but is generally less than 10%. Calcite-lined vugs and intergranular openings are the main porosity types. Permeability likewise is generally low, commonly being less than 0.1 md but reaching as high as 100 md in small intervals. The hydrocarbons produced are light oils and condensates, as well as gas in porous limestone intervals. Because of the combination stratigraphic-structural anomalies present in the area, the James was considered an excellent exploration target (Hermann, 1976).

Rodessa Formation

Producing Parishes

Caddeo, Bossier, Webster, Claiborne, Lincoln, Bienville, De Soto, Red River

The term Rodessa Formation includes the strata above the James Limestone and below the base of the Ferry Lake Anhydrite (Roberts and Lock, 1988). The type well for the formation is located in Rodessa Field, Caddo Parish, Louisiana (Forgotson, 1957). In the type well, the Rodessa interval is at depths of 5,320 to 5,805 ft. In this part of Louisiana, the Rodessa Formation consists of oolitic and crystalline limestone, lenticular fine-grained sandy limestone, anhydrite, coquinoid limestone and gray shale. Southward from the type area in northwest Louisiana, the limestone of the Rodessa has reduced porosity and grade into dense, crystalline limestone. The Rodessa siliciclastics were derived from the craton to the north. Ostracode assemblages in the Rodessa are typical of open-to-restricted shelf environmental conditions. Yurewicz et al. (1993) described the Rodessa in east Texas as typically skeletal–peloid-oncoid packstone that grades downdip into skeletal grainstone and packstone shoals and rudist and coral-red algae at the platform margin.

According to Roberts and Lock (1988), in 1982 a well in Sligo field, Boissier Parish was perforated through the intervals 4,360 to 4,366 ft and 4,442 to 4,446 ft with initial production of 68 bbls of 41.8 API gravity oil per day through a 14/64 choke. Between September 1982 and June 1987, total production was 38,951 bbls of oil and 28,846 Mcf casing head gas. Only 900 bbls were produced in the first six months of 1987. Of the two zones perforated, the upper is in miliolid packstone with up to 5 md permeability and 16% porosity (moldic and intercrystalline). The lower is dolomitized and has permeabilities of up to 15 md and porosities of up to 15%. The Rodessa also produces from a light-gray, porous, chalky, pseudo-oolitic, fossiliferous limestone with a few

streaks of white, fine-grained sandstone in the western half of the field. This reservoir is about 25 ft thick, has a porosity of 20%, and produces from an area of approximately 19,000 acres.

Other Rodessa reservoirs are productive in northern Louisiana (Frizzel, 1987). Depth to the top of pay ranges from 3,700 to 6,000 ft. Net pay is generally 10 to 30 ft thick. Reservoir porosity ranges from 10 to 26% and permeability from 10 to 650 md. Hydrocarbons produced are typically 34° to 41° API gravity oil, condensate, and gas.

Ferry Lake Anhydrite

Producing Parishes

Caddo, De Soto, Bossier

The Lower Cretaceous Ferry Lake Anhydrite is one of the most distinctive, widespread sedimentary units within the Gulf Coastal Plain. The formation extends from east Texas across southern Arkansas, northern Louisiana, central Mississippi, and southern Alabama, and to south Florida where it has been correlated with anhydrite beds of the Punta Gorda Formation (Forgotson, 1957). The approximately 250 foot thick Ferry Lake Anhydrite was deposited above the Rodessa in an extensive lagoonal sea. It is believed that the thickness of individual beds accumulating within the lagoon were controlled mainly by water depth, development of a restrictive barrier, subsidence, duration of each evaporative pulse, and areal salinity variation (Forgotson, 1957; Pittman, 1985). The Ferry Lake is described as consisting of white to gray, finely crystalline anhydrite that contains minor amounts of interbedded gray to black shale, dense limestone, and dolomite. The type well is the Gulf Refining Company's Gas Unit No. 1, in Jeems Bayou Field, Caddo Parish, Louisiana, with the top placed at 3,823 ft and the base 4,072 ft.

Only minor production has been reported to date from fractured intervals within the Ferry Lake Anhydrite from scattered fields within the interior salt basins. Kimball et al. (1989) described hydrocarbon production in Caddo-Pine Island field from the thin Haygood Limestone, found near the base of the Ferry Lake Anhydrite. The high resistivities of the anhydrite beds require the use of porosity logs such as sonic logs, micrologs, or neutron density logs, in order to adequately evaluate the formation. Where production has been found, pay depths range from 3,000 to 4,000 ft. Net pay is only 20 to 50 ft thick with minor porosity and low permeability.

Mooringsport Formation

Producing Parishes

Caddo, Bossier, De Soto, Red River

The Mooringsport Formation (early Albian age) consists of shallow marine carbonates that are predominantly crystalline and fossiliferous limestone interbedded with sandstone, red beds, anhydrite, and shale (Yurewicz et al., 1993). It is located above the Ferry Lake Anhydrite in the Mooringsport field area of Caddo Parish, Louisiana. In the Union Producing Company's Noel Estate well No. 1-A, the Mooringsport occurs at a depth of 3,565 ft (Forgotson, 1957). McNamee (1969) included the Mooringsport and Upper Glen Rose formations as part of the Glen Rose Reef Complex in Texas and Louisiana. The Mooringsport (Rusk equivalent of Texas) has been extended into Mississippi. Adams (1985) placed the Mooringsport in the upper section of the Glen Rose Subgroup. He described six depositional environments in the Mooringsport, including basin, forereef, reef, bank margin, bank interior and restricted shelf. Adams (1985)

reported that relatively rapid subsidence/sea level rise is responsible for the vertical growth of the Mooringsport reef complex of up to 1,600 ft thick.

In the areas where the Mooringsport produces in northern Louisiana, the depth to top of pay ranges from 3,000 to 5,000 ft with net pays of 10 to 30 ft. Porosity of 10 to 20% and permeability of 10 to 500 md are common. According to Baria (1981), in the deeper reservoirs (13,400 ft) in some areas of Waveland field, Mississippi, porosity and permeability are both related to primary intergranular and intraparticulate pore space in shoal or shallow bank deposits. In this field, porosity varies from 10 to 17%, and permeability averages about 7 md. In these reservoirs, fractures are an important factor controlling the prolonged and prolific production at Waveland field. The produced hydrocarbons are primarily gas and condensate.

Lower Cretaceous Comanche (Fredericksburg/Washita-Paluxy, Walnut, Goodland)

Fredericksburg Group

Producing Parishes

Caddo, De Soto, Sabine, Franklin, Tensas

Shallow water platform Fredericksburg deposition occurred over most of east Texas, but farther to the east in northern Louisiana the section is partially truncated (Granata, 1963). In northern Louisiana the Middle-Upper Albian Paluxy, Walnut and Goodland formations are considered part of the Fredericksburg Group. The younger Upper Albian–Lower Cenomanian Washita Group is truncated and, in some cases, cannot be differentiated from the Fredericksburg Group in areas of Louisiana. Early workers like Spofford (1945), placed the Paluxy at the base of Fredericksburg (Walnut clays) and observed from well study that the Paluxy trended northwest and southeast through Caddo

Parish and northern De Soto Parish. To the west, the Goodland limestone, and the overlying Washita limestone and shale were also recognized in wells. Cullom et al. (1962) divided the Washita-Fredericksburg section into a lower Walnut Formation and an upper Goodland Formation. The former consists of dark shale and dense gray crystalline to earthy limestone found above the top of the Trinity and the latter unit consists of porous and non-porous light gray to tan crystalline, fossiliferous shallow water limestone and interbedded dark marine shale. The top of the Goodland is marked by the unconformity between beds of Comanchean and those of Gulfian age. According to these authors, post-Comanchean truncation on the south flank of the South Arkansas Uplift was cited as being responsible for the erosion of the beds of Washita age. Across the southern platform area, between 700 and 1,200 ft of Comanchean section is missing due to the uplift and truncation that accompanied the South Arkansas Uplift. Granata (1963) reported that the entire Washita Group is only present in a narrow band in east Texas that trends north into Arkansas but thins east and is no longer present at the north Louisiana border. According to Granata (1963), the end of Comanchean time was characterized by uplift and erosion across east Texas, southern Arkansas, north Louisiana and across into west central portions of Mississippi. With the retreat of the seas in this region, workers estimate that up to 10,000 ft of sediments were removed by erosion in southwest Arkansas alone.

Minor hydrocarbon production occurs in Washita-Fredericksburg reservoirs. Depth to top of the pay ranges from 2,300 to 9,800 ft. The net pay of mostly gas prone carbonates is 10 to 30 ft thick. Although porosity can range from 10 to 30%, permeability tends to be low.

Upper Cretaceous Gulf Series (Tuscaloosa, Austin, Taylor, Navarro) Tuscaloosa Group

Producing Parishes

Bienville, Webster, Red River, Natchitoches, Bossier, De Soto, Richland, Franklin, Tensas, Concordia

According to Granata (1963), deposition of Woodbine in Texas and Tuscaloosa in Louisiana began with the advance of the Gulfian seas over Lower Cretaceous Comanchean formations. From northwestern Louisiana and eastward, the Tuscaloosa thickens from 100 to almost 1,000 ft at the Mississippi border (Cullom et al., 1962). In northern Louisiana, the Upper Cretaceous consists of the Eagle Ford and Tuscaloosa Group, including upper, middle and lower Tuscaloosa formations. The sequence consists mostly of red and gray shale, red and gray mudstone, gray siltstone, and fine- to medium-grained sandstone, that contain silt, ash, glauconite, mica and/or calcite. Conglomerate and/or pebbly sandstone and occasional thin, tan to gray fossiliferous limestone are also present.

Across northern Louisiana in the producing fields of Bienville, Richland, Franklin, Tensas and Concordia Parishes, the Tuscaloosa consists of fine- to coarse-grained quartz arenite and fossiliferous clays, ashy sand, red beds, gray shale, and minor chert gravel deposited in fluvial-deltaic to shallow marine environments. Generally, the Tuscaloosa is overlain by the shaly Eagle Ford Formation that averages approximately 100 ft in thickness (Lenert and Kidda, 1958; Morrow, 1958; Rogers, 1958). Production is from the basal sandstone of the lower Tuscaloosa where net porous sand ranges from 90 to 250 in thickness (Cullom et al., 1962). Depth to the top of the sandstone reservoirs across the region ranges from 2,400 to 9,700 ft. Production of 24° to 46° API gravity oil,

condensate, and gas is derived from quality reservoirs with porosities of 25 to 30% and permeabilities ranging from 200 to 2,000 md.

Austin Group

Producing Parishes

Caddo, Bossier, Webster, Claiborne, Union

The basal sediments of the Austin Group were deposited over a truncated surface of the Tuscaloosa Group (Forgotson, 1958). In north Louisiana, the Austin Group includes the Brownstown and Tokio formations, with a thickness that ranges from zero on the Monroe Uplift to over 2,000 ft in Central Louisiana (Cullom et al., 1962). These shallow marine deposits consist mainly of medium- to coarse-grained glauconitic carbonaceous and argillaceous sandstone and alternating chalky, shaly and silty units. Carbonates that replace the sand and shale to the south typically are chalk or marl and have poor definition on well logs. Ogier (1963) described the Tokio Formation as consisting of coarse, gray and brown crossbedded quartz and dark gray lignitic fossiliferous clay. In Caddo Parish, it attains a thickness of 620 ft on top of the Brownstown Formation. A number of reservoir quality sands exist within the Tokio and produce in Caddo, Bossier, and Webster Parishes. Located at depths of 2,400 to 3,100 ft, these reservoirs have porosities of 20 to 35% and permeabilities of 200 to 450 md. The overlying Brownstown Formation consists of dark gray calcareous clay or marl with sandy marl and fine-grained sand. The reservoir quality sands are reported to be located near the top of the formation in Caddo Parish (Ogier, 1963).

On the southern edge of the basin and overlying the Washita-Fredericksburg and parts of the older Cretaceous barrier reef system (Glen Rose), a band of Austin Chalk

extends from Texas through Vernon Parish to the southwestern corner of Mississippi and beyond to the southeast. In this area of southernmost north Louisiana, approximately 50 miles south of the nearest shallow piercement salt dome in the North Louisiana Salt Basin, the Austin Chalk consists primarily of compacted argillaceous foraminiferal and coccolith limestone (biomicrite) with interbeds of marl and bentonitic marl. Hydrocarbon targets in the chalk include the fractured basal section of the Austin. The hydrocarbon bearing target section is approximately 180 to 400 ft in thickness and encountered at drill-depths of 12,500 to 17,500 ft (Zimmerman, 1998). According to Zimmerman (1998), the reservoirs within this Texas-Louisiana trend generally have a dual pore system which is derived from a microporous matrix and fractures that yield low porosity and low permeability reservoirs with high water content and less than 50% residual oil saturations. In-situ matrix porosities and permeabilities are generally less than 5% and 0.05 millidarcies, respectively. Reservoir development is through long lateral (horizontal) wellbores.

Taylor Group

Producing Parishes

Caddo, Bossier, Webster, Claiborne, Bienville, De Soto, Red River, Sabine

The Taylor Group averages 300 ft thick in north Louisiana and includes the Saratoga Chalk, Marlbrook Marl, Annona Chalk, and the more siliciclastic Ozan Formation (Cullom et al., 1962). These are primarily shallow marine deposits consisting of hard, gray glauconitic fossiliferous chalk, calcareous shale, marl, fine-grained sandstone and siltstone on the Sabine Uplift and in south Arkansas. In Vernon Parish, these deposits were probably deeper water limestone. In Sabine Parish, production of light oil and

condensate from the Saratoga and Annona has been reported (Cameron, 1963; Woods, 1963). Where Taylor reservoirs produce in northern Louisiana they are located from 1,250 to 2,900 ft in depth. Production of light oil and condensate is derived from the deeper reservoirs with fracture porosity of 20 to 33% and permeability ranging from 100 to 1000 md. Farther to the north in Caddo Parish, the basal siliciclastic Ozan Formation is productive. The Ozan productive interval is called the Buckrange, located at 1,750 ft in the subsurface and averaging 30 ft thick. The reservoir consists of fine- to medium-grained calcareous and argillaceous sandstone interbedded with calcareous shale. According to Cullom et al. (1962), the greatest overall concentration of sands in the Ozan Formation is in southern Arkansas and northwest Louisiana, but coarse siliciclastics may be present to the south of the Sabine Uplift as well.

Navarro Group

Producing Parishes

Caddo, Bossier, Claiborne, Union

The uppermost sequence of the Gulfian Series is the Navarro Group consisting of the Nacatoch and Arkadelphia formations. The Nacatoch is a shallow marine deposit consisting predominantly of fine- to medium-grained unconsolidated quartz sandstone, sandy limestone, clay, marl, and shale. Sandstone tends to be glauconitic, ashy and argillaceous. The Arkadelphia also consists of shallow marine sediments, mainly light gray chalk/marl with calcareous, micaceous sandstone, and minor volcanic ash. The Navarro attains a maximum thickness of 600 ft in northwestern Louisiana. It thins southeasterly and gradually disappears in Natchitoches and Grant Parishes (Cullom et al., 1962). The Nacatoch is reported to have produced gas in shallow sandstones at depths of

960 ft in Caddo and Bossier Parishes. Where the Navarro produces, the reservoirs are located from 300 to 2,200 ft in depth. They have porosities of 20 to 28% and permeability of 200 to 2,500 md.

The Monroe Gas Rock Formation, originally described in the Monroe Gas field by Stroud and Shayer (1923), is a shallow marine deposit consisting of hard white and gray sandy chalk that produces in the Monroe Gas field in northeastern Louisiana. Other upper Cretaceous secondary reservoirs in the Monroe field area are the Arkadelphia, Nacatoch, and Ozan formations. Sourced through fracture systems from the Smackover, the Monroe Gas field is the largest gas field in Louisiana with a cumulative production of more than 7.3 trillion cubic feet of gas produced from the field since its discovery in 1916 (Zimmerman and Sassen, 1993). Its areal extent covers more than 365 square miles over a portion of a 25-township area within adjoining parts of 3 northeastern Louisiana Parishes: Union, Morehouse, and Ouachita. Depth to the top of the gas rock ranges from 2,000 to 2,500 ft with net pay of 10 to 70 ft. The porosity of the reservoir is from 5 to 25% and permeability can be as high as 500 md (Bebout et al., 1992).

Paleogene Paleocene-Eocene (Midway, Wilcox)

Midway Group

According to Murray (1955), the end of the Cretaceous is characterized by an interruption of deposition, accompanied by withdrawal of the seas, resulting in a widespread regional unconformity at the base of the Paleocene in the Coastal Plain province. Before the Cretaceous seas withdrew, they covered all of the Coastal Plain and much of the Central Interior of North America. Continued retreat of the early Tertiary seas in the Coastal Plain area is also evident because of appreciable quantities of later

Midwayan, shallow-water, lignitic, arenaceous to argillaceous, marginal marine deposits. In outcrops from eastern Texas, Rainwater (1964) identified the Midway as including shallow marine to moderately deepwater environments consisting of prodeltaic marine silts and clays that are very carbonaceous and with marine fossils.

Alexander (1935) in a study of well cuttings from wells drilled in southwest Arkansas and northwest Louisiana was able to identify the Midway section based upon his correlations of ranges of foraminifera. The only microfossils observed by Alexander (1935) in the upper, silty, non-calcareous Midway shale of this region are small species of *Ammobaculites* and *Spiroplectammina*. Highly calcareous shale, commonly marly or chalky in character, and rich in microfauna, is usually encountered within a few feet, after the first hyaline foraminifera appear. Cores from the Midway in Bossier and Webster Parishes, Louisiana, were also used to recognize and describe the lower part of the Midway Group as predominantly calcareous, with true chalk occurring as lenses in Arkansas and Louisiana. This study showed that the Midway Group ranges in thickness in southwest Arkansas and northwest Louisiana from about 400 to 600 ft, and that the basal, calcareous portion ranges in thickness from 40 to about 100 ft. The change from the calcareous, marly or chalky, shales of the lower Midway to the dark, steel-gray, finely laminated, silty shale or mudstone of the upper Midway, is apparently transitional (Alexander, 1935).

Murray (1955) stated that the contact between the Midway and the underlying Cretaceous strata in southern Arkansas is marked by a bed of white to gray ash, having a maximum observed thickness of about 6 ft. This bed of volcanic ash has been extensively used as a marker for the Midway-Cretaceous contact. In wells examined in southwestern

Arkansas and northwestern Louisiana, this bentonite bed was observed to lie either at the top, or in the uppermost part of the lower, calcareous section of the Midway.

Wilcox Group

Because of prolific hydrocarbon production from numerous reservoirs in Texas, Louisiana and Mississippi, the Wilcox Group of Paleocene/Eocene age, has been extensively studied (Echols and Malkin, 1948; Fisher and McGowen, 1967; Galloway, 1968; McCulloh and Eversull, 1986; Sassen et al., 1988; Tye et al., 1988, 1991; Echols, 1991; Echols and Goddard, 1992, 1993; Glawe, et al., 1999). Sourced primarily from the northeast and northwest, the Wilcox in northern Louisiana reaches a thickness of 1,000 ft; and where production exists in Winn Parish, it is 2,200 ft thick. In Colgrade field, the reservoirs are at a depth of 1,500 ft with porosities of 15 to 35% and permeability of 200 to 600 md (Nelson, 1963). In Natchitoches Parish, the Wilcox reservoirs are at a depth of 5,100 to 5,800 feet. Southeast of the North Louisiana Salt Basin, the Wilcox is oil productive in east-central Louisiana and adjoining southwest Mississippi (Echols, 1991). Echols (1991) estimated that over one billion barrels of oil remains in place for this area. The reservoirs are unstructured deltaic facies. The North Louisiana Salt Basin is filled with about 3,600 ft of deltaic sediments of the Wilcox Group, which is subdivided into upper, middle, and lower intervals. Wilcox production has totaled about one billion barrels of oil since the initial Wilcox discovery in the early 1940's. The Wilcox is considered a thick sequence of complexly interbedded, continental to deltaic deposits that consist of seven principal component facies of a delta system, including the (1) bar-finger sand facies, (2) interdistributary bay mud-silt facies, (3) distributary channel sand facies, (4) prodelta mud facies, (5) distributary mouth bar-delta front sand facies, (6)

interdistributary deltaic plain sand-mud-lignite facies, and (7) destructional phase sand-mud-lignite facies (Galloway, 1968). Tye et al. (1991) divided the Wilcox into five lithostratigraphic units on the basis of sedimentary processes and resistivity-log character, and mapped unit thicknesses and sand content in 22 parishes. Tye et al. (1991) showed the units varied from 115 to 1,000 ft in thickness and the sand content ranged from 25 to 60%.

Paleogene Eocene-Oligocene (Claiborne, Jackson, Vicksburg)

Claiborne Group

The Eocene Claiborne Group overlies the Wilcox Group and outcrops in many parts of north-central Louisiana and in southern Arkansas. In ascending order the group consists of the following units: 1) Cane River, consisting mainly of glauconitic very fossiliferous clay; 2) Sparta, a predominantly sandy sequence with interbedded clay lenses; 3) Cook Mountain, fossiliferous marine clay unit, and 4) Cockfield, composed mainly of fine-grained sands and silts (Andersen, 1960, 1993).

Jackson Group

The Eocene Jackson Group outcrops in a line trending northeast from the southern part of Sabine Parish through Grant and La Salle Parishes. Therefore, in northern Louisiana, this group is absent at the surface where only Claiborne and Wilcox Groups are present. The Jackson consists of fossiliferous clay and limestone and thick clays.

Vicksburg Group

The Oligocene Vicksburg Group more or less parallels the older Jackson Group in Sabine, Natchitoches, Grant, La Salle and Catahoula Parishes. The Vicksburg consists of

a basal crossbedded sand, a middle fossiliferous bentonic clay, and an upper marly clay unit.

Upper Jurassic Smackover Petroleum System

The Smackover petroleum system as described in this project is based on the study of the digitized well logs, cross sections, selected seismic sections, subsurface structure and isopach maps, geohistory (burial history) profiles, thermal maturation history profiles, hydrocarbon expulsion profiles, hydrocarbon flow pathway modeling, additional organic geochemical analysis (Table 5), the results from the basin modeling of the North Louisiana Salt Basin, and the results of the comparative study of the North Louisiana and Mississippi Interior Salt Basins. Our description of the Smackover petroleum system in the North Louisiana Salt Basin is consistent with how this petroleum system has been characterized in the Mississippi Interior Salt Basin by Mancini et al. (2003) and in our 2006 DOE report on the resource assessment of the deep gas resource of the onshore interior salt basins for the North Louisiana Salt Basin (Mancini et al., 2006a, 2008a). We summarize the description of this petroleum system as follows (Fig. 332).

The characteristics of the underburden rocks are a result of their rift-related history and include pre-rift Paleozoic crystalline and sedimentary rocks, Upper Triassic to Lower Jurassic graben-fill red beds, Middle Jurassic evaporites, and Upper Jurassic siliciclastics, and the overburden post-rift strata consist of Upper Jurassic, Cretaceous, Paleogene, and Neogene deposits.

Figure 332. Event chart for Smackover petroleum system, North Louisiana and Mississippi Interior Salt Basins (modified from Mancini et al., 2003).

Organic-rich and laminated lime mudstone of the lower to middle beds of the Upper Jurassic Smackover Formation serves as the regional source rock (Oehler, 1984; Sassen et al., 1987; Claypool and Mancini, 1989; Mancini et al., 2003, 2005, 2008a). Present-day Smackover microbial and amorphous lime mudstone beds average 0.58% of TOC in the North Louisiana Salt Basin (Table 2). To adjust for the loss of organic carbon caused by the thermal maturation process, Li (2006) used the conversion of Daly and Edman (1987). The use of this conversion indicates that the original TOC in the Smackover was reduced by 1.5 to 1.8 times during the thermal maturation process. An original TOC value of 1.00% was calculated and used in this study. Thermal maturation of the Type IIS kerogen in the Smackover exhibited vitrinite reflectance (R_o) percents of 0.5 (TAI of 2-) to 1.89 (TAI of 3+). Thermally mature Smackover source rock samples have HI values of 14-94 mg HC/g TOC (Table 5), with an average of 39 HC/g TOC (Mancini et al., 2008a). Sassen and Moore (1988) reported that thermally immature Smackover lime mudstone samples have HI values of 306-656 mg HC/g TOC. An original HI of 481 mg HC/g TOC was used in this project after Mancini et al. (2008a).

The generation of crude oil from the Smackover source rocks in the North Louisiana Salt Basin has been interpreted to have been initiated at a level of thermal maturity of 0.55% R_o (435°C T_{max} ; 2 TAI) and concluded at a level of thermal maturity of 1.5% R_o (470°C T_{max} ; 3 TAI) (Nunn and Sassen 1986; Sassen and Moore 1988). This requires a depth of burial of 9,840 ft according to Driskill et al. (1988). Nunn and Sassen (1986) reported that the generation of crude oil was initiated at a depth of 11,500 ft. The generation of crude oil was determined to have been initiated from basinal Smackover lime mudstone beds in the Early Cretaceous, and the generation and migration of low to

intermediate gravity crude oil is interpreted to have continued into Cenozoic time (Nunn and Sassen 1986; Driskill et al. 1988; Sassen and Moore 1988). Updip Smackover lime mudstone beds have been reported to have generated low gravity crude oil beginning in the Late Cretaceous or 20 my later than the basinal lime mudstone (Driskill et al. 1988). At a depth of burial of 16,400 to 19,700 ft, the basinal Smackover lime mudstone beds were determined to be over-mature for the generation of crude oil (Nunn and Sassen 1986; Driskill et al. 1988). The low to intermediate gravity crude oils that migrated into reservoirs were subjected to thermal cracking with increasing depth of burial and time (Sassen and Moore, 1988; Claypool and Mancini, 1989).

From burial history and thermal maturation history profiles for wells in the North Louisiana Salt Basin (Figs. 62, 66, 108, and 112), hydrocarbon generation and maturation trends can be observed. In wells in much of the North Louisiana Salt Basin, the generation of hydrocarbons from Smackover lime mudstone was initiated at 6,000 to 8,500 ft during the Early Cretaceous from the southern part of the basin and continued into the Paleogene. For this study, the initiation of oil and associated gas was at a Ro level of 0.55%, and the commencement of essentially only thermogenic gas generation was at a Ro level of 1.3%. Cessation of thermogenic gas generation was at a Ro level of 4.0%. Hydrocarbon expulsion (Figs. 150 and 154) and migration (Figs. 326-328) from Smackover source rocks in the North Louisiana Salt Basin commenced during the Early Cretaceous and continued into the Paleogene with peak expulsion mainly in the Early to Late Cretaceous. The hydrocarbon expulsion profiles for the wells are in agreement with the thermal maturation profiles. The timing of commencement of hydrocarbon expulsion is consistent with the tectonic, depositional, burial and thermal maturation histories of the

basin. Hydrocarbon flow pathway modeling supports an intermediate range migration process for Smackover hydrocarbons. Smackover hydrocarbon migration into overlying strata was facilitated by vertical migration along faults. Evans (1987), Sassen (1990) and Zimmerman and Sassen (1993) also published information in support of combined intermediate range and vertical hydrocarbon migration in this area. Smackover hydrocarbons migrated into Upper Jurassic, Cretaceous, and lower Paleogene sandstone and carbonate reservoirs.

These reservoir rocks include Upper Jurassic, Cretaceous, and Paleogene nonmarine, coastal, nearshore, marine shelf, and deep-marine siliciclastics and nearshore marine, shelf, ramp, and reef carbonates (Table 4). Porosity is chiefly depositional in the sandstone reservoirs and includes depositional and diagenetic resulting from dissolution and diagenesis in the carbonate reservoirs. Fracture porosity is common in the sandstone and carbonate reservoirs. Specific petroleum reservoir rocks in the North Louisiana Salt Basin include the Upper Jurassic Smackover limestone, Haynesville (Buckner) sandstone and limestone, and Cotton Valley (Schuler) sandstone and limestone; the Lower Cretaceous Hosston sandstone, Sligo limestone, Pine Island sandstone, James limestone, Rodessa limestone, Ferry Lake limestone, Mooringsport limestone, Paluxy sandstone, and Fredericksburg limestone; the Upper Cretaceous Tuscaloosa/Eagle Ford sandstone, Austin sandstone and chalk, Taylor chalk and sandstone, Navarro sandstone and Monroe gas rock chalk; and Lower Paleogene Wilcox sandstone (Tables 3-4).

Petroleum seal rocks consist of Upper Jurassic and Lower Cretaceous anhydrite and shale, Upper Cretaceous chalk and shale, and lower Paleogene (Fig. 325). Specific petroleum seal rocks in the North Louisiana Salt Basin include the Upper Jurassic

Buckner anhydrite and Cotton Valley (Bossier) shale; the Lower Cretaceous Pine Island shale, Bexar shale, Ferry Lake anhydrite, and Paluxy shale; the Upper Cretaceous Eagle Ford shale; and the Lower Palogene Midway shale.

Petroleum traps include structural, stratigraphic, and combination structural-stratigraphic. Salt related structures are common and consist of pillows, diapirs, extensional faults and half grabens (Fig. 2). Rift-related Paleozoic basement paleohighs, such as the Sabine and Monroe uplifts, produce opportunities for combination stratigraphic and structural traps and the development of stratigraphic traps.

Lower Cretaceous/Upper Jurassic Bossier Petroleum System

The Bossier petroleum system as described in this project is based on the study of the digitized well logs, cross sections, selected seismic sections, subsurface structure and isopach maps, geohistory (burial history) profiles, thermal maturation history profiles, hydrocarbon expulsion profiles, hydrocarbon flow pathway modeling, additional organic geochemical analysis (Table 6), and the results from the basin modeling of the North Louisiana Salt Basin. Upper Jurassic (Tithonian) to Lower Cretaceous (Berriasian) Bossier shale beds have been described as source rocks in the East Texas Salt Basin by Ridgley et al. (2006), and Hermann et al. (1991) reported that gas in the Ruston Field of north Louisiana was sourced by Cotton Valley shale beds. A preliminary evaluation of the Bossier in the North Louisiana Salt Basin indicated that these shale beds were possible source rocks in this basin given the proper organic facies and sufficient total organic carbon contents for they have experienced the required thermal conditions for thermogenic hydrocarbon generation (Table 1).

To constrain the stratigraphic positions of the samples taken for geochemical analyses and to observe the thickness of the Bossier shale in the basin, north-south and west-east regional stratigraphic cross sections were constructed by us using several selected wells (Figs. 333-337 and Tables 7-10). These correlations show that the Bossier thickness increases from north to south and ranges from 350 feet in the north to over 2000 feet to the south, and averages approximately 1000 feet within the North Louisiana Salt Basin. Bossier shale thickness also increases in an easterly direction. Thin section petrography by us shows that the Bossier interval is diverse lithologically consisting of the following rock types: muddy fine-grained sandstone, laminated fine-grained sandstone, sandy mudstone, and silty mudstone (338-341).

Samples of Bossier, Cotton Valley and Haynesville rocks in the basin were collected from cored wells for organic geochemical analyses. From our geochemical analyses, we found the following. Vitrinite particles had %Ro values that range from 0.91 to 2.62. The total organic carbon (TOC) contents of these samples range from 0.19% to 0.75% for the Bossier, which are low values for shale (Table 6). The S_1 and S_2 values from Rock Eval pyrolysis are low, and the S_2 versus TOC diagram (Fig. 342) shows the samples plotting below the HI 200 line and mainly in the Type III and IV kerogen fields of the diagram because of the low S_2 and TOC values. We found that the hydrogen index (HI) for these samples ranged from 14 to 147 and that the oxygen index ranged from 0 to 109. An HI vs. OI diagram suggests that these rocks are mostly gas generative, which is typical for Type III kerogen (Fig. 343). A %Ro versus depth plot shows that the Bossier samples mainly fall in the principal zone of gas formation (Fig. 344). Rock Eval pyrolysis data combined with visual kerogen study indicate that the Bossier is gas prone (Fig. 345). Our visual kerogen

determination through petrographic analysis demonstrated that the principal kerogen types in these samples included liptinite, vitrinite, and minor amounts of inertinite and humic debris (Figs. 346-348). These kerogen types originate from land plants and tend to mature along the Type III kerogen pathway, indicating that they are gas-prone.

Based on these data and analyses, we concluded that the Bossier shale beds are thermally mature and represent petroleum source rocks that generated and potentially expelled mostly gas and some oil. These shale beds at their present maturity level have mostly low to moderate total organic carbon contents and Type III kerogen. Original kerogen types in the immature stage, as assessed by kerogen petrography, were mainly gas-prone Type III and some oil and gas prone Type II/III. The principal macerals are partly oxidized, unstructured amorphous organic matter (liptinite) and vitrinite in varying proportions. Amorphous material was derived from degraded marine algal and humic matter (higher plant material). Visual kerogen data support the predominantly gas-prone nature of the source rocks. Vitrinite reflectance (R_o) values (0.91% to 2.62%) and thermal alteration indices (TAI) values of 2^+ to 3^+ suggest that these source rocks entered the late oil window to main gas maturity window and thus have generated mostly gas with some oil. Through thin section petrography of the samples collected in the geochemically analyzed intervals, we found that the following rock types characterized the Bossier: muddy fine-grained sandstone, laminated fine-grained sandstone, sandy mudstone, and silty mudstone. These combined analytical results indicate that abundant woody organic material of continental origin was deposited in offshore areas in association with fine siliciclastic sediments in a marine prodelta environment during the Late Jurassic to Early Cretaceous. We concluded that the thickness and widespread

deposition of predominantly gas-prone source rocks within this basin and their high thermal maturity led to potential sourcing of mainly thermogenic gas that was first generated from source beds in the southern part of the basin (Mancini et al., 2008a).

The Bossier unconventional petroleum system includes basically the same underburden and overburden rocks as the Smackover petroleum system. The petroleum source and seal rocks are the Bossier shale beds. Potential generation of liquid hydrocarbons was initiated in the late Early Cretaceous; and thermogenic gas from Type III kerogen commenced in the late Early to Late Cretaceous (Figs. 349-351). Hydrocarbon expulsion appears minimal because of a insufficient saturation level caused by the low TOC values, kerogen type, and rock pyrolysis data resulting in the Bossier having potential as an unconventional shale gas reservoir (Fig. 352). The Type III kerogen in these beds is gas-prone, and the total organic carbon content in this shale is low. These factors resulted in a saturation threshold that was not adequate to promote expulsion. Therefore, most of the gas generated probably was retained in the Bossier making this shale a potential unconventional gas reservoir. Thermogenic gas principally migrated laterally and vertically within the Bossier following heterogeneities in Bossier lithology and stratigraphic bedding and lamination. Siliceous beds within the Bossier served potentially as reservoirs and Cotton Valley sandstone beds also probably acted as reservoirs for the hydrocarbons that were expelled from the Bossier shale beds. Thermogenic gas, if expelled from the Bossier, migrated vertically into the Cotton Valley in the Tertiary via faults (Figs. 353-354).

Refined Reservoir and Associated Resource Assessment

The refined assessment of the potential undiscovered and underdeveloped reservoirs

and associated resources based on petroleum system study and sequence stratigraphic analysis confirms that the potential undiscovered and/or underdeveloped reservoirs in the North Louisiana Salt Basin are pre-rift subsalt Triassic Eagle Mills sandstone and deeply buried Upper Jurassic Norphlet transgressive aggrading sandstone facies and regressive infilling Smackover carbonate facies; Upper Jurassic-Lower Cretaceous regressive infilling Bossier and Cotton Valley siliciclastic facies; and Lower Cretaceous transgressive aggrading Hosston sandstone facies and regressive infilling Sligo, James, Rodessa, Mooringsport-Glen Rose, and Fredericksburg (Goodland) carbonate facies. Petroleum system characterization and modeling further show that thermogenic gas is probably the hydrocarbon resource that will be associated with these deeply buried reservoirs (Fig. 331). These potential reservoirs are projected to be associated with salt-cored structures in the basin proper and with combination structural and stratigraphic and stratigraphic traps on the Sabine and Monroe uplifts. The Lower Cretaceous (Valanginian) unconformity on the Sabine Uplift and the Upper Cretaceous (mid-Cenomanian) unconformity on the Monroe Uplift have potential as stratigraphic traps. Petroleum system modeling indicates that the upper depth limit for secondary thermogenic gas generation in this basin is 12,000 ft. Using a petroleum system approach for resource assessment, Mancini et al. (2008a) estimated that potentially 67-115 trillion cubic feet of in-place thermogenic gas remains to be recovered in this basin assuming a gas expulsion, migration, and trapping efficiency of 2-3%.

Sequence stratigraphic analysis and particularly the use of transgressive-regressive sequences assists with the identification of specific facies in the North Louisiana Salt Basin that have reservoir potential. Using a classification based on transgressive-

regressive sequences, we assigned known reservoirs and their associated production in the North Louisiana and Mississippi Interior Salt Basins to specific systems tracts and facies associations (Tables 11-12). This classification showed that potential underdeveloped reservoirs include Lower Cretaceous sandstone and limestone and Upper Cretaceous sandstone. The potential Upper Cretaceous sandstone reservoirs are transgressive backstepping facies associated with a transgressive-regressive sequence (Fig. 325). These facies onlap onto the Monroe Uplift, resulting in stratigraphic and combination structural and stratigraphic traps (Figs. 2 and 12). Specifically, these sandstone units, which are associated with crude oil, include the Tokio, Ozan, and Nacatoch (Table 12). The potential Lower Cretaceous oil and gas reservoirs include transgressive aggrading Hosston sandstone facies and regressive infilling Paluxy sandstone facies and Sligo, James, Rodessa, and Fredericksburg carbonate facies.

Table 11. Oil and gas production for the North Louisiana and Mississippi Interior salt basins by reservoirs and facies associations of T–R sequences.

Reservoir	North Louisiana Salt Basin		Mississippi Interior Salt Basin		*T-R Facies
	Oil (bbls)	Gas (Mcf)	Oil (bbls)	Gas (Mcf)	
UPPER CRETACEOUS Arkadelphia/Monroe Gas Rock	44,038	7,452,904,183			RI
Selma/Jackson Gas Rock			39,205,424	224,393,889	RI
Nacatoch	758,374,196	4,431,274,239			TB
Ozan/Buckrange	265,037,353	1,007,534,243			TB
Tokio/Blossom	128,817,273	1,718,406,462			TB
Eutaw			301,449,711	1,754,506,272	TB
Tuscaloosa/Eutaw	3,971,873	75,601,381			TB/RI
Upper Tuscaloosa			26,338,415	19,226,238	RI
Lower Tuscaloosa			610,702,463	1,805,166,543	TA/TB
LOWER CRETACEOUS Dantzler			783,201	72,450,931	RI
Fredericksburg/Andrew	1,643,190	34,409,159	56,943,318	255,821,157	RI
Paluxy	6,206,760	88,408,279	56,544,588	568,991,732	RI
Mooringsport	312,309	1,171,999	11,633,767	215,885,662	RI
Ferry Lake			7,381	8,175	TB
Rodessa/Donovan	198,858,232	5,615,080,804	235,162,019	314,331,628	RI
James	12,409	2,869,335	902,320	80,356,905	RI
Pine Island	8,745,072	545,229,418	543,856	676,027	TB
Sligo	140,715,109	3,557,065,945	30,927,220	157,859,597	TB
Hosston	12,896,970	1,641,948,296	54,887,990	995,065,210	TA
UPPER JURASSIC Cotton Valley	114,348,835	2,223,486,076	106,461,276	146,163,240	RI
Haynesville	13,923,298	152,081,744	6,421,491	349,786,844	RI
Smackover	33,800,601	271,765,406	522,979,535	4,069,721,819	RI
Norphlet			12,664,335	331,269,443	TA

Production data for Louisiana are from the 2002 International Oil Scout Association Yearbook (2006, personal communication), production data for 2005 for Mississippi are from the Mississippi Oil and Gas Board (2006, personal communication, and production data for 2005 for Alabama are from the Alabama Oil and Gas Board (2006, personal communication). *T–R facies associations: TA=Transgressive aggrading, TB=Transgressive backstepping, RI=Regressive infilling.

Table 12. Summary of oil and gas production from the North Louisiana and Mississippi Interior salt basins by facies associations of T-R sequences.

Basin	*T-R RI Oil (billion/bbls)	T-R RI Gas (Tcf)	T-R TB Oil (billion/bbls)	T-R TB Gas (Tcf)	T-R TA Oil (billion/bbls)	T-R TA Gas (Tcf)
North Louisiana Salt Basin	0.369	15.841	1.306	11.334	0.013	1.642
Mississippi Interior Salt Basin	1.063	6.345	0.337	1.061	0.373	2.229
Total	1.432	22.186	1.643	12.395	0.386	3.871

Production data for Louisiana are from the 2002 International Oil Scout Association Yearbook (2006, personal communication), production data for 2005 for Mississippi are from the Mississippi Oil and Gas Board (2006, personal communication, and production data for 2005 for Alabama are from the Alabama Oil and Gas Board (2006, personal communication). *T-R facies associations: T-R RI=Regressive infilling, T-R TB=Transgressive backstepping, T-R TA=Transgressive aggrading.

Technology Transfer

Several presentations on the results of this work have been made at the annual meetings of the American Association of Petroleum Geologists and Gulf Coast Association of Geological Societies by Mancini, Li, Goddard, and Barnaby. Five technology transfer workshops have been conducted in Shreveport, Louisiana; Jackson, Mississippi; and Tuscaloosa, Alabama on the research results of this project. Research results from this project have been published in the Bulletin of the American Association of Petroleum Geologists (2 papers by Mancini et al., 2008) and in the Transactions of the Gulf Coast Association of Geological Societies (6 papers-2 by Mancini et al., 2005, 2007; 2 by Li, 2006, 1 by Barnaby, 2006, and 1 by Goddard et al. 2008). These papers are as follows:

Barnaby, R., 2006, Modeling of the burial and thermal history, organic maturation, and oil expulsion of the North Louisiana petroleum system, Gulf Coast Association of Geological Societies Trans. 56: 23-25.

Goddard, D.A, Mancini, E.A., Horn, M.R., and Talukdar, S.C., 2008, Hydrocarbon generating potential: Jurassic Cotton Valley-Bossier Group, North Louisiana Salt Basin, Gulf Coast Association of Geological Societies Trans. 58 (in press).

Li, P., 2006a, Modeling of thermal maturity history of strata in the North Louisiana Salt Basin area, Gulf Coast Association of Geological Societies Trans. 56: 439-454.

Li, P., 2006b, Reconstruction of burial history of strata in the North Louisiana Salt Basin area, Gulf Coast Association of Geological Societies Trans. 56: 455-472.

Mancini, E.A., Li, P., Goddard, D.A., and Zimmerman, R.K., 2005, Petroleum source rocks of the onshore interior salt basins, north central and northeastern Gulf of Mexico, Gulf Coast Association of Geological Societies Trans. 55:486-504.

Mancini, E. A., D. A. Goddard, P. Li, and V. O. Ramirez, 2007, Gas potential of deeply buried Mesozoic facies and reservoirs in the onshore interior salt basins, north central and northeastern Gulf of Mexico, Gulf Coast Association of Geological Societies Trans. 57:543-555.

Mancini, E.A., Li, P., Ramirez, V.O., Goddard, D.A., and Talukdar, S.C., 2008, Mesozoic (Upper Jurassic-Lower Cretaceous) deep gas reservoir play, central and eastern Gulf Coastal Plain, Am. Assoc. Petroleum Geologists Bull. 92:283-308.

Mancini, E. A., J. Obid, M. Badali, K. Liu, and W. C. Parcell, 2008, Sequence-stratigraphic analysis of Jurassic and Cretaceous strata and petroleum exploration in the central and eastern Gulf Coastal Plain, United States, Am. Assoc. Petroleum Geologists Bull. 92:1655-16.

Technical Reports

Quarterly, annual, first phase, second phase, and final reports on the results of this research projects have been prepared and submitted to DOE.

DISCUSSION

The principal objectives of the project, within a sequence stratigraphic framework, were to develop the concept that petroleum systems acting in a basin can be identified through basin analysis and to demonstrate that the information and analysis resulting from characterizing and modeling of the petroleum systems inherent to the North Louisiana Salt Basin and the Mississippi Interior Salt Basin can be used in providing a more reliable and advanced approach for targeting stratigraphic traps and potential reservoir facies and in providing a refined assessment of undiscovered and underdeveloped reservoirs and associated oil and gas resources.

The formulation of an integrated sequence stratigraphic and biostratigraphic framework is fundamental to stratal correlation, sedimentary basin analysis, petroleum systems studies, resource assessment, and in the development of an effective petroleum exploration strategy for a sedimentary basin. In studying, Upper Jurassic and Cretaceous strata of the Gulf Coastal Plain that are characterized by nonmarine to marine siliciclastic

and carbonate deposition and in which stratal patterns are driven by low-frequency, tectonic-eustatic events associated with post-rift, passive margin conditions similar to the strata in the North Louisiana Salt Basin, Mancini and Puckett (2002, 2003a) and Mancini et al. (2004) reported that a sequence stratigraphic analysis, based on the transgressive-regressive (T-R) sequences of Embry (1993, 2002) and integrated with biostratigraphy, is a useful method for establishing a stratigraphic framework for petroleum exploration in the interior salt basins of the Gulf Coastal Plain. In this project, we have found that the sequence stratigraphic classification (Fig. 325), based on T-R sequences and integrated with biostratigraphic data, established for this project and published in 2008 by Mancini et al. is optimal for studying the North Louisiana Salt Basin.

The Upper Jurassic and Cretaceous T-R sequences recognized by us provide a means for intrabasin correlation of strata within the North Louisiana Salt Basin and for interbasin correlation of the strata in this basin to those in the Mississippi Interior Salt Basin. Maximum flooding surfaces have been identified and correlated in these basins by us (Fig. 325). These regional marine flooding surfaces have been observed to be the key for potential correlation by Mancini and Puckett (2005) because these surfaces are assumed to approximate synchronous horizons. Based on available biostratigraphic data, surfaces of maximum transgression or maximum flooding surfaces approximate synchronicity in strata of the eastern and western Gulf Coastal Plain areas (Mancini et al., 1996). Correspondence of these T-R sequences and their associated maximum flooding surfaces in strata of the North Louisiana Salt Basin with those of the Mississippi Interior Salt Basin demonstrates the utility of constructing an integrated sequence-stratigraphic and biostratigraphic framework for regional correlation.

By using a T-R sequence stratigraphic approach for the North Louisiana Salt Basin, the interpretation of the geohistory of this basin is facilitated. The recognition of the systems tracts and associated facies associations is important to the identification of the potential petroleum systems and the component parts of these systems, such as potential petroleum source rocks. Beds of the transgressive backstepping facies associations and the lower part of the regressive infilling facies associations, which are separated by maximum flooding surfaces, have the highest source rock potential. These beds typically consist of marine shale and lime mudstone and typically are organic-rich. Fourteen maximum flooding surfaces were identified (Fig. 325). These major marine flooding events include the following: Oxfordian (Smackover), Kimmeridgian (Haynesville), Berriasian (Cotton Valley and Knowles), Aptian (Pine Island and Bexar), Albian (Ferry Lake, Goodland, and lower Washita), Cenomanian (upper Washita), Turonian (Eagle Ford), Campanian (Browstown and Marlbrook), Maastrichtian (Arkadelphia). The Oxfordian, Berriasian, Albian, and Turonian are petroleum source rocks in the Gulf of Mexico area (Mancini et al., 2006a); and, as a result of the basin analysis work performed as part of this project, the Oxfordian (Smackover) and Tithonian-Berriasian (Bossier) were found to have the highest source rock potential in the North Louisiana Salt Basin. Therefore, these were the two petroleum systems (Smackover and Bossier) studied.

The Smackover lime mudstone and the uppermost Jurassic and Lower Cretaceous shale beds (Bossier) also serve as petroleum seal rocks along with anhydrite beds of the Upper Jurassic Buckner (mainly regressive infilling facies association) and of the Lower Cretaceous Ferry Lake (transgressive backstepping facies association) (Fig. 325).

Sequence stratigraphic analysis is also important in identifying potential reservoir

facies. As part of this project, we used our established T-R sequence framework for classifying producing reservoirs in the North Louisiana and Mississippi Interior Salt Basins and published these results in Mancini et al. (2006a,b, 2008c). These reservoirs were classified as to their T-R systems tracts and facies (Table 11). The major oil reservoirs for the North Louisiana Salt Basin are Upper Cretaceous transgressive backstepping marine sandstone facies of T-R sequences. The chief gas reservoirs in this basin are Cretaceous regressive infilling nearshore marine, shelf, and reef carbonate facies and Cretaceous fluvial and marine sandstone facies (Tables 11, 12). The main oil reservoirs for the Mississippi Interior Salt Basin are Upper Cretaceous transgressive aggrading fluvial and coastal sandstone facies, and Upper Jurassic regressive infilling ramp and reef carbonate facies. The primary gas reservoirs are Cretaceous transgressive aggrading fluvial and coastal sandstone facies and transgressive backstepping marine facies, and Upper Jurassic regressive infilling ramp and reef carbonate facies. Transgressive aggrading eolian facies of the Upper Jurassic Norphlet Formation are a major gas reservoir in the offshore Alabama area (Mancini and Puckett, 2003b). The transgressive aggrading eolian and fluvial sandstone facies of the Norphlet Formation, the fluvial and coastal sandstone deposits of the Lower Cretaceous Hosston Formation, and the fluvial and coastal lower sandstone facies of the Upper Cretaceous Tuscaloosa Group have produced some 36% of the total gas volume for the onshore Mississippi and Alabama and offshore Alabama area (Mancini and Puckett, 2003b).

The prediction of potential reservoir facies is important in the design of a cost-effective oil and gas exploration strategy. As illustrated by the hydrocarbon productivity of the transgressive aggrading reservoirs in the eastern Gulf coastal plain, these facies

have excellent potential as exploration targets. The targets include Norphlet eolian and fluvial, Hosston fluvial and coastal, and lower Tuscaloosa fluvial and coastal sandstone facies (Table 4). These aggrading facies association intervals exceed a thickness of hundreds of feet and have a widespread geographic distribution. The sandstone deposits are quartz rich having porosities of 12 to 28.5% and permeabilities of 4 to 495 md (Mancini and Puckett, 2003b). Based on sequence stratigraphic analysis and production history, other high-potential reservoir intervals include Upper Jurassic and Cretaceous regressive infilling fluvial to nearshore marine Haynesville, Cotton Valley, Rodessa, Mooringsport, Paluxy, Fredericksburg, and Eutaw sandstone facies, and Upper Jurassic Smackover and Upper Cretaceous Selma (Jackson gas rock) marine shelf, ramp, and reef carbonate facies in the Mississippi Interior Salt Basin. In the North Louisiana Salt Basin, Upper Cretaceous transgressive backstepping nearshore marine sandstone facies of the Tokio, Ozan, and Nacatoch formations and regressive infilling nearshore marine, shelf, ramp, and reef carbonate facies of the Upper Jurassic Smackover, Lower Cretaceous Sligo and Rodessa, and Upper Cretaceous Arkadelphia (Monroe gas rock) formations and fluvial to marine sandstone facies of the Cotton Valley Group constitute high-potential reservoir intervals.

The T-R sequence classification for the North Louisiana Salt Basin can be used to identify sequence boundaries and unconformities that have high potential to be associated with a stratigraphic trap. From our interpretation of the geohistory of the North Louisiana Salt Basin, we have found that major base-level falls in the basin occurred during the Callovian-Oxfordian (Louann-Norphlet interval), Valanginian (Cotton Valley-Hosston interval), Cenomanian (Washita-Tuscaloosa interval), Turonian to Coniacian

(Eagle Ford-Tokio interval), and Campanian to Maastrichtian (Nacatoch interval) These findings are consistent with those of Pessagno (1990), Buffler (1999), McFarlan and Menes (1991), Salvador (1991a), Thompson et al. (1991), and Mancini et al. (1996). The Callovian-Oxfordian, Valanginian, and Cenomanian unconformities are especially significant products of these episodes of base-level fall (Buffler, 1991; McFarlan and Menes, 1991; Salvador, 1991a). Therefore, the opportunity for stratigraphic traps to have developed in the North Louisiana Basin area is high. The Mesozoic stratigraphic horizons (T-R sequence boundaries and associated unconformities) to search for include the Cotton Valley-Hosston boundary on the Sabine and Monroe uplifts and the Washita-Tuscaloosa, Eagle Ford-Tokio, and Nacatoch intra-formation boundaries on the Monroe Uplift.

In combining the sequence stratigraphic analysis with the results from this project on petroleum system study, an exploration strategy for deeply buried Mesozoic facies with reservoir potential can be formulated for siliciclastic and carbonate rocks. These potential reservoirs include Upper Jurassic and Lower Cretaceous facies of the Smackover, Cotton Valley, Bossier, Hosston, and Sligo stratigraphic units at depths greater than 20,000 ft. Vitrinite reflectance values of 1.89% at a depth of 17,480 ft have been reported by Mancini et al. (2006b) for the Cotton Valley Group in this basin. As shown by this vitrinite reflectance data and by the vitrinite reflectance profile (Fig. 331), these Upper Jurassic and Lower Cretaceous strata are projected to be in the thermogenic dry-gas generative and preservation window (R_o value range of 2.0-4.0) to 30,000 ft in this basin. Cotton Valley and Hosston potential gas reservoir facies are expected to be associated with transgressive and regressive deposits that accumulated in shallow-nearshore and

deep-marine sandstone deposits. Porosity is predicted to be a combination of depositional and diagenetic (fracture) in these sandstone reservoirs. The Smackover and Sligo potential gas reservoir facies are projected to be associated with carbonate nearshore, marine shelf, ramp, and reef deposits of transgressive and regressive systems tracts. Porosity is predicted to be diagenetic (vuggy and fracture) in these carbonate reservoirs.

The Mississippi Interior Salt Basin has potential for deeply buried Mesozoic gas reservoirs. The thermogenic gas in these reservoirs is interpreted to be from late thermal cracking of oil to gas in the source rock and is categorized as secondary, nonassociated gas based on using a depth limit of greater than 16,500 ft, which approximates the upper depth limit for secondary thermogenic gas generation for this basin. The potential reservoirs include Upper Jurassic and Lower Cretaceous facies of the Norphlet, Smackover, Haynesville, Cotton Valley, Hosston, and Sligo stratigraphic units at depths greater than 25,000 ft. Vitrinite reflectance values of 2.0% at a depth of 23,981 ft have been reported by Mancini et al. (2003) for the Smackover Formation in this basin. As shown by this vitrinite reflectance data and by the vitrinite reflectance profile in Figure 331, these Upper Jurassic and Lower Cretaceous strata are projected to be in the thermogenic dry-gas generative and preservation window (R_o value range of 2.0-4.0%) to 35,000 ft in this basin. Norphlet, Cotton Valley, and Hosston potential gas reservoir facies are expected to be associated with transgressive and regressive eolian, fluvial, coastal, and nearshore marine sandstone deposits. Porosity is predicted to be a combination of depositional and diagenetic (fracture) in these sandstone reservoirs. The Smackover, Haynesville, and Sligo potential gas reservoir facies are projected to be associated with transgressive and regressive carbonate nearshore, marine shelf, ramp, and

reef deposits. Porosity is predicted to be diagenetic (vuggy and fracture) in these carbonate reservoirs.

In using a combined petroleum system and sequence stratigraphic approach, an estimate of the volume of the in-place thermogenic gas that is potentially associated with these reservoir facies in this basin can be made. Potentially 67-115 trillion cubic feet of in-place thermogenic gas is available to be recovered in the North Louisiana Salt Basin, assuming a gas expulsion, migration, and trapping efficiency of 2-3%. This resource assessment was part of our 2006 DOE report and was published in 2008 by us.

CONCLUSIONS

1. Existing information and new data resulting from this study on the North Louisiana Salt Basin have been integrated into an electronic database, and regional cross sections have been developed. Structure, isopach, erosional thickness, and formation lithology maps have been constructed, and geohistory (burial history), thermal maturation history, and hydrocarbon expulsion profiles have been prepared. Seismic data, cross sections, subsurface maps, and geohistory (burial history), thermal maturation history, hydrocarbon expulsion profiles, hydrocarbon flow pathway modeling, and organic geochemical data have been used in evaluating the tectonic, depositional, burial and thermal maturation histories of the basin.

2. The origin of the North Louisiana Salt Basin is comparable to the origin of the Mississippi Interior Salt Basin. The geohistory of these basins is directly linked to the evolution of the Gulf of Mexico. The timing of tectonic events and the nature of the structural styles control the type and size of petroleum traps formed and the volume of

hydrocarbons contained within these traps. The dominant structural styles include salt-supported pillows, diapirs, anticlines, extensional faults, and half grabens and large regional Paleozoic domal basement structures, such as the Sabine and Monroe uplifts. These structural styles produced structural, combination structural and stratigraphic, and stratigraphic petroleum traps.

3. The main difference in the geohistories of the North Louisiana Salt Basin and the Mississippi Interior Salt Basin is the elevated heat flow the strata in the North Louisiana Salt Basin experienced in the Cretaceous due primarily to reactivation of basement faults resulting in upward movement, igneous activity, and erosion associated with the Monroe and Sabine uplifts. The Jackson Dome in the Mississippi Interior Salt Basin is a similar phenomenon, but the effects of this igneous intrusion are on a much lower level geographically.

4. The Upper Jurassic Smackover petroleum system is the principal petroleum system in these basins. The underburden, source, overburden, reservoir, and seal rocks associated with this petroleum system are a result of its rift-related geohistory. The Smackover lime mudstone generated hydrocarbons from Type IIS kerogen starting in the Early Cretaceous in the southern part of the North Louisiana Salt Basin and continuing into the Paleogene. Hydrocarbon expulsion and migration commenced during the Early Cretaceous and continued into the Paleogene. Vertical migration along faults and lateral migration along bedding planes, physical surfaces, and sequence boundaries are important to the productivity of these basins. In the North Louisiana Salt Basin, petroleum reservoirs include continental, coastal, and marine sandstone facies and nearshore marine, shelf, ramp, and reef carbonate facies. Seal rocks include Upper

Jurassic and Lower Cretaceous anhydrite and shale, Upper Cretaceous chalk and shale, and lower Paleogene shale.

5. The Upper Jurassic to Lower Cretaceous Bossier shale generated thermogenic gas from Type III kerogen. Siliceous beds in the Bossier serve as the reservoir rocks making the Bossier an unconventional petroleum system.

6. Potential undiscovered reservoirs in the North Louisiana Salt Basin are pre-rift subsalt Triassic Eagle Mills nonmarine sandstone and deeply buried Upper Jurassic to Lower Cretaceous transgressive aggrading and regressive infilling sandstone, shale, and limestone. Potential underdeveloped reservoirs include Lower Cretaceous regressive infilling sandstone and limestone and Upper Cretaceous transgressive backstepping sandstone.

7. Knowledge of basin geohistory and of the concepts of petroleum systems and sequence stratigraphy (transgressive-regressive sequences) facilitates the design of new exploration strategies for the targeting of potential combination structural and stratigraphic traps, potential stratigraphic traps, and specific facies with reservoir potential in a transgressive-regressive sequence. The Lower Cretaceous (Valanginian) and Upper Cretaceous (Cenomanian) unconformities and sequence boundaries have potential as stratigraphic traps throughout the North Louisiana Salt Basin area. In this basin, Upper Cretaceous sandstone reservoirs are recognized as transgressive backstepping facies in transgressive-regressive sequences that onlap onto the Monroe Uplift that serves as a combination structural and stratigraphic trap. Thermogenic gas is predicted to occur in Upper Jurassic to Lower Cretaceous transgressive aggrading sandstone facies and regressive infilling sandstone and carbonate facies that are deeply

buried and exhibit porousdepositional and diagenetic porosity. The Bossier shale is identified as a potential unconventional gas reservoir as a result of petroleum system study.

8. The utilization of an integrated sequence stratigraphic framework, in conjunction with sedimentary basin analysis and petroleum systems study, has resulted in a refined assessment of potential petroleum reservoirs and associated resources in the North Louisiana Salt Basin. Potentially 67-115 trillion cubic feet of in-place thermogenic gas remains to be recovered in this basin from undiscovered and underdeveloped reservoirs, assuming a gas expulsion, migration, and trapping efficiency of 2-3%.

REFERENCES

- Adams, G.S., 1985, Depositional history and diagenesis of the middle Glen Rose reef complex (lower Cretaceous), east Texas and Louisiana: Unpublished Master's Thesis, Louisiana State University, 200 p.
- Alexander, C.I., 1935, Stratigraphy of Midway Group (Eocene) of southwest Arkansas and northwest Louisiana: AAPG Bulletin, v. 19, no. 5, p. 696-699.
- Andersen, H.V., 1960, Geology of Sabine Parish, Louisiana Geological Survey, Geological Bulletin No. 34, 164 p.
- Andersen, H.V., 1993, Geology of Natchitoches Parish: Louisiana Geological Survey, Geological Bulletin No. 44, 227 p.
- Andrews, D.I., 1960, The Louann Salt and its relationship to Gulf Coast salt domes: GCAGS Transactions, v. 10, p. 215-240.
- Bailey, J., 1978, Black Lake Field Natchitoches Parish, Louisiana: a review, GCAGS Transactions, v. 28, p. 11-24.

- Baria, L.R., 1981, Waveland field: an analysis of facies, diagenesis, and hydrodynamics in the Mooringsport reservoirs: GCAGS Transactions, v. 31, p. 19-30.
- Bebout, D.G., 1978, Frio sandstone reservoirs in the deep subsurface along the Texas Gulf Coast: their potential for prediction of geopressed geothermal energy: BEG RI 91, 93 p.
- Bebout, D.G., and Garrett, C.M., et al., 1992, Upper Cretaceous Gas Rock—Louisiana and Mississippi: Atlas of Major Central and Eastern Gulf Coast Gas Reservoirs, Bureau of Economic Geology, University of Texas, p. 51.
- Beckman, M.W., and Bloomer, P.A., 1953, Athens Field, Claiborne Parish, Louisiana: Shreveport Geological Society; Reference Report on Certain Oil and Gas Fields of North Louisiana, South Arkansas, Mississippi and Alabama, v. III, no. 2, p. 41-53.
- Bishop, W.F., 1967, Age of pre-Smackover Formations, North Louisiana and South Arkansas: AAPG Bulletin v. 51, p. 244-250.
- Bishop, W.F., 1968, Petrology of upper Smackover Limestone in North Haynesville Field, Claiborne Parish, Louisiana: AAPG Bulletin, v. 52, no. 1, p. 92-128.
- Bishop, W.F., 1971, Geology of Upper Member of Buckner Formation, Haynesville Field area, Claiborne Parish, Louisiana: AAPG Bulletin, v. 55, p. 566-580.
- Breedlove, R.L., Jones, J.P., and Jackson, A.M., 1953, Ruston Field, Lincoln Parish, Louisiana: Shreveport Geological Society; Reference Report on Certain Oil and Gas Fields of North Louisiana, South Arkansas, Mississippi and Alabama, v. III, no. 2, p. 87-94.

- Breedlove, R.L, and Ogden, R.H., 1955, A study of the Crain trend of the Pettet Formation in the Bethany area of Texas and Louisiana: GCAGS Transactions, v. 5, p. 221.
- Buffler, R.T., 1991, Early evolution of the Gulf of Mexico basin, in D. Goldthwaite, ed., An Introduction to Central Gulf Coast geology, New Orleans, New Orleans Geological Society, p. 1-15.
- Buffler, R.T., and Sawyer, D.S., 1985, Distribution of crust and early history, Gulf of Mexico basin: GCAGS Transactions, v. 35, p. 333-344.
- Cagle, J.W., and Khan, M.A., 1983, Smackover-Norphlet stratigraphy, South Wiggins Arch, Mississippi and Alabama: GCAGS Transactions, v. 33, p. 23-29.
- Cameron, L.G., 1963, Pendleton-Many-Ft. Jesup Field, Sabine Parish Louisiana: Shreveport Geological Society; Report on Selected North Louisiana and South Arkansas Oil and Gas Fields, v. V, p. 160-176.
- Claypool, G.E., and Mancini, E.A., 1989, Geochemical relationships of petroleum in Mesozoic reservoirs to carbonate source rocks of Jurassic Smackover Formation, southwestern Alabama, AAPG Bulletin, v. 73, p. 904-924.
- Coleman, J.L., and Coleman, C.J. 1981, Stratigraphic, sedimentologic and diagenetic framework of the Jurassic Cotton Valley Terryville massive sandstone complex, North Louisiana: GCAGS Transactions, v. 31, p. 71-80.
- Collins, S.E., 1980, Jurassic Cotton Valley and Smackover reservoir trends, East Texas, North Louisiana, and South Arkansas: AAPG Bulletin, v. 64, p. 1004-1013.
- Crider, A.F., 1938, Geology of Bellevue oil field, Bossier Parish, Louisiana: AAPG Bulletin, v. 22, p. 1658-1681.

- Crump, J.H., 1953, Hico Field, Lincoln Parish: Shreveport Geological Society; Reference Report on Certain Oil and Gas Fields of North Louisiana, South Arkansas, Mississippi and Alabama, v. III, p. 75-81.
- Cullom, T., Granata, W., Gayer, S., Heffner, R., Pike, S., Hermann, L., Meyertons, C., and Sigler, G., 1962, The basin frontiers and limits for exploration in the Cretaceous System of central Louisiana: GCAGS Transactions, v. 12, p. 97-115.
- Davies D.K., Williams, B.P., and Vessell, R.K., 1991, Reservoir models for meandering and straight fluvial channels; examples from the Travis Peak Formation: GCAGS Transactions., v. 41, p. 152-174.
- Daly, A.R., and Edman. J.D., 1987, Loss of organic carbon from source rocks during thermal maturation (abs.): AAPG Bulletin, v. 71, p. 456.
- Dawson, W.C., and Callender, C.A., 1991, Petrography and diagenesis of Eagle Mills sandstones, subsurface—northeast Texas and southwest Arkansas: AAPG Bulletin, v. 75, p. 558. Deming, D. and D.S. Chapman, 1989, Thermal histories and hydrocarbon generation: Example from Utah-Wyoming thrust belt: AAPG Bulletin, v. 73, p. 1455-1471.
- Deming, D. and Chapman, D.S., 1989, Thermal histories and hydrocarbon generation: Example from Utah-Wyoming thrust belt: AAPG Bulletin, v. 73, p. 1455-1471.
- Dickinson, K.A., 1968a, Upper Jurassic stratigraphy of some adjacent parts of Texas, Louisiana, and Arkansas: USGS Prof. Paper 594-E, 25 p.
- Dickinson, K.A., 1968b, Petrology of Buckner Member of Haynesville Formation in adjacent parts of Texas, Louisiana, and Arkansas: Jour. Sed. Petrology, v. 38, p. 555-557.

- Dickinson, K.A., 1969, Upper Smackover carbonate rocks in northeastern Texas, and adjoining parts of Arkansas and Louisiana: GCAGS Transactions., v. 19, p. 175-187.
- Dobson, L.M., 1990, Seismic stratigraphy and geologic history of Jurassic rocks, northeastern Gulf of Mexico: Unpublished Master's Thesis, The University of Texas, Austin, 165 p.
- Dobson, L.M., and Buffler, R.T., 1991, Basement rocks and structure, northeast Gulf of Mexico: AAPG Bulletin, v. 75, p. 1521.
- Dow, W.G., 1977, Kerogen studies and geological interpretations: Jour. Geochem. Explor., v. 7, p. 79-99.
- Driskill, B.W., Nunn, J.A., Sassen, R., and Pilger, R.H. Jr., 1988, Tectonic subsidence, crustal thinning and petroleum generation in the Jurassic trend of Mississippi, Alabama and Florida: GCAGS Transactions, v. 38, p. 257-265.
- Dunbar, J.A., and Sawyer, D.S., 1987, Implications of continental crust extension for plate reconstructions; an example from the Gulf of Mexico: Tectonics, v. 6, p. 739-755.
- Dutton, S.P., Clift, S.J., Hamilton, D.S., Hamlin, H.S., and Hentz, T.F., 1993, Major low-permeability sandstone gas reservoirs in the continental United States: Bureau of Economic Geology, University of Texas/GRI Report of Investigations No. 211, 221 p.
- Dutton, S.P., and Finley, R.J., 1988, Controls on reservoir quality in tight sandstones of the Travis Peak Formation, east Texas SPE Paper #15220.
- Dutton, S.P., Laubach, S.E., Tye, R.S., Baumgardner, R.W., and Harrington, K.L., 1990, Geology of the Lower Cretaceous Travis Peak Formation, East Texas-depositional

- history, diagenesis, structure, and reservoir engineering implications: Bureau of Economic Geology, University of Texas/GRI Topical Report 90/0090, 170 p.
- Echols, D.J., and Malkin, D., 1948, Wilcox (Eocene) stratigraphy, a key to production: AAPG Bulletin, v. 32, p. 11-33.
- Echols, J.B., 1991, Sea level high stand shales and thin-stacked deltas, Paleocene Middle Wilcox of central Louisiana and Mississippi: GCAGS Transactions, v. 41, p. 221-236.
- Echols, J.B., and Goddard, D.A., 1992, Sea level fluctuations, Paleocene Middle Wilcox stratigraphy and hydrocarbon distribution in east-central Louisiana: GCAGS Transactions, v. 42, p. 333-340.
- Echols, J.B., and Goddard, D.A., 1993, Lower Wilcox reservoir characteristics: evidence for bypassed and subjacent hydrocarbon potential, east central Louisiana (abs): AAPG Bulletin, v. 77, no. 13, p. 96.
- Embry, A.F., 1993, Transgressive-regressive (T-R) sequence analysis of the Jurassic succession of the Sverdrup Basin, Canadian Arctic archipelago: Canadian Journal of Earth Sciences, v. 30, p. 301-20.
- Embry, A.F., 2002, Transgressive-regressive (T-R) sequence stratigraphy, in J.M. Armentrout and N.C. Rosen, eds., Sequence stratigraphic models for exploration and production: Evolving methodology, emerging models and application histories: Proceedings of the 22nd Annual Bob F. Perkins Research Conference: Houston, Gulf Coast Section, SEPM, p. 151-172.
- Evans, R., 1987, Pathways of migration of oil and gas in the south Mississippi Salt Basin: GCAGS Transactions, v. 37, p. 75-76.

- Eversull, L.G., 1985, Depositional systems and distribution of Cotton Valley blanket sandstones in northern Louisiana: GCAGS Transactions, v. 35, p. 49-57.
- Ewing, T.E., 1991, Structural framework: *in* A. Salvador, ed., The Gulf of Mexico Basin: Geological Society of America, Decade of North American Geology, v. J, p.31-52.
- Fisher, W.L., and McGowen, J.H., 1967, Depositional systems in the Wilcox Group of Texas and their relationship to occurrence of oil and gas: GCAGS Transactions, v. 17, p. 105-125.
- Forgotson, J.M., 1954, Regional stratigraphic analysis of Cotton Valley Group of Upper Gulf Coastal Plain: AAPG Bulletin, v. 38, p. 2476-2499.
- Forgotson, J.M., 1957, Stratigraphy of Comanchean Cretaceous Trinity Group: AAPG Bulletin, v. 41, p. 2328-2363.
- Forgotson, J.M., 1958, The basal sediments of the Austin Group and the stratigraphic position of the Tuscaloosa Formation of central Louisiana: GCAGS Transactions, v. 8, p. 117-125.
- Forgotson, J.M., 1963, Depositional history and paleotectonic framework of Comanchean Cretaceous Trinity Stage, Gulf Coast Area: AAPG Bulletin, v. 47, no. 1, p. 69-103.
- Forgotson, J.M., Jr., and Forgotson, J.M., 1975, "Porosity pod": concept for successful stratigraphic exploration of fine-grained sandstones: AAPG Bulletin, v. 59, p. 1113-1125.
- Forgotson, J.M., and Forgotson, J.M., Jr., 1976, Definition of Gilmer Limestone, Upper Jurassic formation, northeast Texas: AAPG Bulletin, v. 60, p. 1119-1123.

- Frizzel, L.G., 1987, North Shongaloo—Red Rock Field, Hill Sand (Rodessa), Webster Parish, Louisiana: Shreveport Geological Society Report on Selected Oil and Gas Fields, ARK-LA-TEX and Mississippi, v. VII, p. 80-84.
- Galloway, W.E., 1968, Depositional systems of the Lower Wilcox Group, North-Central Gulf Coast Basin: GCAGS Trans., v. 18, p. 275-289.
- Garner, N., Franks, C., and Livingston, J., 1987, Cotton Plant Field-Hosston, T13N-R2E, Caldwell Parish Louisiana: Shreveport Geol. Soc., Report on Selected Oil & Gas Fields, v. 7, p. 62-65.
- Glawe, L.N., Young, L.M., and Roberts, H.H., 1999, Petrology, paleontology, and paleoenvironments of Wilds and Lower Nichols sands; Paleocene Wilcox units of Louisiana: GCAGS Transactions, v. 49, p. 265-273.
- Gorrod, H.M., 1980, Clear Branch Field-Hosston, T-14 & 15N, R-1 & 2W, Jackson Parish, Louisiana: Shreveport Geol. Soc., Report on Selected Oil & Gas Fields, v. 6, p. 58-62.
- 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 W.A. Berggren, D.V. Kent, M.P. Aubrey, and J. Hardenbol, eds., *Geochronology, Time Scales and Global Stratigraphic Correlation*: SEPM Special Publication No. 54, p. 95-126.
- Granata, W.H., 1963, Cretaceous stratigraphy and structural development of the Sabine Uplift Area, Texas and Louisiana: Reference Report of the Shreveport Geological Society, v. 5, p. 50-96.
- Hazzard, R.T., Spooner, W.C., and Blanpied, B.W., 1947, Notes on the stratigraphy of the formations which underlie the Smackover Limestone in south Arkansas,

- northeast Texas, and north Louisiana: Shreveport Geological Society 1945 Reference Report, v. 2, p. 483-503.
- Herrmann, L.A., 1971, Lower Cretaceous Sligo reef trends in central Louisiana: GCAGS Transactions, v. 21, p. 187-198.
- Herrmann, L.A., 1976, James Limestone in Winn and Natchitoches Parishes, Louisiana: AAPG Bulletin, v. 60, p. 1611.
- Herrmann, L.A., Lott, J.A., and Davenport, R.E., 1991, Ruston field-USA Gulf Coast Basin, Louisiana: AAPG Special Volume; Structural Traps V, p. 151-186.
- Imlay, R.W., 1942, Late Paleozoic age of Morehouse Formation of northeastern Louisiana: AAPG Bulletin, v. 29, p. 451-453.
- Imlay, R.W., 1943, Jurassic formations of Gulf Region: AAPG Bulletin, v. 27, p. 1407-1533.
- Jackson, M.L.W. and Laubach, S.E., 1988, Cretaceous and Tertiary compressive tectonics as the cause of the Sabine Arch, East Texas and northeast Louisiana: GCAGS Transactions, v. 38, p. 245-256.
- Jarvis, G.T., and McKenzie, D.P., 1980, Sedimentary basin formation with finite extension rates: Earth and Planetary Science Letters, v. 40, p. 25-32.
- Kimball, C.E., Anderson, E.G., Sartin, A.A., and Young, L.M., 1989, Petrology and hydrocarbon potential of the Ferry Lake Anhydrite, Caddo Pine Island Field, Caddo Parish, Louisiana: GCAGS Transactions, v. 39, p. 141-151.
- Kingston, D.R., Dishroon, C.P., and Williams, P.A., 1983, Global basin classification system: AAPG Bulletin, v. 67, p. 2175-2193.

- Klitgord, K.D., Popence, P., and Schouten, H., 1984, Florida: a Jurassic transform plate boundary: *Jour. Geophysical Res.*, v. 89, p. 7753-7772.
- Koons, C.B., Bond, C.B., and Peirce, F.L., 1974, Effects of depositional environment and postdepositional history on chemical composition of Lower Tuscaloosa oils: *AAPG Bulletin*, v. 58, p. 1272-1280.
- Kornfeld, I.E., 1985, Depositional environments and hydrocarbon occurrence of Upper Jurassic Cotton Valley sandstones, Mississippi, Louisiana, and Texas: *AAPG Bulletin*, v. 69, p. 275.
- Kupfer, D.A., Crowe, C.T., and Hessenbruch, J.M., 1976, North Louisiana Basin and salt movements (halokinetics): *GCAGS Transactions*, v. 26, p. 94-110.
- Laubach, S.E. and Jackson, M.L.W., 1990, Origin of arches in the northwestern Gulf of Mexico basin: *Geology*, v. 18, p. 595-598.
- Lenert, H.A., and Kidda, M.K., 1958, Baskinton Field, Franklin Parish Louisiana: *Shreveport Geological Society Reference Report of Certain Oil and Gas Fields*, v. IV, p. 120-122.
- Li, P., 2006, Modeling of thermal maturity history of strata in the North Louisiana Salt Basin area: *GCAGS Transactions*, v. 56, p. 439-454.
- Lobao, J.J., and Pilger, R.H., 1985, Early evolution of salt structures in the North Louisiana Salt Basin: *GCAGS Transactions*, v. 35, p. 189-198.
- Lowrie, A., Sullivan, N.M., Krotzer, C., Carter, J., Lerche, I., and Petersen, K., 1993, Tectonic and depositional model of the north Louisiana-south Arkansas basin: *GCAGS Transactions*, v. 43, p. 231-238.

- MacRae, G., and Watkins, J.S., 1996, Desoto Canyon Salt Basin: tectonic evolution and salts structural styles, in J.O. Jones, and R.L. Freed, eds., Structural Framework of the Northern Gulf of Mexico, A Special Publication of GCAGS, Austin, GCAGS, p. 53-61.
- Mancini, E.A., Badali, M., Puckett, T. M., Llinas, J. C., and Parcell, W. C., 2001, Mesozoic carbonate petroleum systems in the northeastern Gulf of Mexico area, in Petroleum Systems of Deep-Water Basins: GCS-SEPM Foundation 21st Annual Research Conference, p. 423-451.
- Mancini, E.A., Mink, R.M., Bearden, B.L., and Wilkerson, R.P., 1985, Norphlet Formation (Upper Jurassic) of southwestern and offshore Alabama; environments of deposition and petroleum geology: AAPG Bulletin, v. 69, p. 881-898.
- Mancini, E.A., Goddard, D.A., Barnaby, R., and Aharon, P., 2006a, Resource assessment of the in-place and potentially recoverable deep natural gas resource of the onshore interior salt basins, north central and northeastern Gulf of Mexico: U.S. Department of Energy Final Technical Report, Project Number DE-FC26-3NT41875, 173 p.
- Mancini, E. A., Goddard, D.A., Obid, J.A., and Ramirez, V.O., 2006b, Characterization of Jurassic and Cretaceous facies and petroleum reservoirs in the interior salt basins, central and eastern Gulf coastal plain, in The Gulf Coast Mesozoic Sandstone Gas Province Symposium Volume: Tyler, East Texas Geological Society 2006 Symposium, p. 11-1 to 11-27.
- Mancini, E.A., P. Li, Goddard, D.A., Ramirez, V., and Talukdar, S.C., 2008a, Mesozoic (Upper Jurassic-Lower Cretaceous) deep gas reservoir play, central and eastern Gulf coastal plain: AAPG Bulletin, v. 93, p. 283-308.

- Mancini, E.A., P. Li, Goddard, D.A., and Zimmerman, R.K., 2005, Petroleum source rocks of the onshore interior salt basins, north central and northeastern Gulf of Mexico: GCAGS Transactions, v. 55, p. 486-504.
- Mancini, E. A., Obid, J., Badali, M., Liu, K., and Parcell, W.C., 2008c, Sequence-stratigraphic analysis of Jurassic and Cretaceous strata and petroleum exploration in the central and eastern Gulf Coastal Plain, United States, AAPG Bulletin, v. 92, p.1655-1686.
- Mancini, E. A., Obid, J., and Puckett, T.M., 2004, Upper Jurassic transgressive-regressive sequences, Mississippi Interior Salt Basin area: Gulf Coast Association of Geological Societies Transactions, v. 54, p. 415-424.
- Mancini, E.A., Parcell, W.C., Ahr, W.M., Ramirez, V.O., Llinas, J.C., and Cameron, M., 2008b, Upper Jurassic updip stratigraphic trap and associated Smackover microbial and nearshore carbonate facies, eastern Gulf Coastal Plain, AAPG Bulletin, v. 92, p. 417-442.
- Mancini, E.A., Parcell, W.C., Puckett, T.M., and Benson, D.J., 2003, Upper Jurassic (Oxfordian) Smackover carbonate petroleum system characterization and modeling, Mississippi interior salt basin area, northeastern Gulf of Mexico, USA: Carbonates and Evaporites, v. 18, p. 125-150.
- Mancini, E. A., and Puckett, T.M., 2002, Transgressive-regressive cycles in Lower Cretaceous strata, Mississippi Interior Salt Basin area of the northeastern Gulf of Mexico, U.S.A.: Cretaceous Research, v. 23, p. 409-438.

- Mancini, E. A., and Puckett, T.M., 2003a, Integrated biostratigraphic and sequence stratigraphic approach for correlation and basin interpretation: GCAGS Transactions, v. 53, p. 517-526.
- Mancini, E. A., and Puckett, T.M., 2003b, Petroleum potential of aggrading sandstones of transgressive-regressive cycles in the Mississippi-Alabama area: GCAGS Transactions, v. 53, p. 527-536.
- Mancini, E. A., and Puckett, T.M., 2005, Jurassic and Cretaceous transgressive-regressive (T-R) cycles, northern Gulf of Mexico, U.S.A.: Stratigraphy, v. 2, p. 31-48.
- Mancini, E. A., and Tew, B.H., 1991, Relationships of Paleogene stage and planktonic foraminiferal zone boundaries to lithostratigraphic and allostratigraphic contacts in the eastern Gulf coastal plain: Journal of Foraminiferal Research, v. 21, p. 48-66.
- Mancini, E.A., Puckett, T.M., Parcell, W.C., and Panetta, B., 1999, Basin analysis of the Mississippi interior salt basin and petroleum system modeling of the Jurassic Smackover Formation, Eastern Gulf Coastal Plain; U.S. Department of Energy Topical Reports 1 and 2, Project DE-FG22-96BC14946, 425 p.
- Mancini, E. A., Puckett, T.M., and Tew, B.H., 1996, Integrated biostratigraphic and sequence stratigraphic framework for Upper Cretaceous strata of the eastern Gulf Coastal Plain, U.S.A.: Cretaceous Research, v. 17, p. 645-669.
- Mann, C.J., and Thomas, W.A., 1964, Cotton Valley Group (Jurassic) nomenclature, Louisiana and Arkansas: GCAGS Transactions, v. 14, p. 143-152.

- McCulloh, R.P., and Eversull, L.G., 1986, Shale-filled channel system in the Wilcox Group (Paleocene-Eocene), north-central south Louisiana: GCAGS Transactions, v. 36, p. 213-218.
- McFarlan, E., Jr., and Menes, L.S., 1991, Lower Cretaceous, in A. Salvador, ed., The Gulf of Mexico Basin: Decade of North American Geology: Boulder, Geological Society of America, p. 181-204.
- McNamee, D.F., 1969, The Glen Rose reef complex of east Texas and central Louisiana: GCAGS Transactions, v. 19, p. 11-21.
- Miller, J.A., 1982, Structural control of Jurassic sedimentation in Alabama and Florida: AAPG Bulletin, v. 66, p. 1289-1301.
- 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: Geological Survey of Alabama Bull. 140, 58 p.
- Mitchell-Tapping, H.J., 1981, Petrophysical properties of the Sligo Formation of northern Louisiana and Arkansas: GCAGS. Transactions, v. 31, p 155-166.
- Montgomery, S.L., Petty, A.J., and Post, P.J., 2002, James Limestone, northeastern Gulf of Mexico: Refound opportunity in a Lower Cretaceous trend: AAPG Bulletin, v. 86, p. 381-398.
- Moore, C.H., and Druckman, Y., 1981, Burial diagenesis and porosity evaluation, upper Jurassic Smackover, Arkansas and Louisiana: AAPG Bulletin, v. 65, p. 597-628.

- Morrow, E.H., 1958, Topy Creek Field, Bienville Parish, Louisiana: Shreveport Geological Society Reference Report of Certain Oil and Gas Fields, v. IV, p. 117-119.
- Murray, G.E., 1955, Midway Stage, Sabine Stage, and Wilcox Group: AAPG Bulletin, v. 39, p. 671-696.
- Murray, G.E., 1961, Geology of the Atlantic and Gulf coastal province of North America: New York, Harper and Bros., 692 p.
- Nelson, N.E., 1963, Colgrade Field Winn Parish, Louisiana: GCAGS Transactions, v. 13, p. 3-7.
- Nichols, J.L., 1958, Sligo stratigraphy of North Louisiana, Arkansas and east Texas: Shreveport Geological Society Reference Report on Certain Oil and Gas Fields, v. IV, p. 124.
- Nunn, J.A., 1984, Subsidence histories for the Jurassic sediments of the northern Gulf Coast: thermal-mechanical model: Third Annual Research Conf., Gulf Coast Section, SEPM Foundation, p. 309-322.
- Nunn, J.A., and Sassen, R., 1986, The framework of hydrocarbon generation and migration, Gulf of Mexico continental slope: GCAGS Transactions, v. 36, p. 257-262.
- Oehler, J.H., 1984, Carbonate source rocks in the Jurassic Smackover trend of Mississippi, Alabama, and Florida, in J.G. Palacas, ed., Petroleum Geochemistry and Source Rock Potential of Carbonate Rocks, AAPG Studies in Geology, v. 18, p. 63-69.

- Ogier, S.H., 1963, Stratigraphy of the Upper Cretaceous Tokio Formation, Caddo Parish, Louisiana: Shreveport Geological Society: Report on Selected North Louisiana and South Arkansas Oil and Gas Fields, v. V, p. 97-107.
- Palacas, J.G., 1978, Preliminary assessment of organic carbon content and petroleum source rock potential of Cretaceous and Lower Tertiary carbonates, South Florida Basin: GCAGS Transactions, v. 28, p. 357-381.
- Palacas, J.G., Anders, D.E., and King, J.D., 1984, South Florida Basin—A prime example of carbonate source rocks for petroleum, in J.G. Palacas, ed., Petroleum Geochemistry and Source Rock Potential of Carbonate Rocks: AAPG Studies in Geology, v. 18, p. 71-96.
- Parker, T.J., and McDowell, A.N., 1955, Model studies of salt-dome tectonics: AAPG Bulletin, no. 12, v. 39, p. 2384-2470.
- Pessagno Jr., E. A., 1990, Cretaceous microfossils of north central Texas, micropaleontology field trip: Geological Society of America 1990 Annual Meeting Guidebook, 48 p.
- Petty, A.J., 1995, Ferry Lake, Rodessa, and Punta Gorda Anhydrite bed correlation, Lower Cretaceous, offshore eastern Gulf of Mexico: GCAGS Transactions, v. 45, p. 487-493.
- Pilger, R.H., Jr., 1981, The opening of the Gulf of Mexico: implications for the tectonic evolution of the northern Gulf Coast: GCAGS Transactions, v. 31, p. 377-381.
- Pindell, J.L., 1985, Alleghenian reconstruction and subsequent evolution of the Gulf of Mexico, Bahamas, and Proto-Caribbean: Tectonics, v. 4, p. 1-39.

- Pitman, J.C., 1985, Correlation of beds within the Ferry Lake Anhydrite of the Gulf Coastal Plain: GCAGS Transactions, v. 35, p. 251-260.
- Rainwater, E.H., 1964, Transgressions and regressions in the Gulf Coast Tertiary: GCAGS Transactions, v. 14, p. 217-230.
- Ridgley, J.L., King, J.D., and Pawlewicz, M.L., 2006, Geochemistry of natural gas and condensates and source rock potential of the Jurassic Bossier Formation and adjacent formations, East Texas Salt Basin, in The Gulf Coast Mesozoic Sandstone Gas Province Symposium Volume: East Texas Geological Society Symposium, Tyler, Texas, p. 5-1 to 5-37.
- Roberts, J.L., and Lock, B.E., 1988, The Rodessa Formation in Bossier Parish Louisiana: lithofacies analysis of a hydrocarbon productive shallow water clastic-carbonate sequence: GCAGS Transactions, v. 38, p. 103-111.
- Rogers, R.L., 1958, Killens Ferry Field, Franklin and Tensas Parishes, Louisiana: Shreveport Geological Society Reference Report of Certain Oil and Gas Fields, v. IV, p. 137-140.
- Rogers, R.L., 1987, Palynological age determination for Dorcheat and Hosston Formations—Jurassic-Cretaceous Boundary in northern Louisiana: AAPG Bulletin, v. 71, p. 1121.
- Salvador, A., 1987, Late Triassic-Jurassic paleogeography and origin of Gulf of Mexico basin: AAPG Bulletin, v. 71, p. 419-451
- Salvador, A., 1991a, The Gulf of Mexico Basin: decade of North American geology, v. DNAG, v. J: Boulder, Colorado, GSA, 568 p.

- Salvador, A., 1991b, Triassic-Jurassic, in A. Salvador, ed., The Gulf of Mexico Basin, Boulder, Colorado, GSA, p. 131-180.
- Sassen, R., Tye, R.S., Chinn, E.W., and Lemoine, R.C., 1988, Origin of crude oil in the Wilcox trend of Louisiana and Mississippi: evidence of long-range migration: AAPG Bulletin, v. 72, p. 1122-1123.
- Sassen, R., 1990, Lower Tertiary and Upper Cretaceous source rocks in Louisiana and Mississippi: implications to Gulf of Mexico crude oil: AAPG Bulletin, v. 74, p. 857-878.
- Sassen, R., and Moore, C.H., 1988, Framework of hydrocarbon generation and destruction in eastern Smackover trend: AAPG Bulletin, v. 72, p. 649-663.
- Sassen, R., Moore, C.H., and Meendsen, F.C., 1987, Distribution of hydrocarbon source potential in the Jurassic Smackover Formation: Organic Geochemistry, v. 11, p. 379-383.
- Saucier, A.E., Finley, R.J., and Dutton, S.P., 1985, The Travis Peak (Hosston) Formation of east Texas and north Louisiana: SPE/DOE Paper #13850, Conference on Low Permeability Gas Reservoirs, Denver, Colorado. p. 15.
- Sawyer, D.S., Buffler, R.T., and Pilger, Jr., R.H., 1991, The crust under the Gulf of Mexico, in A. Salvadore, ed., The Gulf of Mexico Basin: decade of North American Geology, Boulder, GSA, p. 53-72.
- Scardina, A.D., 1982, Tectonic subsidence history of the North Louisiana Salt Basin: in LSU Publications in Geology and Geophysics, Gulf Coast Studies, v. 2, 34 p., Louisiana State University, Baton Rouge, LA.

- Scott, K.R., Hayes, W.E., and Fietz, R.P., 1961, Geology of the Eagle Mills Formation: GCAGS Transactions, v. 11, p. 1-14.
- Sloane, B.J., Jr., 1958, The subsurface Jurassic Bodcaw Sand in Louisiana: Louisiana Geological Survey Bulletin, 33 p.
- Smith, D.L., and Dees, W.J., 1982, Heat flow in the Gulf Coast Plain, Jour. of Geophysical Research, v. 87, no. B9, p. 7687-7693.
- Smith, D.L., Dees, W.J., and Harrelson, D.W., 1981, Geothermal conditions and their implications for basement tectonics in the Gulf Coast margin: GCAGS Transactions, v. 31, p. 181-190.
- Spofford, H.N., 1945, Holly Field, De Soto Parish, Louisiana: AAPG Bulletin, v. 29, p. 96-100.
- Stroud, B.K., and Shayer, F.P., 1923, The Monroe Gas Field, Louisiana: AAPG Bulletin, v. 7, p. 565-574.
- Swain, F.M., 1944, Stratigraphy of Cotton Valley beds of northern Gulf Coastal Plain: AAPG Bulletin, v. 28, p. 577-614.
- Swain F.M., and Anderson, E.G., 1993, Stratigraphy and Ostracoda of the Cotton Valley Group, north central Louisiana: Louisiana Geological Survey, Geological Bulletin No. 45, 239 p.
- Tew, B.H., Mink, R.M., Mann, S.D., Bearden, B.L., and Mancini, E.A., 1991, Geologic framework of Norphlet and pre-Norphlet strata of the onshore and offshore eastern Gulf of Mexico area: GCAGS Transactions., v. 41, p. 590-600.
- Thomas, W.A., and Mann, C.J., 1966, Late Jurassic depositional environments, Louisiana and Arkansas: AAPG Bulletin, v. 50, p. 178-182.

- Thompson, L. B., C. J. Heine, S. F. Percival Jr., and M. R. Selznick, 1991, Stratigraphy and micropaleontology of the Campanian shelf in northeast Texas: Micropaleontology Special Publication 5, 66 p.
- Tolson, J.S., C.W. Copeland, and B.L. Bearden, 1983, Stratigraphic profiles of Jurassic strata in the western part of the Alabama Coastal Plain: Geological Survey of Alabama Bulletin 122, 425 p.
- Tye, R.S., Moslow, T.F., Kimbrell, W.C., and Wheeler, C.W., 1991, Lithostratigraphy and production characteristics of the Wilcox Group (Paleocene-Eocene) in central Louisiana: AAPG Bulletin, v. 75, v. 11, p. 1675-1713.
- Tye, R.S., Wheeler, C.W., Kimbrell, W.C., and Moslow, T.F., 1988, Lithostratigraphic framework and production history of Wilcox in central Louisiana: AAPG Bulletin, v. 72, p. 255.
- Van Siclen, D.C., 1984, Early opening of initially-closed Gulf of Mexico and central North Atlantic Ocean: GCAGS Transactions, v. 34, p. 265-275.
- Whitfield, M., 1963, A subsurface study of the Pine Island Formation of north central Louisiana: Shreveport Geological Society; Report on Selected North Louisiana and South Arkansas Oil and Gas Fields, v. V, p. 19-49.
- Winker, C.D., and Buffler, R.T., 1988, Paleogeographic evolution of early deep-water Gulf of Mexico and margins, Jurassic to Middle Cretaceous (Comanchaeen): AAPG Bulletin, v. 72, p. 318-346.
- Woods, D.J., 1963, Fractured chalk oil reservoirs, Sabine Parish, Louisiana: GCAGS Transactions, v. 13, p. 127-138.

- Yurewicz, D.A., Marler, T.B., Meyerholtz, K.A., and Siroky, F.X., 1993, Early Cretaceous carbonate platform, north rim of the Gulf of Mexico, Mississippi and Louisiana, in J. A. Toni Simo, R. W. Scott, and J. P. Masse, eds., Cretaceous carbonate platforms: AAPG Memoir 56, p. 81-96.
- Zimmerman, R.K., 1992, Fractured Smackover Limestone in northeast Louisiana, implication for hydrocarbon exploitation: GCAGS Transactions, v. 42, p. 401-412.
- Zimmerman, R.K., 1995, Evidence and effects of wrench faulting, north central Gulf Coast region: GCAGS Transactions, v. 45, p. 629-635.
- Zimmerman, R.K., 1998, Chronology of oil generation in Louisiana's fractured Austin Chalk deep horizontal drilling trend: GCAGS Transactions, v. 48, p. 517-525.
- Zimmerman, R.K., 1999, Potential oil generation capacity of the north Louisiana hydrocarbon system: GCAGS Transactions, v. 49, p. 532-540.
- Zimmerman, R.K., 2000, Predicting a north Louisiana Jurassic pinnacle reef trend from palinspastic reconstruction: Louisiana State University Basin Research Institute Bulletin, v. 9, p. 1-17.
- Zimmerman, R. K., and Goddard, 2001, D.A., A north Louisiana gas-prone Hosston slope-basin sand trend: Gulf Coast Association of Geological Societies Transactions, v. 51, p. 423-432.
- Zimmerman, R.K., and Sassen, R., 1993, Hydrocarbon transfer pathways from Smackover source rocks to younger reservoir traps in the Monroe Gas Field, northeast Louisiana: Gulf Coast Association of Geological Societies Transactions, v. 43, p. 473-480.

Appendix

A.

B.

Figure 1. Location of salt basins and index for wells for North Louisiana Salt Basin maps.

Figure 2. Seismic cross sections.

Figure 3. Cross section A-A' for the North Louisiana Salt Basin. See Figure 2 for location of cross section.

VE:22X

Figure 4. Cross section B-B' for the North Louisiana Salt Basin. See Figure 2 for location of cross section.

VE:30X

Figure 5. Cross section C-C' for the North Louisiana Salt Basin. See Figure 2 for location of cross section.

VE:29X

Figure 6. Cross section D-D' for the North Louisiana Salt Basin. See Figure 2 for location of cross section.

VE:32X

Figure 7. Cross section E-E' for the North Louisiana Salt Basin. See Figure 2 for location of cross section.

VE:34X

Figure 8. Cross section F-F' for the North Louisiana Salt Basin. See Figure 2 for location of cross section.

VE:32X

Figure 9. Cross section G-G' for the North Louisiana Salt Basin. See Figure 2 for location of cross section.

VE:25X

Figure 10. Cross section H-H' for the North Louisiana Salt Basin. See Figure 2 for location of cross section.

VE:35X

Figure 11. Cross section I-I' for the North Louisiana Salt Basin. See Figure 2 for location of cross section.

VE:31X

Figure 12. Cross section J-J' for the North Louisiana Salt Basin. See Figure 2 for location of cross section.

VE:30X

Figure 13. Cross section K-K' for the North Louisiana Salt Basin. See Figure 2 for location of cross section.

VE:22X

Figure 14. Structure map on the top of the Cotton Valley.
Contour interval = 500 feet

Figure 15. Structure map on the top of the Lower Cretaceous.
Contour interval = 500 feet

Figure 16. Structure map on the top of the Upper Cretaceous.
Contour interval = 500 feet

Figure 18. Isopach map of Lower Cretaceous strata, from the top of the Cotton Valley to the top of the Lower Cretaceous.

Contour Interval = 500 feet

Figure 19. Isopach map of Upper Cretaceous strata, from the top of the Lower Cretaceous to the top of the Upper Cretaceous.

Contour Interval = 250 feet

Figure 20. Erosion thickness of total Lower Cretaceous section. Prepared by Roger Barnaby.

Figure 21. Lithology map of Miocene strata. Prepared by Roger Barnaby.

Figure 22. Lithology map of Oligocene strata. Prepared by Roger Barnaby.

Figure 23. Lithology map of Cockfield. Prepared by Roger Barnaby.

Figure 24. Lithology map of Sparta. Prepared by Roger Barnaby.

Figure 25. Lithology map of Wilcox. Prepared by Roger Barnaby.

Figure 26. Lithology map of Upper Cretaceous strata. Prepared by Roger Barnaby.

Figure 27. Lithology map of Austin. Prepared by Roger Barnaby.

Figure 28. Lithology map of Tuscaloosa. Prepared by Roger Barnaby.

Figure 29. Lithology map of Paluxy. Prepared by Roger Barnaby.

Figure 30. Lithology map of Upper Glen Rose. Prepared by Roger Barnaby.

Figure 31. Lithology map of Mooringsport. Prepared by Roger Barnaby.

Figure 32. Lithology map of Ferry Lake. Prepared by Roger Barnaby.

Figure 33. Lithology map of Rodessa. Prepared by Roger Barnaby.

Figure 34. Lithology map of Bexar. Prepared by Roger Barnaby.

Figure 35. Lithology map of James. Prepared by Roger Barnaby.

Figure 36. Lithology map of Pine Island. Prepared by Roger Barnaby.

Figure 37. Lithology map of Sligo. Prepared by Roger Barnaby.

Figure 38. Lithology map of Hosston. Prepared by Roger Barnaby.

Figure 39. Lithology map of Cotton Valley. Prepared by Roger Barnaby.

Figure 40. Lithology map of Smackover. Prepared by Roger Barnaby.

Figure 41. Burial history for well 1701521100, North Louisiana Salt Basin.

Figure 42. Burial history for well 1701500464, North Louisiana Salt Basin.

Figure 43. Burial history for well 1701521099, North Louisiana Salt Basin.

Figure 44. Burial history for well 1701500977, North Louisiana Salt Basin.

Figure 45. Burial history for well 1701501689, North Louisiana Salt Basin.

1703120488 BURIAL HIST

Figure 46. Burial history for well 1703120488, North Louisiana Salt Basin.

1703120378 BURIAL HIST

Figure 47. Burial history for well 1703120378, North Louisiana Salt Basin.

1703100304 BURIAL HIST

Figure 48. Burial history for well 1703100304, North Louisiana Salt Basin.

1703100117 BURIAL HIST

Figure 49. Burial history for well 1703100117, North Louisiana Salt Basin.

1708520238 BURIAL HIST

Figure 50. Burial history for well 1708520238, North Louisiana Salt Basin.

Figure 51. Burial history for well 1708520177, North Louisiana Salt Basin.

Figure 52. Burial history for well 1711920068, North Louisiana Salt Basin.

Figure 53. Burial history for well 1711900502, North Louisiana Salt Basin.

Figure 54. Burial history for well 1711920195, North Louisiana Salt Basin.

Figure 55. Burial history for well 1711901517, North Louisiana Salt Basin.

Figure 56. Burial history for well 1701320275, North Louisiana Salt Basin.

1708120147 BURIAL HIST

Figure 57. Burial history for well 1708120147, North Louisiana Salt Basin.

Figure 58. Burial history for well 1708120267, North Louisiana Salt Basin.

Figure 59. Burial history for well 1708100714, North Louisiana Salt Basin.

Figure 60. Burial history for well 1706920034, North Louisiana Salt Basin.

Figure 61. Burial history for well 1702701875, North Louisiana Salt Basin.

Figure 62. Burial history for well 1702701974, North Louisiana Salt Basin.

Figure 63. Burial history for well 1702720557, North Louisiana Salt Basin.

Figure 64. Burial history for well 1701320349, North Louisiana Salt Basin.

1701320054 BURIAL HIST

Figure 65. Burial history for well 1701320054, North Louisiana Salt Basin.

Figure 66. Burial history for well 1706920079, North Louisiana Salt Basin.

Figure 67. Burial history for well 1706900047, North Louisiana Salt Basin.

Figure 68. Burial history for well 1706900174, North Louisiana Salt Basin.

Figure 69. Burial history for well 1702720242, North Louisiana Salt Basin.

Figure 70. Burial history for well 1702700522, North Louisiana Salt Basin.

Figure 71. Burial history for well 1706100051, North Louisiana Salt Basin.

1706100091 BURIAL HIST

Figure 72. Burial history for well 1706100091, North Louisiana Salt Basin.

1701300138 BURIAL HIST

Figure 73. Burial history for well 1701300138, North Louisiana Salt Basin.

Figure 74. Burial history for well 1704920029, North Louisiana Salt Basin.

Figure 75. Burial history for well 1712720324, North Louisiana Salt Basin.

1712701324 BURIAL HIST

Figure 76. Burial history for well 1712701324, North Louisiana Salt Basin.

1706700012 BURIAL HIST

Figure 77. Burial history for well 1706700012, North Louisiana Salt Basin.

1706700043 BURIAL HIST

Figure 78. Burial history for well 1706700043, North Louisiana Salt Basin.

1706700182 BURIAL HIST

Figure 79. Burial history for well 1706700182, North Louisiana Salt Basin.

Figure 80. Burial history for well 1706700008, North Louisiana Salt Basin.

Figure 81. Burial history for well 1706700061, North Louisiana Salt Basin.

Figure 82. Burial history for well 1712300011, North Louisiana Salt Basin.

- wells w/ BHTs
- wells w/ BHTs & %Ro

55: heat flow value (mW/m^2)

Figure 83. Present-day heat flow values. Prepared by Roger Barnaby.

Figure 84. Lithospheric stretching beta factors. Prepared by Roger Barnaby.

Figure 85. The relationship of vitrinite reflectance and depth. Prepared by Roger Barnaby.

Figure 86. Comparison of the modeled %Ro with measured %Ro.
Prepared by Roger Barnaby.

Figure 87. Thermal maturation profile for well 1701521100, North Louisiana Salt Basin.

Figure 88. Thermal maturation profile for well 1701500464, North Louisiana Salt Basin.

Figure 89. Thermal maturation profile for well 1701521099, North Louisiana Salt Basin.

Figure 90. Thermal maturation profile for well 1701500977, North Louisiana Salt Basin.

Figure 91. Thermal maturation profile for well 1701501689, North Louisiana Salt Basin.

Figure 92. Thermal maturation profile for well 1703120488, North Louisiana Salt Basin.

Figure 93. Thermal maturation profile for well 1703120378, North Louisiana Salt Basin.

Figure 94. Thermal maturation profile for well 1703100304, North Louisiana Salt Basin.

Figure 95. Thermal maturation profile for well 1703100117, North Louisiana Salt Basin.

Figure 96. Thermal maturation profile for well 1708520238, North Louisiana Salt Basin.

1708520177 MATURITY

Figure 97. Thermal maturation profile for well 1708520177, North Louisiana Salt Basin.

Figure 98. Thermal maturation profile for well 1711920068, North Louisiana Salt Basin.

Figure 99. Thermal maturation profile for well 1711900502, North Louisiana Salt Basin.

Figure 100. Thermal maturation profile for well 1711920195, North Louisiana Salt Basin.

Figure 101. Thermal maturation profile for well 1711901517, North Louisiana Salt Basin.

Figure 102. Thermal maturation profile for well 1701320275, North Louisiana Salt Basin.

Figure 103. Thermal maturation profile for well 1708120147, North Louisiana Salt Basin.

Figure 104. Thermal maturation profile for well 1708120267, North Louisiana Salt Basin.

Figure 105. Thermal maturation profile for well 1708100714, North Louisiana Salt Basin.

Figure 106. Thermal maturation profile for well 1706920034, North Louisiana Salt Basin.

Figure 107. Thermal maturation profile for well 1702701875, North Louisiana Salt Basin.

Figure 108. Thermal maturation profile for well 1702701974, North Louisiana Salt Basin.

Figure 109. Thermal maturation profile for well 1702720557, North Louisiana Salt Basin.

Figure 110. Thermal maturation profile for well 1701320349, North Louisiana Salt Basin.

Figure 111. Thermal maturation profile for well 1701320054, North Louisiana Salt Basin.

Figure 112. Thermal maturation profile for well 1706920079, North Louisiana Salt Basin.

Figure 113. Thermal maturation profile for well 1706900047, North Louisiana Salt Basin.

Figure 114. Thermal maturation profile for well 1706900174, North Louisiana Salt Basin.

Figure 115. Thermal maturation profile for well 1702720242, North Louisiana Salt Basin.

Figure 116. Thermal maturation profile for well 1702700522, North Louisiana Salt Basin.

Figure 117. Thermal maturation profile for well 1706100051, North Louisiana Salt Basin.

Figure 118. Thermal maturation profile for well 1706100091, North Louisiana Salt Basin.

Figure 119. Thermal maturation profile for well 1701300138, North Louisiana Salt Basin.

Figure 120. Thermal maturation profile for well 1704920029, North Louisiana Salt Basin.

Figure 121. Thermal maturation profile for well 1712720324, North Louisiana Salt Basin.

Figure 122. Thermal maturation profile for well 1712701324, North Louisiana Salt Basin.

Figure 123. Thermal maturation profile for well 1706700012, North Louisiana Salt Basin.

Figure 124. Thermal maturation profile for well 1706700043, North Louisiana Salt Basin.

Figure 125. Thermal maturation profile for well 1706700182, North Louisiana Salt Basin.

Figure 126. Thermal maturation profile for well 1706700008, North Louisiana Salt Basin.

Figure 127. Thermal maturation profile for well 1706700061, North Louisiana Salt Basin.

Figure 128. Thermal maturation profile for well 1712300011, North Louisiana Salt Basin.

Figure 129. Hydrocarbon expulsion plot for well 1701521100, North Louisiana Salt Basin.

1701500464 EXPULSION

Figure 130. Hydrocarbon expulsion plot for well 1701500464, North Louisiana Salt Basin.

Figure 131. Hydrocarbon expulsion plot for well 1701521099, North Louisiana Salt Basin.

Figure 132. Hydrocarbon expulsion plot for well 1701500977, North Louisiana Salt Basin.

Figure 133. Hydrocarbon expulsion plot for well 1701501689, North Louisiana Salt Basin.

1703120488 EXPULSION

Figure 134. Hydrocarbon expulsion plot for well 1703120488, North Louisiana Salt Basin.

1703120378 EXPULSION

Figure 135. Hydrocarbon expulsion plot for well 1703120378, North Louisiana Salt Basin.

1703100304 EXPULSION

Figure 136. Hydrocarbon expulsion plot for well 1703100304, North Louisiana Salt Basin.

1703100117 EXPULSION

Figure 137. Hydrocarbon expulsion plot for well 1703100117, North Louisiana Salt Basin.

Figure 138. Hydrocarbon expulsion plot for well 1708520238, North Louisiana Salt Basin.

1708520177 EXPULSION

Figure 139. Hydrocarbon expulsion plot for well 1708520177, North Louisiana Salt Basin.

Figure 140. Hydrocarbon expulsion plot for well 1711920068, North Louisiana Salt Basin.

Figure 141. Hydrocarbon expulsion plot for well 1711900502, North Louisiana Salt Basin.

Figure 142. Hydrocarbon expulsion plot for well 1711920195, North Louisiana Salt Basin.

Figure 143. Hydrocarbon expulsion plot for well 1711901517, North Louisiana Salt Basin.

Figure 144. Hydrocarbon expulsion plot for well 1701320275, North Louisiana Salt Basin.

Figure 145. Hydrocarbon expulsion plot for well 1708120147, North Louisiana Salt Basin.

Figure 146. Hydrocarbon expulsion plot for well 1708120267, North Louisiana Salt Basin.

Figure 147. Hydrocarbon expulsion plot for well 1708100714, North Louisiana Salt Basin.

Figure 148. Hydrocarbon expulsion plot for well 1706920034, North Louisiana Salt Basin.

Figure 149. Hydrocarbon expulsion plot for well 1702701875, North Louisiana Salt Basin.

1702701974 EXPULSION

Figure 150. Hydrocarbon expulsion plot for well 1702701974, North Louisiana Salt Basin.

1702720557 EXPULSION

Figure 151. Hydrocarbon expulsion plot for well 1702720557, North Louisiana Salt Basin.

1701320349 EXPULSION

Figure 152. Hydrocarbon expulsion plot for well 1701320349, North Louisiana Salt Basin.

Figure 153. Hydrocarbon expulsion plot for well 1701320054, North Louisiana Salt Basin.

Figure 154. Hydrocarbon expulsion plot for well 1706920079, North Louisiana Salt Basin.

1706900047 EXPULSION

Figure 155. Hydrocarbon expulsion plot for well 1706900047, North Louisiana Salt Basin.

Figure 156. Hydrocarbon expulsion plot for well 1706900174, North Louisiana Salt Basin.

Figure 157. Hydrocarbon expulsion plot for well 1702720242, North Louisiana Salt Basin.

Figure 158. Hydrocarbon expulsion plot for well 1702700522, North Louisiana Salt Basin.

Figure 159. Hydrocarbon expulsion plot for well 1706100051, North Louisiana Salt Basin.

Figure 160. Hydrocarbon expulsion plot for well 1706100091, North Louisiana Salt Basin.

Figure 161. Hydrocarbon expulsion plot for well 1701300138, North Louisiana Salt Basin.

Figure 162. Hydrocarbon expulsion plot for well 1704920029, North Louisiana Salt Basin.

Figure 163. Hydrocarbon expulsion plot for well 1712720324, North Louisiana Salt Basin.

Figure 164. Hydrocarbon expulsion plot for well 1712701324, North Louisiana Salt Basin.

Figure 165. Hydrocarbon expulsion plot for well 1706700012, North Louisiana Salt Basin.

1706700043 EXPULSION

Figure 166. Hydrocarbon expulsion plot for well 1706700043, North Louisiana Salt Basin.

1706700182 EXPULSION

Figure 167. Hydrocarbon expulsion plot for well 1706700182, North Louisiana Salt Basin.

Figure 168. Hydrocarbon expulsion plot for well 1706700008, North Louisiana Salt Basin.

Figure 169. Hydrocarbon expulsion plot for well 1706700061, North Louisiana Salt Basin.

Figure 170. Hydrocarbon expulsion plot for well 1712300011, North Louisiana Salt Basin.

Figure 172. Burial history for well 2305500032, Mississippi Interior Salt Basin.

Figure 173. Burial history for well 2305500066, Mississippi Interior Salt Basin.

Figure 174. Burial history for well 2312520004, Mississippi Interior Salt Basin.

Figure 175. Burial history for well 2304920011, Mississippi Interior Salt Basin.

Figure 176. Burial history for well 2304920005, Mississippi Interior Salt Basin.

Figure 177. Burial history for well 2312120025, Mississippi Interior Salt Basin.

Figure 178. Burial history for well 2312900178, Mississippi Interior Salt Basin.

Figure 179. Burial history for well 2312920006, Mississippi Interior Salt Basin.

Figure 180. Burial history for well 2312900061, Mississippi Interior Salt Basin.

Figure 181. Burial history for well 2306120203, Mississippi Interior Salt Basin.

Figure 182. Burial history for well 2306120028, Mississippi Interior Salt Basin.

Figure 183. Burial history for well 2306120244, Mississippi Interior Salt Basin.

Figure 184. Burial history for well 2306720002, Mississippi Interior Salt Basin.

Figure 185. Burial history for well 2315301008, Mississippi Interior Salt Basin.

Figure 186. Burial history for well 2315320545, Mississippi Interior Salt Basin.

Figure 187. Burial history for well 2315320122, Mississippi Interior Salt Basin.

Figure 188. Burial history for well 112920054, Mississippi Interior Salt Basin.

Figure 189. Burial history for well 112920024, Mississippi Interior Salt Basin.

Figure 190. Burial history for well 112920012, Mississippi Interior Salt Basin.

Figure 191. Burial history for well 2308320011, Mississippi Interior Salt Basin.

Figure 192. Burial history for well 2305120020, Mississippi Interior Salt Basin.

Figure 193. Burial history for well 2305120036, Mississippi Interior Salt Basin.

Figure 194. Burial history for well 2316300049, Mississippi Interior Salt Basin.

Figure 195. Burial history for well 2316320150, Mississippi Interior Salt Basin.

Figure 196. Burial history for well 2308920043, Mississippi Interior Salt Basin.

Figure 197. Burial history for well 2304920004, Mississippi Interior Salt Basin.

Figure 198. Burial history for well 2304920032, Mississippi Interior Salt Basin.

Figure 199. Burial history for well 2310100014, Mississippi Interior Salt Basin.

Figure 200. Burial history for well 2310120005, Mississippi Interior Salt Basin.

Figure 201. Burial history for well 2312900015, Mississippi Interior Salt Basin.

Figure 202. Burial history for well 2312920057, Mississippi Interior Salt Basin.

Figure 203. Burial history for well 2312920122, Mississippi Interior Salt Basin.

Figure 204. Burial history for well 2312720055, Mississippi Interior Salt Basin.

Figure 205. Burial history for well 2306520141, Mississippi Interior Salt Basin.

Figure 206. Burial history for well 2302300270, Mississippi Interior Salt Basin.

Figure 207. Burial history for well 2302320114, Mississippi Interior Salt Basin.

Figure 208. Burial history for well 2315320042, Mississippi Interior Salt Basin.

Figure 209. Burial history for well 2315320265, Mississippi Interior Salt Basin.

Figure 210. Burial history for well 2315320232, Mississippi Interior Salt Basin.

Figure 211. Burial history for well 2315320077, Mississippi Interior Salt Basin.

Figure 212. Burial history for well 2311100069, Mississippi Interior Salt Basin.

Figure 213. Burial history for well 2304520075, Mississippi Interior Salt Basin.

Figure 214. Burial history for well 102320114, Mississippi Interior Salt Basin.

Figure 215. Burial history for well 102320197, Mississippi Interior Salt Basin.

Figure 216. Burial history for well 112920051, Mississippi Interior Salt Basin.

Figure 217. Burial history for well 109720134, Mississippi Interior Salt Basin.

Figure 218. Burial history for well 109720141, Mississippi Interior Salt Basin.

Figure 219. Burial history for well 109720299, Mississippi Interior Salt Basin.

Figure 220. Thermal maturation profile for well 2305500032, Mississippi Interior Salt Basin.

Figure 221. Thermal maturation profile for well 2305500066, Mississippi Interior Salt Basin.

Figure 222. Thermal maturation profile for well 2312520004, Mississippi Interior Salt Basin.

Figure 223. Thermal maturation profile for well 2304920011, Mississippi Interior Salt Basin.

Figure 224. Thermal maturation profile for well 2304920005, Mississippi Interior Salt Basin.

Figure 225. Thermal maturation profile for well 2312120025, Mississippi Interior Salt Basin.

Figure 226. Thermal maturation profile for well 2312900178, Mississippi Interior Salt Basin.

Figure 227. Thermal maturation profile for well 2312920006, Mississippi Interior Salt Basin.

Figure 228. Thermal maturation profile for well 2312900061, Mississippi Interior Salt Basin.

Figure 229. Thermal maturation profile for well 2306120203, Mississippi Interior Salt Basin.

Figure 230. Thermal maturation profile for well 2306120028, Mississippi Interior Salt Basin.

Figure 231. Thermal maturation profile for well 2306120244, Mississippi Interior Salt Basin.

Figure 232. Thermal maturation profile for well 2306720002, Mississippi Interior Salt Basin.

Figure 233. Thermal maturation profile for well 2315301008, Mississippi Interior Salt Basin.

Figure 234. Thermal maturation profile for well 2315320545, Mississippi Interior Salt Basin.

Figure 235. Thermal maturation profile for well 2315320122, Mississippi Interior Salt Basin.

Figure 236. Thermal maturation profile for well 112920054, Mississippi Interior Salt Basin.

Figure 237. Thermal maturation profile for well 112920024, Mississippi Interior Salt Basin.

Figure 238. Thermal maturation profile for well 112920012, Mississippi Interior Salt Basin.

Figure 239. Thermal maturation profile for well 2308320011, Mississippi Interior Salt Basin.

Figure 240. Thermal maturation profile for well 2305120020, Mississippi Interior Salt Basin.

Figure 241. Thermal maturation profile for well 2305120036, Mississippi Interior Salt Basin.

Figure 242. Thermal maturation profile for well 2316300049, Mississippi Interior Salt Basin.

Figure 243. Thermal maturation profile for well 2316320150, Mississippi Interior Salt Basin.

Figure 244. Thermal maturation profile for well 2308920043, Mississippi Interior Salt Basin.

Figure 245. Thermal maturation profile for well 2304920004, Mississippi Interior Salt Basin.

2304920032 MATURITY

Figure 246. Thermal maturation profile for well 2304920032, Mississippi Interior Salt Basin.

Figure 247. Thermal maturation profile for well 2310100014, Mississippi Interior Salt Basin.

Figure 248. Thermal maturation profile for well 2310120005, Mississippi Interior Salt Basin.

Figure 249. Thermal maturation profile for well 2312900015, Mississippi Interior Salt Basin.

Figure 250. Thermal maturation profile for well 2312920057, Mississippi Interior Salt Basin.

Figure 251. Thermal maturation profile for well 2312920122, Mississippi Interior Salt Basin.

Figure 252. Thermal maturation profile for well 2312720055, Mississippi Interior Salt Basin.

Figure 253. Thermal maturation profile for well 2306520141, Mississippi Interior Salt Basin.

Figure 254. Thermal maturation profile for well 2302300270, Mississippi Interior Salt Basin.

Figure 255. Thermal maturation profile for well 2302320114, Mississippi Interior Salt Basin.

Figure 256. Thermal maturation profile for well 2315320042, Mississippi Interior Salt Basin.

Figure 257. Thermal maturation profile for well 2315320265, Mississippi Interior Salt Basin.

Figure 258. Thermal maturation profile for well 2315320232, Mississippi Interior Salt Basin.

Figure 259. Thermal maturation profile for well 2315320077, Mississippi Interior Salt Basin.

Figure 260. Thermal maturation profile for well 2311100069, Mississippi Interior Salt Basin.

Figure 261. Thermal maturation profile for well 2304520075, Mississippi Interior Salt Basin.

Figure 262. Thermal maturation profile for well 102320114, Mississippi Interior Salt Basin.

Figure 263. Thermal maturation profile for well 102320197, Mississippi Interior Salt Basin.

Figure 264. Thermal maturation profile for well 112920051, Mississippi Interior Salt Basin.

Figure 265. Thermal maturation profile for well 109720134, Mississippi Interior Salt Basin.

Figure 266. Thermal maturation profile for well 109720141, Mississippi Interior Salt Basin.

Figure 267. Thermal maturation profile for well 109720299, Mississippi Interior Salt Basin.

Figure 268. Hydrocarbon expulsion plot for well 2305500032, Mississippi Interior Salt Basin.

2305500066 EXPULSION

Figure 269. Hydrocarbon expulsion plot for well 2305500066, Mississippi Interior Salt Basin.

2312520004 EXPULSION

Figure 270. Hydrocarbon expulsion plot for well 2312520004, Mississippi Interior Salt Basin.

Figure 271. Hydrocarbon expulsion plot for well 2304920011, Mississippi Interior Salt Basin.

Figure 272. Hydrocarbon expulsion plot for well 2304920005, Mississippi Interior Salt Basin.

2312120025 EXPULSION

Figure 273. Hydrocarbon expulsion plot for well 2312120025, Mississippi Interior Salt Basin.

2312900178 EXPULSION

Figure 274. Hydrocarbon expulsion plot for well 2312900178, Mississippi Interior Salt Basin.

Figure 275. Hydrocarbon expulsion plot for well 2312920006, North Louisiana Salt Basin.

2312900061 EXPULSION

Figure 276. Hydrocarbon expulsion plot for well 2312900061, Mississippi Interior Salt Basin.

Figure 277. Hydrocarbon expulsion plot for well 2306120203, Mississippi Interior Salt Basin.

Figure 278. Hydrocarbon expulsion plot for well 2306120028, Mississippi Interior Salt Basin.

Figure 279. Hydrocarbon expulsion plot for well 2306120244, Mississippi Interior Salt Basin.

Figure 280. Hydrocarbon expulsion plot for well 2306720002, Mississippi Interior Salt Basin.

Figure 281. Hydrocarbon expulsion plot for well 2315301008, Mississippi Interior Salt Basin.

Figure 282. Hydrocarbon expulsion plot for well 2315320545, Mississippi Interior Salt Basin.

Figure 283. Hydrocarbon expulsion plot for well 2315320122, Mississippi Interior Salt Basin.

Figure 284. Hydrocarbon expulsion plot for well 112920054, Mississippi Interior Salt Basin.

Figure 285. Hydrocarbon expulsion plot for well 112920024, Mississippi Interior Salt Basin.

112920012 EXPULSION

Figure 286. Hydrocarbon expulsion plot for well 112920012, Mississippi Interior Salt Basin.

Figure 287. Hydrocarbon expulsion plot for well 2308320011, Mississippi Interior Salt Basin.

Figure 288. Hydrocarbon expulsion plot for well 2305120020, Mississippi Interior Salt Basin.

Figure 289. Hydrocarbon expulsion plot for well 2305120036, Mississippi Interior Salt Basin.

Figure 290. Hydrocarbon expulsion plot for well 2316300049, Mississippi Interior Salt Basin.

Figure 291. Hydrocarbon expulsion plot for well 2316320150, Mississippi Interior Salt Basin.

Figure 292. Hydrocarbon expulsion plot for well 2308920043, Mississippi Interior Salt Basin.

Figure 293. Hydrocarbon expulsion plot for well 2304920032, Mississippi Interior Salt Basin.

Figure 294. Hydrocarbon expulsion plot for well 2310120005, Mississippi Interior Salt Basin.

Figure 295. Hydrocarbon expulsion plot for well 2312900015, Mississippi Interior Salt Basin.

2312920057 EXPULSION

Figure 296. Hydrocarbon expulsion plot for well 2312920057, Mississippi Interior Salt Basin.

Figure 297. Hydrocarbon expulsion plot for well 2312920122, Mississippi Interior Salt Basin.

Figure 298. Hydrocarbon expulsion plot for well 2312720055, Mississippi Interior Salt Basin.

Figure 299. Hydrocarbon expulsion plot for well 2302300270, Mississippi Interior Salt Basin.

Figure 300. Hydrocarbon expulsion plot for well 102320114, Mississippi Interior Salt Basin.

Figure 301. Hydrocarbon expulsion plot for well 2315320042, Mississippi Interior Salt Basin.

Figure 302. Hydrocarbon expulsion plot for well 2315320265, Mississippi Interior Salt Basin.

2315320232 EXPULSION

Figure 303. Hydrocarbon expulsion plot for well 2315320232, Mississippi Interior Salt Basin.

Figure 304. Hydrocarbon expulsion plot for well 2315320077, Mississippi Interior Salt Basin.

2311100069 EXPULSION

Figure 305. Hydrocarbon expulsion plot for well 2311100069, Mississippi Interior Salt Basin.

Figure 306. Hydrocarbon expulsion plot for well 2304520075, Mississippi Interior Salt Basin.

Figure 307. Hydrocarbon expulsion plot for well 102320114, Mississippi Interior Salt Basin.

102320197 EXPULSION

Figure 308. Hydrocarbon expulsion plot for well 102320197, Mississippi Interior Salt Basin.

Figure 309. Hydrocarbon expulsion plot for well 112920051, Mississippi Interior Salt Basin.

Figure 310. Hydrocarbon expulsion plot for well 109720134, Mississippi Interior Salt Basin.

Figure 311. Hydrocarbon expulsion plot for well 109720141, Mississippi Interior Salt Basin.

Figure 312. Hydrocarbon expulsion plot for well 109720299, Mississippi Interior Salt Basin.

Figure 313. Burial history for well 170150097700. Sabine Uplift.
Prepared by Roger Barnaby.

Figure 314. Burial history for well 170272055700. Updip/Margin.
Prepared by Roger Barnaby.

Figure 315. Burial history for well 170670018200. Monroe Uplift.
Prepared by Roger Barnaby.

Figure 316. Burial history for well 170690004700. Downdip/Basin Center.
Prepared by Roger Barnaby.

Figure 317. Thermal maturation profile for well 170150097700. Sabine Uplift.
Prepared by Roger Barnaby.

Figure 318. Thermal maturation profile for well 170272055700. Updip/Margin.
Prepared by Roger Barnaby.

Figure 319. Thermal maturity profile for well 170670018200. Monroe Uplift.
Prepared by Roger Barnaby.

Figure 320. Thermal maturation profile for well 1706900047700. Downdip/Basin Center.
Prepared by Roger Barnaby.

Figure 321. Hydrocarbon expulsion plot for well 170150097700. Sabine Uplift.
Prepared by Roger Barnaby.

Figure 322. Hydrocarbon expulsion plot for well 170272055700. Updip/Margin.
Prepared by Roger Barnaby.

Figure 323. Hydrocarbon expulsion plot for well 170670018200. Monroe Uplift.
Prepared by Roger Barnaby.

Figure 324. Hydrocarbon expulsion plot for well 170690004700. Downdip/Basin Center.
Prepared by Roger Barnaby.

Age (ma)	Ser.	Stage		Western Gulf Coast		Central Gulf Coast		Eastern Gulf Coast		T-R Seq.	Facies Assoc.				
Upper Cretaceous	Pal.	Paleocene	L	Kincaid Fm.		Kincaid Fm.		Clayton Fm.							
	Maastrichtian	U		Hiatus		Hiatus									
				Kemp Clay	Arkadelphia Marl		Prairie Bluff Chalk								
			L	Corsicana Fm.	Nacatoch Sand		Ripley Fm.		GC14	RI TB					
	Campanian	U		Nacatoch Sand		Nacatoch Sand		Ripley Fm.		GC13	RI TB				
				Neylandville Marl	Saratoga Chalk		Demopolis Chalk								
				Marlbrook Marl	Marlbrook Marl										
		M		Pecan Gap Chalk	Annona Chalk										
				Wolfe City Sand	Ozan Fm.		Sardis Fm.								
		L	Brownstown Marl		Brownstown Marl		Tupelo Tongue Arcola Ls. Mbr. Mooreville Fm.		GC12	RI TB					
	Santonian	U	Austin Group		Tokio Fm.		Tombigbee Sand Mbr.								
									Coniacian	U	Eutaw Fm.				
	Turonian	U	Eagle Ford Gp.		Hiatus		upper Tuscaloosa Fm.						GC11	RI TB TA	
									M	Eagle Ford Gp		middle Tuscaloosa Fm.			
															L
Cenomanian	U	Woodbine Fm.		Tuscaloosa Fm.		lower Tuscaloosa Fm.		GC10	RI TB TA						
		M	Hiatus												
			L	Wash. Gp.	Washita Gp.		Washita Gp.			Dantzler Fm.					
Lower Cretaceous	Albian	U	Frd. Gp.	Georgetown Ls.		Goodland Ls.		Andrew Fm.		Fredericksburg Gp.		GC8	RI TB		
				Edwards Ls.											
				Walnut Clay											
		M	Paluxy Fm.		Paluxy Fm.		Paluxy Fm.		GC7	RI TB TA					
			L	Glen Rose Ls.							Upper Glen Rose	Mooringsport Fm.		Mooringsport Fm.	
	Lower Glen Rose										Ferry Lake Anhydrite		Ferry Lake Anhydrite		
	Aptian	U	Pearsall Fm.	Bexar Shale Mbr.		Bexar Shale Mbr.		Bexar Shale Mbr.		GC6	RI TB				
				Cow Creek Ls. Mbr.		James Ls.		James Ls.				"Donovan" ss.			
				Hammett Shale Mbr.		Pine Island Shale		Pine Island Shale							
		Barremian	L	Sligo Fm.		Sligo Fm.		Sligo Fm.		GC5	RI TB TA				
				Hosston Fm.		Hosston Fm.		Hosston Fm.							
	Hauterivian	U	Hosston Fm.		Hosston Fm.		Hosston Fm.		GC2	RI TB TA					
Valanginian	U	Hiatus		Hiatus		Hiatus		GC4	RI TB						
Berriasian	U	Cotton Valley	Knowles Ls.		Knowles Ls.		Knowles Ls.		GC3	RI TB					
			Schuler Fm.		Schuler Fm.		Dorcheat Mbr.								
			Bossier Fm.		Bossier Fm.		Shongaloo Mbr.								
Tithonian	U	Cotton Valley	Gilmer Ls.		Gilmer Ls.		Gilmer Ls.		GC2	RI TB TA					
			Haynesville Fm.		Haynesville Fm.		Haynesville Fm.								
			Buckner Fm.		Buckner Fm.		Buckner Mbr.								
Oxfordian	U	Smackover Fm.		Smackover Fm.		Smackover Fm.		GC1	RI TB TA						
		Norphlet Fm.		Norphlet Fm.		Norphlet Fm.									
M. Jur.	U	Hiatus		Hiatus		Hiatus		GC1	RI TB TA						
Callovian	U	Louann Salt		Louann Salt		Louann Salt		GC1	RI TB TA						

Figure 325. Sequence stratigraphy of the North Louisiana Salt basin.

A.

B.

Figure 326. (A) Thermal-maturity and migration modeling at the initiation of oil expulsion during the Early Cretaceous in the southern part of the basin based on the geologic model constructed from cross section D-D'. (B) Thermal-maturity and migration modeling at peak dry-gas expulsion during the early Late Cretaceous in the southern part of the basin. See Figure 1 for the location of cross section D-D'.

A.

B.

Figure 327. (A) Thermal-maturity and migration modeling at the initiation of oil expulsion during the Early Cretaceous in the southern part of the basin based on the geologic model constructed from cross section J-J'. (B) Thermal-maturity and migration into the Monroe uplift area during the early Eocene from the southern part of the basin. See Figure 1 for location of the cross section J-J'.

Figure 328. (A) Thermal-maturity and migration modeling at the time of oil expulsion during the Early Cretaceous in the southern part of the basin based on the geologic model constructed from seismic cross section D-D'. (B) Thermal-maturity and migration modeling at peak dry-gas expulsion during the early Late Cretaceous in the southern part of the basin. See Figure 1 for location of seismic cross section D-D'.

Figure 329. Distribution of crustal types and depth to basement in the Gulf of Mexico basin. Depth to basement is in kilometers (modified from Buffler, 1991).

Figure 330. Tectonic framework of part of the northern Gulf of Mexico region (modified from MacRae and Watkins, 1996).

Figure 331. Vitrinite reflectance profiles: A. North Louisiana Salt Basin B. Mississippi Interior Salt Basin.

Figure 332. Event chart for Smackover petroleum system, North Louisiana and Mississippi Interior Salt Basins (modified from Mancini et al., 2003).

Figure 333. Regional map showing the north-south and west-east cross sections with cored (red) and selected wells (white) that penetrate the Cotton Valley – Bossier Group within the North Louisiana Salt Basin.

Figure 334. Map of Vernon Field, Jackson Parish with sampled wells highlighted in red.

Figure 335. Electric logs from cored wells in the North Louisiana Salt Basin with major stratigraphic boundaries (Cotton Valley, Bossier & Haynesville) and depths for samples analyzed in the present study.

Figure 336. Electric logs for wells selected from Vernon Field, Jackson Parish showing depths where samples chosen for analysis. The Anadarko Davis Bros 29-2Alt sample at 15,120 ft depth is not shown at the scale of the electric logs.

Figure 337. (A) North-south stratigraphic cross section showing the cored wells together with other wells that penetrate the Cotton Valley - Bossier Group, and (B) west-east stratigraphic cross section showing the cored wells together with other wells that penetrate the Cotton Valley - Bossier Group.

Figure 338. Thin section micrographs of the Cotton Valley – Bossier and Haynesville rocks that were described petrographically from the Amoco Davis well (A&B), Amoco CZ 5-7 (C&D), and Exxon Pardee wells (E).

Figure 339. Amoco Davis well electric log in Jackson Parish showing sample depths within the Cotton Valley interval and within the Haynesville Formation accompanied by thin section micrographs.

Figure 340. Amoco CZ 5-7 well electric log showing sample depths within the Bossier Shale with corresponding thin section micrographs.

Figure 341. Exxon Pardee well electric log (Winn Parish) showing sample depths within the Bossier Shale and corresponding thin section micrograph.

Figure 342. Diagram of S₂ versus TOC. The majority of the wells analyzed plot below the HI 200 line and lie in the III and IV fields, with TOCs ranging from 0.1 to 0.6 wt % (B=Bossier, CV=Cotton Valley, H=Haynesville).

Figure 343. HI versus OI diagram. The majority of data plot between the III and IV fields, indicating they are mostly gas generative rocks. Haynesville and some Cotton Valley samples tend to be more oil prone (B=Bossier, CV=Cotton Valley, H= Haynesville).

Figure 344. Ro versus depth plot. % Ro of the analyzed samples increases with depth, placing them within the main gas window (B=Bossier, H=Haynesville).

Figure 345. Rock-Eval pyrolysis analyses (Tmax), and organic maturation parameters (%Ro, TAI, kerogen coloration) obtained from visual kerogen analysis. Values obtained from the Cotton Valley – Bossier Group and Haynesville Formation samples (yellow) fall between the oil window and the principal zone of gas formation (modified after Senfle and Landis, 1991).

Figure 346. Visual kerogen analyses of Amoco Davis well sampled at 12,956 ft depth (A) and the Amoco Davis well at 12,976 ft depth (B).

Figure 347. Visual kerogen analyses of Exxon Pardee well sampled at 16,400 depth (A) and the Amoco CZ 5-7 well at 16,431 depth (B).

Figure 348. Visual kerogen analysis of the Pan Am Venzina well sampled at 9,347(A), 9,357'(B) and 9,372 (C) depths.

Figure 349. Index map showing location of the well studied to characterize source potential of the Bossier Formation.

Figure 350. Burial history profile for well 1712720281, used in characterizing the Bossier Formation. See Figure 349 for location of well.

Figure 351. Thermal maturation profile for well 1712720281, North Louisiana Salt Basin.

Figure 352. Hydrocarbon expulsion plot for well 1712720281, North Louisiana Salt Basin.

Figure 353. Cross section D-D' showing potential onset of oil expulsion from the Bossier in the North Louisiana Salt Basin. See Figure 2 for location of cross section.

Figure 354. Cross section D-D' showing potential peak gas expulsion from the Bossier in the North Louisiana Salt Basin. See Figure 2 for location of cross section.

Table 1. Organic geochemical analyses of potential source rocks, North Louisiana Salt Basin.

Well	Parish	Depth (ft)	Unit ¹	TOC (%)	Kerogen ²	TAI	%R _o [*]	T _{max} (°C)	S ₁ (mg/g)	S ₂ (mg/g)	S ₃ (mg/g)	HI	OI
N. Manning	Union	16,016	p-salt	0.26	Am	3.4	1.54	311	0.03	0.03	0.15	12	58
N. Manning	Union	16,057	p-salt	0.18	Am	3.7	1.80	252	0.01	0.00	0.29	0	161
N. Manning	Union	16,074	p-salt	0.13	Am	3.8	1.89	252	0.01	0.00	0.12	0	92
George Franklin #1	Richland	11,770	Smk	0.25	Am	3.4	1.54	344	0.13	0.09	0.16	36	64
Colvin #2	Lincoln	10,856	Smk	0.32	H	3.2	1.37	333	0.16	0.15	0.38	47	119
McGehee #1	Lincoln	13,439	Smk	0.78	Am/H	3.6	1.71	286	0.20	0.10	1.10	13	141
McGehee #1	Lincoln	13,602	Smk	0.38	Am/H	3.6	1.71	314	0.09	0.04	0.36	11	95
Bearden #1	Union	10,170	Smk	0.14	H	3	1.22	288	0.11	0.04	0.16	29	114
B-1 Hamiter	Bossier	10,568	Smk	0.19	H	2.8	1.07	318	0.13	0.06	0.24	32	126
Waller #1	Claiborne	10,390	Smk	0.18	Am	2.8	1.07	323	0.06	0.04	0.48	22	267
Sherman #1	Claiborne	10,216	Smk	0.24	Am/H	2.8	1.07	430	0.20	0.14	0.18	58	75
L. Enloe	Claiborne	10,714	Smk	0.19	H/W	3	1.22	308	0.21	0.10	0.94	53	495
Frazier Unit	Webster	10,874	Smk	0.24	H	2.9	1.14	318	0.18	0.13	0.59	54	246
Frazier Unit	Webster	11,250	Smk	0.21	H	3	1.22	411	0.06	0.10	0.24	48	114
H. Davis	Webster	11,043	Smk	0.28	Am/H	3.2	1.37	380	0.02	0.03	0.15	11	54
H. Davis	Webster	11,243	Smk	0.16	Am	3.4	1.54	305	0.01	0.01	0.15	6	94
Wheless #1	Claiborne	11,866	Smk	0.32	H	2.7	1.00	378	0.14	0.09	0.20	28	62
Bob #1	Claiborne	10,707	Smk	0.36	H	2.8	1.07	452	0.04	0.07	0.08	19	22
Crown-Zellerbach #1	Natchitoches	13,421	Smk	0.09	H	3.7	1.80	361	0.36	0.31	0.43	344	478
Godfrey "B" #1	Natchitoches	13,305	Smk	1.80	H	3.7	1.80	341	0.94	0.28	0.66	16	37
Teer #1	Red River	14,060	Smk	1.22	H/I	3.8	1.89	418	0.94	0.29	0.27	24	22
Green #1	Union	10,683	Smk	0.08	H	3	1.22	378	0.04	0.12	0.18	150	225
Green #1	Union	10,825	Smk	0.12	H	3.7	1.80	400	0.02	0.09	0.46	75	383
First Bank #1	Bossier	11,173	Smk	0.47	W/I	2.9	1.14	381	0.09	0.13	0.00	28	--
First Bank #1	Bossier	11,178	Smk	0.80	W/I	2.9	1.14	515	0.11	0.33	0.00	41	--
Dillon Heirs	Caddo	7,015	CV	0.41	Am	2.4	0.80	432	0.32	0.35	1.12	85	273
F. Wappler	Caddo	8,683	CV	0.75	Am	2.5	0.86	370	0.17	0.58	0.54	77	72
F. Wappler	Caddo	8,793	CV	0.62	Am/H	2.5	0.86	336	0.09	0.05	0.72	8	116
F. Wappler	Caddo	8,801	CV	1.80	H	2.5	0.86	441	0.30	2.71	0.42	151	23
F. Wappler	Caddo	9,351	CV	0.62	H	2.5	0.86	375	0.19	0.20	0.60	32	97
Bankston	Franklin	14,656	CV	0.35	Am	3.5	1.62	293	0.17	0.09	0.65	26	186
Huffman-McNeely	Natchitoches	17,480	CV	0.11	Am	3.7	1.80	325	0.06	0.04	0.18	36	164
CZ 10-11	Winn	13,690	CV	0.57	Am	3.7	1.80	276	0.03	0.03	0.22	5	39
CZ 10-11	Winn	13,804	CV	0.47	Am/H	3.7	1.80	252	0.03	0.01	0.21	2	45
CZ 10-11	Winn	13,924	CV	0.48	Am	3.7	1.80	252	0.01	0.01	0.02	2	4
CZ 10-11	Winn	13,946	CV	0.30	Am/I	3.7	1.80	354	0.03	0.05	0.13	17	43
Southern Nat Gas #2	Bienville	10,802	CV	0.43	H	3.4	1.54	423	0.11	0.04	0.46	9	107
Lawhorn Amoco #1	Bienville	10,774	CV	1.25	H	2.3	0.74	479	0.06	0.23	0.27	18	22
Expl Ipco #1	De Soto	10,364	CV	0.48	W/I	2.7	1.00	473	0.11	0.18	0.15	38	31

Table 1. Continued.

Well	Parish	Depth (ft)	Unit ¹	TOC (%)	Kerogen ²	TAI	%R _o [*]	T _{max} (°C)	S ₁ (mg/g)	S ₂ (mg/g)	S ₃ (mg/g)	HI	OI
Davis #1	Jackson	11,188	CV	0.31	Am/H	2.5	0.86	394	0.07	0.04	0.05	13	16
Parnell #1	Lincoln	9,127	CV	0.60	H	2.4	0.80	436	0.31	0.60	0.57	100	95
James #1	Lincoln	10,443	CV	0.12	H	3.2	1.37	412	0.05	0.03	0.23	25	192
Terzia F. C. #1	Ouachita	10,193	CV	1.65	H	2.4	0.80	450	0.41	0.82	0.29	50	18
Webb #1	Ouachita	9,620	CV	0.20	Am/H	2.3	0.74	429	0.10	0.18	0.09	90	45
Kennedy #2	Ouachita	9,915	CV	0.76	Am/H	2.4	0.80	443	0.21	0.96	0.17	127	23
Sample #1	Red River	9,676	CV	0.45	H	2.7	1.00	410	0.19	0.23	0.15	51	33
Sample #2	Red River	9,911	CV	0.29	H	2.7	1.00	431	0.09	0.13	0.14	45	48
Phillip #1	Webster	10,290	CV	1.07	H	2.7	1.00	455	0.28	0.71	0.29	66	27
Phillip #1	Webster	10,640	CV	0.25	H/I	2.7	1.00	450	0.05	0.15	0.10	60	40
English #2	Bossier	9,382	CV	0.29	I	2.5	0.86	439	0.04	0.15	0.11	52	38
English #2	Bossier	9,432	CV	0.32	H	2.5	0.86	443	0.08	0.40	0.14	125	44
Davis Bros.	Jackson	10,944	Bossier	0.46	H	2.9	1.14	331	0.14	0.12	0.09	26	20
Davis Bros.	Jackson	12,956	Bossier	0.43	H	3	1.22	304	0.10	0.08	0.22	19	51
Davis Bros.	Jackson	12,976	Bossier	0.61	H	3.1	1.29	313	0.11	0.07	0.02	11	3
CZ 5-7	Winn	15,608	Bossier	0.28	I	3.7	1.80	307	0.02	0.04	0.00	14	0
CZ 5-7	Winn	16,418	Bossier	0.34	I	3.8	1.89	355	0.05	0.07	0.11	21	32
CZ 5-7	Winn	16,431	Bossier	0.34	W/I	3.8	1.89	329	0.06	0.10	0.37	29	109
Pardee	Winn	16,200	Bossier	0.35	Am/I	3.7	1.80	322	0.21	0.29	0.29	83	83
Pardee	Winn	16,400	Bossier	0.35	Am/I	3.7	1.80	328	0.19	0.16	0.16	46	46
English #2	Bossier	11,136	Bossier	0.55	W/I	2.7	1.00	515	0.08	0.23	0.24	42	44
English #2	Bossier	11,168	Bossier	0.91	Am/H	2.7	1.00	498	0.25	0.25	0.40	27	44
First Bank #1	Bossier	11,108	Bossier	0.35	W/I	2.9	1.14	482	0.06	0.11	0.17	31	49
Chicago Mill	Tensas	14,876	Hoss	1.69	H	3.1	1.29	519	0.04	0.09	0.16	5	9
Chicago Mill	Tensas	15,520	Hoss	4.09	H	3.1	1.29	524	0.04	0.20	0.05	5	1
Chicago Mill	Tensas	15,560	Hoss	0.51	H	3.1	1.29	333	0.06	0.06	0.07	12	14
REF. #1	Bienville	7,547	Hoss	0.17	Am	3.2	1.37	333	0.03	0.02	0.10	12	59
J. Bentley	Rapides	12,911	Sligo	0.23	Am/H	3.1	1.29	365	0.10	0.10	0.23	43	100
J. Bentley	Rapides	12,948	Sligo	0.45	Am/H	3.1	1.29	408	0.00	0.07	0.35	16	78
Huffman-Mcneely #1	Natchitoches	15,507	Sligo	0.23	H	3.2	1.37	369	0.04	0.04	0.07	17	30
C. Atkins	Natchitoches	11,203	GR	0.10	Am	2.9	1.14	288	0.09	0.03	0.36	30	360
REF. #1	Bienville	5,819	Rodessa	0.46	Am	2.9	1.14	413	0.04	0.17	0.39	37	85
Huffman-Mcneely #1	Natchitoches	7,685	Austin	0.26	H	2.5	0.86	433	0.24	2.45	0.41	942	158
Huffman-Mcneely #1	Natchitoches	9,747	Mrspt	1.00	H/I	2.7	1.00	437	0.05	0.10	0.13	10	13
Huffman-Mcneely #1	Natchitoches	11,771	James	0.17	H	2.7	1.00	349	0.01	0.00	0.13	-	76

*Vitrinite reflectance (%R_o) was determined by converting TAI values to R_o values.

¹Unit: Smk=Smackover, CV=Cotton Valley, Hoss=Hosston, GR=Glen Rose, p-salt=pre-salt, Mrspt=Mooringsport.

²Kerogen: Am=amorphous, H=herbaceous, W=woody, I=inertinite.

Table 2. Comparison of North Louisiana Salt Basin and Mississippi Interior Salt Basin.

Petroleum system characteristics (Smackover)	North Louisiana Salt Basin				Mississippi Interior Salt Basin	
Thickness (m)	396				116	
Kerogen type	Type IIS (Microbial/Amorphous)				Type IIS (Microbial/Amorphous)	
TOC (wt%) range	0.06 – 8.42				0.24 – 4.55	
TOC (wt%) average	0.58 (measured) - 1.0 (calculated for modeling)				0.85 (measured) – 1.5 (calculated for modeling)	
Depth to generate oil, m (ft)	1829 – 2591 (6,000-8,500)				2438 – 3353 (8,000-11,000)	
Depth to generate gas, m (ft)	3658 – 4877 (12,000-16,000)				5029 – 6401 (16,500-21,000)	
	<u>Basin proper</u>		<u>Monroe Uplift</u>	<u>Sabine Uplift</u>	<u>Updip/Margin</u>	<u>Downdip/Center</u>
	<u>Updip/Margin</u>	<u>Downdip/Center</u>				
Maturity (R _o %)	0.8-1.3	1.3->2.6	<0.5-1.3	0.8-1.5	<0.5-1	1-2.5
Time to generate oil (Ma)	115-135	125-140	105-125	115-125	35-90	90-135
Time to generate gas (Ma)	Present-50	50-105	No gas	20-50	No gas	12-80
Time of expulsion (Ma)	50-110	100-125	<u>100-120*</u>	90-105	30-50	60-110
Time of peak expulsion (Ma)	40-105	80-120	<u>90-110*</u>	60-100	Present-45	50-100
Heat flow (HFU)	1.25				1.09	

* Only in the southwest portion of Monroe Uplift

Table 3. Oil and gas production from the North Louisiana and Mississippi Interior Salt Basins.

Reservoir	North Louisiana Salt Basin				Mississippi Interior Salt Basin			
	Oil (bbls)	Gas (Mcf)	GOR (scf/bbl)	Reservoir Depth, m (ft)	Oil (bbls)	Gas (Mcf)	GOR (scf/bbl)	Formation Depth, m (ft)
Tertiary								
Wilcox	228,200	89,342	392	610-2134 (2,000-7,000)	273,753,647	198,084,956	724	398-1,177 (1,307-3,863)
Upper Cretaceous								
Selma/Jackson Gas Rock					39,205,424	224,393,889	5,724	921-1,570 (3,022-5,150)
Arkadelphia/Monroe Gas Rock	44,038	7,452,904,183	169,238,026	610-762 (2,000-2,500)				
Nacatoch (Navarro)	758,374,196	4,431,274,239	5,843	244-623 (800-2,700)				
Ozan/Buckrange (Taylor)	265,037,353	1,007,534,243	3,801	381-945 (1,250-3,100)				
Tokio/Blossom (Austin)	128,817,273	1,718,406,462	13,340	823-945 (2,700-3,100)				
Eutaw					301,449,711	1,754,506,272	5,820	945-2,448 (3,100-8,030)
Tuscaloosa/Eagle Ford	3,971,873	75,601,381	19,034	945-2,819 (3,100-9,250)				
Tuscaloosa					637,040,878	1,824,392,781	2,598	1,084-2,602 (3,558-8,537)
Lower Cretaceous								
Dantzler					783,201	72,450,931	92,506	943-2,955 (3,095-9,695)
Washita-Fredericksburg					56,943,318	255,821,157	4,493	1,446-2,955 (4,744-9,695)
Fredericksburg	1,643,190	34,409,159	20,940	914-1829 (3,000-6,000)				
Paluxy	6,206,760	88,408,279	14,244	762-2,591 (2,500-8,500)	56,544,588	568,991,732	10,063	1,730-3,706 (5,677-12,160)
Mooringsport/Ferry Lake	312,309	1,171,999	3,753	914-1,524 (3,000-5,000)	11,641,148	215,893,837	18,546	1,677-4,215 (5,502-13,830)
Rodessa	198,858,232	5,615,080,804	28,237	1,250-1,829 (4,100-6,000)	235,162,019	341,331,628	1,451	1,715-4,088 (5,628-13,413)
James	12,409	2,869,335	231,230	1,433-1,829 (4,700-6,000)	902,320	80,356,905	89,056	2,479-4,237 (8,133-13,900)
Pine Island	8,745,072	545,229,418	62,347	1,219-2,134 (4,000-7,000)	543,856	676,027	1,243	2,479-4,237 (8,133-13,900)
Sligo/Pettet	140,715,109	3,557,065,945	25,278	1,524-2,743 (5,000-9,000)				
Sligo					30,927,220	157,859,597	5,104	2,543-4,478 (8,343-14,692)
Hosston	12,896,970	1,641,948,296	127,313	1,524-3,658 (5,000-12,000)	54,887,990	995,065,210	18,129	2,664-4,640 (8,740-15,223)
Upper Jurassic								
Cotton Valley	114,348,835	2,223,486,076	19,445	2,195-4,420 (7,200-14,500)	106,461,276	146,163,240	1,373	1,437-5,502 (4,713-18,050)
Haynesville	13,923,298	152,081,744	10,923	2,957-3,200 (9,700-10,500)	6,421,491	349,786,844	54,471	1,990-6,367 (6,528-20,890)
Smackover	33,800,601	271,765,406	8,040	3,048-3,810 (10,000-12,500)	522,979,535	4,069,721,819	7,782	2,038-7,179 (6,685-23,553)
Norphlet					12,664,335	331,269,443	26,158	2,209-7,500 (7,247-24,606)
Others	25,388,311	130,564,541	5,143		872,883,419	1,277,775,162	1,464	
Total for Reservoirs	1,713,324,029	28,949,890,852	16,897		3,221,195,376	12,864,541,430	3,994	

Production data for Louisiana from the 2002 International Oil Scout Association Yearbook (unpublished), and production data for 2005 for Mississippi from Mississippi Oil and Gas Board. Reservoir depths for the North Louisiana Salt basin are from Goddard (2006), Quick look handbook onshore Louisiana petroleum producing formations (unpublished). Formation depths for the Mississippi Interior Salt basin are from well logs in Mancini et al. (1999).

Table 4. Sedimentary and petrophysical characteristics of the reservoirs in the onshore interior salt basins and subbasins, central and eastern Gulf Coastal Plain

Reservoir	Lithology ₁	Environment ₂	Porosity (%) ³	Permeability (md)
Wilcox	SS	FD	15–35	200–600
Arkadelphia/Monroe Gas Rock	CK	NS, MS	5–25	1–500
Selma/Jackson Gas Rock	CK	MS	5–18	1–500
Nacatoch	SS	NS	20–28	200–2,500
Ozan	SS	NS	20–33	100–1,000
Tokio	SS	NS	20–35	200–450
Eutaw	SS	T, NS, MS	13–39	1–5,470
Tuscaloosa	SS	FD, C, MS	25–30	200–2,000
Dantzler	SS	FD	25–30	50–150
Fredericksburg	SS, LS	NS, MS, R	10–30	1–150
Paluxy	SS	F, NS, MS	24–30	150–600
Mooringsport	SS, LS	NS, MS, R	10–20	10–500
Rodessa	SS, LS	NS, MS, R	10–26	10–650
James	LS	NS, MS, R	10–15	6–100
Pine Island	SS	NS	10–15	10–200
Sligo	SS, LS	NS, MS, R	16–20	9–100
Hosston	SS	FD, NS, DM	10–26	10–250
Cotton Valley	SS, LS	FD, NS, R	9–18	1–300
Haynesville	SS, LS	F, NS, R	9–16	50–400
Smackover	LS	CR, R	11–22	1–100
Norphlet	SS	E, F	3–20	1–890

¹ Lithology: SS = sandstone, LS = limestone, CK = chalk.

² Environment: E = eolian, F = fluvial, FD = fluvial-deltaic, C = coastal, T = tidal, NS = nearshore marine, MS = marine shelf, DM = deep marine, CR = carbonate ramp, R = reef.

³ Reservoir porosity and permeability data are from published field studies files of the regulatory agencies and geological surveys, and Goddard (2006), Quick look handbook onshore Louisiana petroleum producing formations (unpublished).

Table 5. Organic geochemical analyses of potential source rocks, North Louisiana Salt Basin.

Sample no.	Well	Parish	Depth (ft)	Unit ¹	TOC (%)	Kerogen ²	TAI	%R _o	Tmax ³ (°C)	S1 ⁴ (mg/g)	S2 ⁵ (mg/g)	S3 ⁶ (mg/g)	PI ⁷	PC ⁸	HI ⁹	OI ¹⁰
"1	George Franklin #1	Richland	11,690.50	Smk	0.16	Am	3.3	1.45	334	0.06	0.08	0.35	0.43	0.00	50	218
"2	George Franklin #1	Richland	11,770.00	Smk	0.25	Am	3.4	1.54	344	0.13	0.09	0.16	0.59	0.02	36	64
"3	Colvin #2	Lincoln	10,856.00	Smk	0.32	H	3.2	1.37	333	0.16	0.15	0.38	0.52	0.03	47	119
"4	McGehee #1	Lincoln	13,439.00	Smk	0.78	Am/H	3.6	1.71	286	0.20	0.10	1.10	0.67	0.02	13	141
"5	McGehee #1	Lincoln	13,602.00	Smk	0.38	Am/H	3.6	1.71	314	0.09	0.04	0.36	0.69	0.01	11	95
"6	Bearden #1	Union	10,170.00	Smk	0.14	H	3.0	1.22	288	0.11	0.04	0.16	0.73	0.01	29	114
"7	B-1 Hamiter	Bossier	10,568.00	Smk	0.19	H	2.8	1.07	318	0.13	0.06	0.24	0.68	0.02	32	126
"8	Waller #1	Claiborne	10,390.00	Smk	0.18	Am	2.8	1.07	323	0.06	0.04	0.48	0.60	0.01	22	267
"9	Sherman #1	Claiborne	10,216.00	Smk	0.24	Am/H	2.8	1.07	430	0.20	0.14	0.18	0.59	0.03	58	75
"10	Dillon Heirs	Caddo	7,015.00	CV	0.41	Am	2.4	0.80	432	0.32	0.35	1.12	0.48	0.05	85	273
"11	F. Wappler	Caddo	8,683.00	CV	0.75	Am	2.5	0.86	370	0.17	0.58	0.54	0.23	0.06	77	72
"12	F. Wappler	Caddo	8,793.00	CV	0.62	Am/H	2.5	0.86	336	0.09	0.05	0.72	0.64	0.01	8	116
"13	F. Wappler	Caddo	8,801.00	CV	1.80	H	2.5	0.86	441	0.30	2.71	0.42	0.10	0.25	151	23
"14	F. Wappler	Caddo	9,351.00	CV	0.62	H	2.5	0.86	375	0.19	0.20	0.60	0.49	0.03	32	97
"15	L. Enloe	Claiborne	10,714.00	Smk	0.19	H/W	3.0	1.22	308	0.21	0.10	0.94	0.68	0.03	53	495
"16	Bankston	Franklin	14,656.00	CV	0.35	Am	3.5	1.62	293	0.17	0.09	0.65	0.65	0.02	26	186
"17	Davis Bros.	Jackson	10,944.00	Boss	0.46	H	2.9	1.14	331	0.14	0.12	0.09	0.54	0.02	26	20
"18	Davis Bros.	Jackson	12,956.00	Boss	0.43	H	3.0	1.22	304	0.10	0.08	0.22	0.56	0.01	19	51
"19	Davis Bros.	Jackson	12,976.00	Boss	0.61	H	3.1	1.29	313	0.11	0.07	0.02	0.61	0.01	11	3
"20	C. Atkins	Natchitoches	11,203.00	GR	0.10	Am	2.9	1.14	288	0.09	0.03	0.36	0.75	0.01	30	360
"21	Huffman-McNeely	Natchitoches	17,480.00	CV	0.11	Am	3.7	1.80	325	0.06	0.04	0.18	0.60	0.01	36	164
"22	J. Bentley	Rapides	12,911.00	Sligo	0.23	Am/H	3.1	1.29	365	0.10	0.10	0.23	0.50	0.02	43	100
"23	J. Bentley	Rapides	12,948.00	Sligo	0.45	Am/H	3.1	1.29	408	0.00	0.07	0.35	0.00	0.01	16	78
"24	Chicago Mill	Tensas	14,876.00	Hoss	1.69	H	3.1	1.29	519	0.04	0.09	0.16	0.31	0.01	5	9
"25	Chicago Mill	Tensas	15,520.00	Hoss	4.09	H	3.1	1.29	524	0.04	0.20	0.05	0.17	0.02	5	1
"26	Chicago Mill	Tensas	15,560.00	Hoss	0.51	H	3.1	1.29	333	0.06	0.06	0.07	0.50	0.01	12	14
"27	N. Manning	Union	16,016.00	p-salt	0.26	Am	3.4	1.54	311	0.03	0.03	0.15	0.50	0.00	12	58
"28	N. Manning	Union	16,057.00	p-salt	0.18	Am	3.7	1.80	252	0.01	0.00	0.29	1.00	0.00	0	161
"29	N. Manning	Union	16,074.00	p-salt	0.13	Am	3.8	1.89	252	0.01	0.00	0.12	1.00	0.00	0	92
"30	Frazier Unit	Webster	10,874.00	Smk	0.24	H	2.9	1.14	318	0.18	0.13	0.59	0.58	0.03	54	246
"31	Frazier Unit	Webster	11,250.00	Smk	0.21	H	3.0	1.22	411	0.06	0.10	0.24	0.38	0.01	48	114
"32	H. Davis	Webster	11,043.00	Smk	0.28	Am/H	3.2	1.37	380	0.02	0.03	0.15	0.40	0.00	11	54
"33	H. Davis	Webster	11,243.00	Smk	0.16	Am	3.4	1.54	305	0.01	0.01	0.15	0.50	0.00	6	94
"34	CZ 10-11	Winn	13,690.00	CV	0.57	Am	3.7	1.80	276	0.03	0.03	0.22	0.50	0.00	5	39
"35	CZ 10-11	Winn	13,804.00	CV	0.47	Am/H	3.7	1.80	252	0.03	0.01	0.21	0.75	0.00	2	45
"36	CZ 10-11	Winn	13,924.00	CV	0.48	Am	3.7	1.80	252	0.01	0.01	0.02	0.50	0.00	2	4
"37	CZ 10-11	Winn	13,946.00	CV	0.30	Am/I	3.7	1.80	354	0.03	0.05	0.13	0.38	0.01	17	43
"38	CZ 5-7	Winn	15,608.00	Boss	0.28	I	3.7	1.80	307	0.02	0.04	0.00	0.33	0.00	14	0
"39	CZ 5-7	Winn	16,418.00	Boss	0.34	I	3.8	1.89	355	0.05	0.07	0.11	0.42	0.01	21	32
"40	CZ 5-7	Winn	16,431.00	Boss	0.34	W/I	3.8	1.89	329	0.06	0.10	0.37	0.38	0.01	29	109
"41	Pardee	Winn	16,200.00	Boss	0.35	Am/I	3.7	1.80	322	0.21	0.29	0.29	0.42	0.04	83	83
"42	Pardee	Winn	16,400.00	Boss	0.35	Am/I	3.7	1.80	328	0.19	0.16	0.16	0.54	0.03	46	46
"43	REF. #1	Bienville	5,819.00	Rodessa	0.46	Am	2.9	1.14	413	0.04	0.17	0.39	0.19	0.02	37	85
"44	REF. #1	Bienville	7,547.00	Hoss	0.17	Am	3.2	1.37	333	0.03	0.02	0.10	0.60	0.00	12	59
"45	Southern Nat Gas #2	Bienville	10,802.00	CV	0.43	H	3.4	1.54	423	0.11	0.04	0.46	0.73	0.01	9	107
"46	Lawhorn Amoco #1	Bienville	10,774.00	CV	1.25	H	2.3	0.74	479	0.06	0.23	0.27	0.20	0.02	18	22
"47	Wheless #1	Claiborne	11,866.00	Smk	0.32	H	2.7	1.00	378	0.14	0.09	0.20	0.60	0.02	28	62
"48	Bob #1	Claiborne	10,707.00	Smk	0.36	H	2.8	1.07	452	0.04	0.07	0.08	0.36	0.01	19	22
"49	Expl Ipco #1	De Soto	10,364.00	CV	0.48	W/I	2.7	1.00	473	0.11	0.18	0.15	0.37	0.02	38	31
"50	Davis #1	Jackson	11,188.00	CV	0.31	Am/H	2.5	0.86	394	0.07	0.04	0.05	0.63	0.01	13	16

Table 5. Organic geochemical analyses of potential source rocks, North Louisiana Salt Basin (continuation).

51	Parnell #1	Lincoln	9,127.00	CV	0.60	H	2.4	0.80	436	0.31	0.60	0.57	0.34	0.08	100	95
52	James #1	Lincoln	10,443.00	CV	0.12	H	3.2	1.37	412	0.05	0.03	0.23	0.62	0.01	25	192
53	Crown-Zellerbach #1	Natchitoches	13,421.00	Smk	0.09	H	3.7	1.80	361	0.36	0.31	0.43	0.54	0.06	344	478
54	Godfrey "B" #1	Natchitoches	13,305.00	Smk/Nor	1.80	H	3.7	1.80	341	0.94	0.28	0.66	0.77	0.10	16	37
55	Terzia F. C. #1	Ouachita	10,193.00	CV	1.65	H	2.4	0.80	450	0.41	0.82	0.29	0.33	0.10	50	18
56	Webb #1	Ouachita	9,620.00	CV	0.20	Am/H	2.3	0.74	429	0.10	0.18	0.09	0.35	0.02	90	45
57	Kennedy #2	Ouachita	9,915.00	CV	0.76	Am/H	2.4	0.80	443	0.21	0.96	0.17	0.18	0.10	127	23
58	Teer #1	Red River	14,060.00	Smk/Nor	1.22	H/I	3.8	1.89	418	0.94	0.29	0.27	0.77	0.10	24	22
59	Sample #1	Red River	9,676.00	CV	0.45	H	2.7	1.00	410	0.19	0.23	0.15	0.45	0.03	51	33
60	Sample #2	Red River	9,911.00	CV	0.29	H	2.7	1.00	431	0.09	0.13	0.14	0.40	0.02	45	48
61	Green #1	Union	10,683.00	Smk	0.08	H	3.0	1.22	378	0.04	0.12	0.18	0.25	0.01	150	225
62	Green #1	Union	10,825.00	Smk	0.12	H	3.7	1.80	400	0.02	0.09	0.46	0.17	0.01	75	383
63	Phillip #1	Webster	10,290.00	CV	1.07	H	2.7	1.00	455	0.28	0.71	0.29	0.28	0.08	66	27
64	Phillip #1	Webster	10,640.00	CV	0.25	H/I	2.7	1.00	450	0.05	0.15	0.10	0.25	0.02	60	40
65	Huffman-Mcneely #1	Natchitoches	7,685.00	Austin	0.26	H	2.5	0.86	433	0.24	2.45	0.41	0.09	0.22	942	158
66	Huffman-Mcneely #1	Natchitoches	9,747.00	Moor	1.00	H/I	2.7	1.00	437	0.05	0.10	0.13	0.32	0.01	10	13
67	Huffman-Mcneely #1	Natchitoches	11,771.00	James	0.17	H	2.7	1.00	349	0.01	0.00	0.13	1.00	0.00	--	76
68	Huffman-Mcneely #1	Natchitoches	15,507.00	Sligo	0.23	H	3.2	1.37	369	0.04	0.04	0.07	0.49	0.01	17	30
69	English #2	Bossier	9,382.00	CV	0.29	I	2.5	0.86	439	0.04	0.15	0.11	0.20	0.02	52	38
70	English #2	Bossier	9,432.00	CV	0.32	H	2.5	0.86	443	0.08	0.40	0.14	0.16	0.04	125	44
71	English #2	Bossier	11,136.00	Boss	0.55	W/I	2.7	1.00	515	0.08	0.23	0.24	0.26	0.03	42	44
72	English #2	Bossier	11,168.00	Boss	0.91	Am/H	2.7	1.00	498	0.25	0.25	0.40	0.50	0.04	27	44
73	First Bank #1	Bossier	11,108.00	Boss	0.35	W/I	2.9	1.14	482	0.06	0.11	0.17	0.34	0.01	31	49
74	First Bank #1	Bossier	11,173.00	Smk	0.47	W/I	2.9	1.14	381	0.09	0.13	0.00	0.40	0.02	28	--
75	First Bank #1	Bossier	11,178.00	Smk	0.80	W/I	2.9	1.14	515	0.11	0.33	0.00	0.25	0.04	41	--
76	Fee Gas #1	Union	9,887.00	Smk	0.08	--	--	--	422	0.04	0.03	0.34	0.57	0.01	37	425
77	Fee Gas #1	Union	9,901.00	Smk	0.12	--	--	--	385	0.02	0.02	0.17	0.50	0.00	17	142
78	Fee Gas #1	Union	9,911.00	Smk	0.06	--	--	--	280	0.01	0.00	0.22	1.00	0.00	--	367
79	Aycock #1	Richland	2,692.00	Arka	0.05	--	--	--	376	0.01	0.00	0.35	1.00	0.00	--	700
80	Aycock #1	Richland	7,894.00	Smk	0.09	--	--	--	330	0.03	0.01	0.13	0.75	0.00	11	144
81	Jackson #1	West Carrol	2,726.00	Arka	0.06	--	--	--	412	0.03	0.08	0.20	0.27	0.02	133	333
82	GH Cooper #1	East Carrol	7,077.00	Smk	0.07	--	--	--	350	0.02	0.01	0.24	0.66	0.02	14	343
83	GH Cooper #1	East Carrol	7,093.00	Smk	0.06	--	--	--	318	0.03	0.04	0.20	0.43	0.02	67	333
84	GH Cooper #1	East Carrol	7,107.00	Smk	0.09	--	--	--	366	0.01	0.05	0.15	0.17	0.02	56	167
85	Hope Fee #1	Morehouse	5,972.50	Smk	0.18	--	--	--	434	0.03	0.05	0.29	0.38	0.03	28	161
86	Hope Fee #1	Morehouse	6,116.50	Smk	0.33	Lip	2.2	0.63	433	0.08	0.25	0.43	0.24	0.06	76	130
87	Hope Fee #1	Morehouse	6,210.50	Smk	0.48	Lip	2.2	0.60	420	1.19	0.70	0.39	0.63	0.09	146	81
88	Hope Fee #1	Morehouse	6,304.50	Smk	0.38	Lip	2.3	0.66	432	0.19	0.43	0.25	0.31	0.06	113	66
89	Hope Fee #1	Morehouse	6,530.50	Smk	0.84	Lip	2.3	0.70	434	0.32	1.43	0.52	0.18	0.16	170	62
90	Hope Fee #1	Morehouse	6,609.50	Smk	1.47	Lip	2.3	0.69	436	0.51	3.12	0.35	0.14	0.29	212	24
91	Hope Fee #1	Morehouse	6,649.50	Smk	1.41	Lip	2.0	0.51	431	0.61	4.85	0.36	0.11	0.43	344	26
92	Hope Fee #1	Morehouse	6,725.50	Smk	0.31	Lip	--	--	431	0.10	0.17	0.52	0.37	0.06	55	168
93	Smith #1	Claiborne	10,808.00	Smk	0.40	Lip	3.0	1.03	470	0.10	0.14	0.64	0.42	0.06	35	160
94	Smith #1	Claiborne	10,836.00	Smk	0.29	Lip	3.0	0.99	358	0.08	0.05	0.68	0.61	0.06	17	234
95	Smith #1	Claiborne	10,866.00	Smk	3.02	Vit	2.5	0.85	448	1.62	1.12	0.6	0.59	0.14	37	20
96	Smith #1	Claiborne	10,875.00	Smk	3.30	Vit	2.6	0.89	446	1.69	1.63	0.64	0.51	0.19	49	19
97	Smith #1	Claiborne	10,899.00	Smk	8.42	Vit	2.5	0.83	450	1.63	3.12	0.89	0.34	0.33	37	11
98	Smith #1	Claiborne	10,920.00	Smk	0.54	Lip	2.6	0.91	453	0.16	0.20	0.77	0.45	0.08	37	143
99	Lowery #1	Union	10,661.00	Smk	1.23	Lip	2.6	0.90	448	0.79	1.16	0.84	0.41	0.17	94	68
100	Lowery #1	Union	10,666.00	Smk	0.88	Lip	2.7	0.94	448	0.47	0.68	0.54	0.41	0.10	77	61
101	Lowery #1	Union	10,676.00	Smk	1.00	Lip	2.7	1.02	447	0.61	0.77	0.49	0.44	0.10	77	49
102	Manville Forest #1	Webster	11,494.00	Smk	0.64	Vit	3.2	1.23	450	0.13	0.14	0.42	0.48	0.05	22	66
103	Manville Forest #1	Webster	11,567.00	Smk	0.37	Lip	3.4	1.47	439	0.08	0.05	0.27	0.62	0.03	14	73
104	Manville Forest #1	Webster	11,618.00	Smk	0.49	Lip	3.4	1.47	422	0.09	0.04	0.48	0.69	0.04	8	98
105	Waller #1	Claiborne	10,313.00	Smk	0.32	Lip	3.0	1.03	436	0.11	0.15	0.34	0.42	0.04	47	106

Table 5. Organic geochemical analyses of potential source rocks, North Louisiana Salt Basin (continuation).

106	Waller #1	Claiborne	10,484.00	Smk	0.27	Lip	3.0	1.04	434	0.12	0.04	0.26	0.75	0.02	15	96
107	Yates A1	Claiborne	10,410.00	Smk	0.42	Lip	2.2	0.59?	448	0.30	0.21	0.22	0.59	0.04	50	52
108	Yates A1	Claiborne	10,476.00	Smk	0.22	Lip	3.0	1.03	429	0.06	0.01	0.22	0.86	0.02	5	100
109	Turner #1	Claiborne	10,175.00	Smk	0.11	Lip	--	--	399	0.07	0.06	0.2	0.54	0.02	55	182
110	Turner #1	Claiborne	10,254.00	Smk	0.14	Lip	2.3	0.70	333	0.09	0.07	0.17	0.57	0.02	50	121
111	Rockhold #1	Claiborne	9,893.00	Smk	0.34	Lip	2.5	0.79	455	0.07	0.07	0.48	0.50	0.05	21	141
112	Rockhold #1	Claiborne	9,928.00	Smk	0.45	Lip	2.5	0.78	445	0.12	0.29	0.49	0.29	0.06	64	109
113	Barrett #1	Union	10,549.00	Smk	0.22	--	--	--	448	0.08	0.03	0.24	0.73	0.02	14	109
114	Barrett #1	Union	10,575.00	Smk	0.12	--	--	--	359	0.04	0.00	0.65	1.00	0.05	--	542
115	Elliot #1	Union	10,140.00	Smk	0.18	Lip	2.2	0.60	320	0.08	0.01	0.14	0.89	0.01	6	78
116	Elliot #1	Union	10,310.00	Smk	0.13	--	--	--	256	0.05	0.00	0.22	1.00	0.02	--	169
117	Elliot #1	Union	10,333.00	Smk	0.23	--	--	--	455	0.07	0.10	0.37	0.41	0.04	43	161
118	Farris #1	Union	10,265.00	Smk	0.11	Lip	--	--	367	0.13	0.09	0.22	0.59	0.03	82	200
119	Exxon #1	Union	8,522.00	Smk	0.12	Lip	--	--	331	0.04	0.01	0.36	0.80	0.03	8	300
120	Parther Est #1	Claiborne	11,837.00	Smk	0.48	Lip	3.2	1.22	425	0.20	0.08	0.56	0.72	0.05	17	117
121	Parther Est #1	Claiborne	11,947.00	Smk	0.53	Lip	3.2	1.27	441	0.18	0.12	0.15	0.60	0.02	23	28
122	Gray Estate #1	Claiborne	10,278.00	Smk	0.22	Lip	2.6	0.85	432	0.08	0.07	0.23	0.53	0.02	32	105
123	Gray Estate #1	Claiborne	10,306.00	Smk	0.28	Lip	2.5	0.82	390	0.09	0.02	0.15	0.82	0.01	7	54
124	Bell #1 "B"	Claiborne	10,920.00	Smk	0.20	Lip	--	--	315	0.08	0.00	0.22	1.00	0.02	--	110
125	Gibson A-1	Claiborne	11,140.00	Smk	0.24	Lip	--	--	422	0.13	0.13	0.16	0.51	0.02	54	67
126	Gibson A-1	Claiborne	11,156.00	Smk	0.27	Lip	--	--	442	0.23	0.10	0.26	0.70	0.03	37	96
127	Northcott #2	Bossier	11,530.00	Smk	0.21	Lip	2.2	0.56?	457	0.11	0.11	0.16	0.50	0.02	52	76
128	Tinsley #1	Claiborne	11,817.00	Smk	1.17	Lip	3.1	1.17	491	0.18	0.31	0.41	0.36	0.06	26	35
129	Tinsley #1	Claiborne	11,835.00	Smk	1.07	Lip	3.2	1.22	349	2.19	0.74	0.62	0.75	0.11	69	58
130	Norman Dowling #1	Lincoln	12,642.00	Smk	1.03	Vit/Lip	3.4	1.49	403	7.10	1.05	0.74	0.87	0.15	102	72
131	Norman Dowling #1	Lincoln	12,649.00	Smk	0.60	Vit/Lip	3.5	1.59	363	0.94	0.29	0.34	0.76	0.05	48	57
132	Colvin #1	Lincoln	11,119.00	Smk	0.34	Lip	3.0	1.03	408	0.09	0.06	0.22	0.60	0.02	18	65
133	Colvin #1	Lincoln	11,166.00	Smk	0.16	Lip	3.1	1.11	425	0.05	0.05	0.29	0.50	0.03	31	181
134	Copeland "A"	Webster	11,288.00	Smk	0.81	Lip	3.0	1.04	492	0.11	0.25	0.4	0.30	0.05	31	49
135	Copeland "A"	Webster	11,338.00	Smk	0.34	Lip	3.1	1.16	415	0.05	0.02	0.24	0.72	0.02	6	71
136	Hearn "A" #1	Webster	11,558.00	Smk	0.46	Lip	3.1	1.19	367	0.11	0.02	0.1	0.84	0.01	4	22
137	Hearn "A" #1	Webster	11,580.00	Smk	0.37	Lip	3.2	1.24	386	0.09	0.10	0.21	0.47	0.03	27	57
138	Alston "A" #1	Webster	11,586.00	Smk	1.11	Vit	3.2	1.21	484	0.21	0.28	0.11	0.42	0.03	25	10
139	Alston "A" #1	Webster	11,622.00	Smk	0.42	Lip	3.3	1.32	457	0.08	0.14	0.24	0.36	0.03	33	57
140	Hearn "C"	Webster	11,930.00	Smk	0.94	Lip	3.2	1.20	514	0.18	0.21	0.16	0.46	0.03	22	17
141	B #1	Webster	10,979.00	Smk	0.30	Lip	3.4	1.42	329	0.54	0.01	0.25	0.98	0.02	3	83
142	B #1	Webster	11,095.00	Smk	0.30	Lip	3.6	1.63	283	0.06	0.00	0.11	1.00	0.01	--	37

1Unit: Smk=Smackover, Nor=Norphlet, CV=Cotton Valley, Boss=Bossier, GR=Glen Rose, Hoss=Hosston, p-salt=pre-salt,

Moor=Mooringsport, Arka=Arkadelphia.

2Kerogen: Am=amorphous, H=herbaceous, W=woody, I=inertinite, Lip=Liptinite, Vit=Vitrinite.

GeoChem Laboratories Inc. and Baseline Resolution Inc. use different classification of visual kerogen.

3Tmax=temperature index.

4S1=free hydrocarbon.

5S2=residual hydrocarbon potential.

6S3=CO₂ produced from kerogen pyrolysis.

7PI=S1/(S1+S2).

8PC=0.083 (S1+S2).

9HI=hydrogen index.

10OI=oxygen index.

*All data by GeoChem Laboratories Inc..

**TOC, Kerogen type, and TAI data by GeoChem Laboratories Inc., Rock Pyrolysis data by Baseline Resolution Inc..

***All data by Baseline Resolution Inc..

Table 6. Total organic carbon, rock–eval pyrolysis and vitrinite reflectance analytical results.

Cotton Valley-Bossier Group and Haynesville Cores Analyzed in North Louisiana Salt Basin													
Well	Rock Sample	Sample Depth (Ft)	TOC Wt. %	S1 mg/g	S2 mg/g	S3 mg/g	Tmax	HI	OI	S1/ TOC	PI	TAI	% Ro VITK
AMOCO DAVIS	Cotton V.	10,944	0.46	0.14	0.12	0.09	331	26	20	30	0.54		
AMOCO DAVIS	Cotton V.	10,945	0.25	0.04	0.04	0.12	442	17	46	17	0.49		
AMOCO DAVIS	Cotton V.	10,948	0.11	0.02	0.04	0.11	424	35	98	18	0.33		
AMOCO DAVIS	Haynesville	12,956	0.43	0.1	0.08	0.22	304	19	20	43	0.56	3.5-3.7	1.73
AMOCO DAVIS	Haynesville	12,976	0.61	0.11	0.07	0.02	313	11	3	18	0.61	3.5-3.7	1.77

AMOCO CZ 5-7	Bossier	15,601	0.27	0.04	0.06	0.13	375	21	50	15	0.42		
AMOCO CZ 5-7	Bossier	15,608	0.28	0.02	0.04	0	307	14	0	7	0.33		
AMOCO CZ 5-7	Bossier	16,413	0.23	0.04	0.05	0.14	379	22	58	18	0.45		
AMOCO CZ 5-7	Bossier	16,418	0.34	0.05	0.07	0.11	355	21	32	15	0.42		
AMOCO CZ 5-7	Bossier	16,431	0.34	0.06	0.1	0.37	329	29	109	18	0.38	3.7-3.8	2.62
AMOCO CZ 5-7	Bossier	16,432	0.28	0.05	0.09	0.15	375	31	55	18	0.37		
EXXON PARDEE	Bossier	16,195	0.19	0.18	0.27	0.12	370	147	62	96	0.39		
EXXON PARDEE	Bossier	16,200	0.35	0.21	0.29	0.29	322	83	83	60	0.42		
EXXON PARDEE	Bossier	16,400	0.35	0.19	0.16	0.16	328	46	46	54	0.54	3.7-3.8	2.06
PAN AM VENZINA	Bossier	9347	0.5	0.06	0.26	0.44	442	52	88	12	0.19	2.8-3.0	0.91
PAN AM VENZINA	Bossier	9357	0.45	0.19	0.43	0.22	451	94	48	41	0.3	2.8-3.0	0.96
PAN AM VENZINA	Bossier	9372	0.39	0.1	0.24	0.32	449	62	83	26	0.29	2.8-3.0	0.96
STWERTHARRISON	Cotton V.	11,805	2.8	0.26	0.52	0.19	491	19	7	9	0.33		
FISHER 16-1	Bossier	13,175	0.51	0.17	0.09	0.57	406	18	112	33	0.65		
FISHER 16-1	Bossier	13,770	0.56	0.16	0.16	0.13	436	29	23	29	0.5		
DAVIS Bros 29-2	Bossier	14,035	0.68	0.87	0.44	0.49	359	65	72	128	0.66		
DAVIS Bros 29-2	Bossier	15,120	0.75	0.53	0.32	0.5	360	42	66	70	0.62		
BEASLEY 9-#2	Cotton V.	11,348	4.46	1.31	2.2	0.47	464	49	11	29	0.37		

Table 7. Cotton Valley-Bossier Group wells selected for analyses.

(Ser#) & API#	OP/Well Name	(LA Parish)	Sample Depth (Ft)
1) (107545) 171110003800	PAN AM Venzina Green # 1	(Union)	9,347 9,357 9,372
4) (162291) 170492011000	AMOCO Davis Bros.	(Jackson)	10,944 10,945 10,948 12,956 12,976
6b) (166680) 171272085700	EXXON Pardee	(Winn)	16,195 16,200 16,400
7) (164798) 171272082000	AMOCO CZ 5-7	(Winn)	15,601 15,608 16,413 16,418 16,431 16,432

Table 8. Cotton Valley-Group samples in Vernon Field selected for analyses.

Serial. #API	Operator	Well Name	Field	Sec	TWP	RGE	Parish	Sample Depth (Ft)
1) 232316 1704920665	Anadarko	Stewart Harrison 34 #2	Vernon	34	16N	03W	Jackson	11,805'
2) 226742 1704920390	Anadarko	Davis Bros 29 #2ALT	Vernon	29	16N	02W	Jackson	14,035' 15,120'
3) 224274 1704920332	Anadarko	Fisher 16 #1ALT	Vernon	16	16N	02W	Jackson	13,175' 13,770'
4) 231813 1704920649	Anadarko	Beasley 9 #2ALT	Vernon	9	16N	02W	Jackson	11,348'

Table 9. Wells used to construct the north-south stratigraphic cross section.

Operator	Well	Field	Sec	Twp	Rge	Parish	TD(Ft)	Top Bossier (Ft.)	Base Bossier (Ft.)
1) Pan Am	Venzina	wc (Bernice)	22	21N	03W	Union	11,031	9,270	9,930
2) Chevron Oil	Eliza Lewis Dunn	Hico-Knowles	31	20N	03W	Lincoln	12,197	9,925	10,495
3) Arkla Expor (Mobil)	Tomlinson #1	Clay	10	17N	03W	Lincoln	12,457	11,780	na
4) Anadarko Petr.	Fisher 16 #2ALT	Vernon	16	16N	02W	Jackson	14,055	11,980	13,000
5) Cabot Oil & Gas	Knight et al 1 #1	Clear Branch	1	14N	02W	Jackson	15,918	12,785	14,890
6b) Exxon	Pardee #1	East Sikes	36	13N	01W	Winn	19,500	15,775	17,310
7) Amoco Prod	C Z.5-7	Wildcat	5	11N	01W	Winn	17,992	15,600	na

Table 10. Wells used to construct the west-east stratigraphic cross section

Operator	Well	Field	Sec	Twp	Rge	Parish	TD(Ft)	Top Bossier (Ft.)	Base Bossier (Ft.)
1) JW Operating	Cupples 18-12 ALT	Elm Grove	3	16N	13W	Caddo	10,612	9,578	10,160
2) Tenneco Oil	Baker #1	Lake Bistineau	12	16N	10W	Bienville	11,123	8,495	9,120
3) Franks & Broyles	Bardin #1	Bear Creek	8	16N	06W	Bienville	12,550	11,770	12,365
4) J-W Operating	Davis Brothers 21-1	Driscoll	21	16N	04W	Bienville	16,900	12,120	12,930
5) Amoco Prod	Davis Bros 8-3 #1	Vernon	8	16N	03W	Jackson	13,250	11,970	12,725
6a) Anadarko Petr.	Fisher 16 #1ALT	Vernon	16	16N	02W	Jackson	14,100	12,000	13,013
7) Cabot Oil & Gas	Weyerh Co. 15-1	Vernon	15	16N	01W	Jackson	13,778	11,895	12,930
8) Burlington Res.	Donner 13-1	Cheniere Creek	13	16N	02E	Ouachita	13,992	11,090	12,150

Table 11. Oil and gas production for the North Louisiana and Mississippi Interior salt basins by reservoirs and facies associations of T–R sequences.

Reservoir	North Louisiana Salt Basin		Mississippi Interior Salt Basin		*T-R Facies
	Oil (bbls)	Gas (Mcf)	Oil (bbls)	Gas (Mcf)	
UPPER CRETACEOUS Arkadelphia/Monroe Gas Rock	44,038	7,452,904,183			RI
Selma/Jackson Gas Rock			39,205,424	224,393,889	RI
Nacatoch	758,374,196	4,431,274,239			TB
Ozan/Buckrange	265,037,353	1,007,534,243			TB
Tokio/Blossom	128,817,273	1,718,406,462			TB
Eutaw			301,449,711	1,754,506,272	TB
Tuscaloosa/Eutaw	3,971,873	75,601,381			TB/RI
Upper Tuscaloosa			26,338,415	19,226,238	RI
Lower Tuscaloosa			610,702,463	1,805,166,543	TA/TB
LOWER CRETACEOUS Dantzler			783,201	72,450,931	RI
Fredericksburg/Andrew	1,643,190	34,409,159	56,943,318	255,821,157	RI
Paluxy	6,206,760	88,408,279	56,544,588	568,991,732	RI
Mooringsport	312,309	1,171,999	11,633,767	215,885,662	RI
Ferry Lake			7,381	8,175	TB
Rodessa/Donovan	198,858,232	5,615,080,804	235,162,019	314,331,628	RI
James	12,409	2,869,335	902,320	80,356,905	RI
Pine Island	8,745,072	545,229,418	543,856	676,027	TB
Sligo	140,715,109	3,557,065,945	30,927,220	157,859,597	TB
Hosston	12,896,970	1,641,948,296	54,887,990	995,065,210	TA
UPPER JURASSIC Cotton Valley	114,348,835	2,223,486,076	106,461,276	146,163,240	RI
Haynesville	13,923,298	152,081,744	6,421,491	349,786,844	RI
Smackover	33,800,601	271,765,406	522,979,535	4,069,721,819	RI
Norphlet			12,664,335	331,269,443	TA

Production data for Louisiana are from the 2002 International Oil Scout Association Yearbook (2006, personal communication), production data for 2005 for Mississippi are from the Mississippi Oil and Gas Board (2006, personal communication, and production data for 2005 for Alabama are from the Alabama Oil and Gas Board (2006, personal communication). *T–R facies associations: TA=Transgressive aggrading, TB=Transgressive backstepping, RI=Regressive infilling.

Table 12. Summary of oil and gas production from the North Louisiana and Mississippi Interior salt basins by facies associations of T-R sequences.

Basin	*T-R RI Oil (billion/bbls)	T-R RI Gas (Tcf)	T-R TB Oil (billion/bbls)	T-R TB Gas (Tcf)	T-R TA Oil (billion/bbls)	T-R TA Gas (Tcf)
North Louisiana Salt Basin	0.369	15.841	1.306	11.334	0.013	1.642
Mississippi Interior Salt Basin	1.063	6.345	0.337	1.061	0.373	2.229
Total	1.432	22.186	1.643	12.395	0.386	3.871

Production data for Louisiana are from the 2002 International Oil Scout Association Yearbook (2006, personal communication), production data for 2005 for Mississippi are from the Mississippi Oil and Gas Board (2006, personal communication, and production data for 2005 for Alabama are from the Alabama Oil and Gas Board (2006, personal communication). *T-R facies associations: T-R RI=Regressive infilling, T-R TB=Transgressive backstepping, T-R TA=Transgressive aggrading.

National Energy Technology Laboratory

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880

One West Third Street, Suite 1400
Tulsa, OK 74103-3519

1450 Queen Avenue SW
Albany, OR 97321-2198

539 Duckering Bldg./UAF Campus
P.O. Box 750172
Fairbanks, AK 99775-0172

Visit the NETL website at:
www.netl.doe.gov

Customer Service:
1-800-553-7681