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Understanding the Regional Haynesville and Bossier Shale Depositional Systems in East Texas and Northern Louisiana: An Integrated Structural/Stratigraphic Approach*

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Abstract

Recent discoveries in the Haynesville and Bossier shales have dramatically increased unconventional gas exploration activity in the mature petroleum provinces of East Texas and Northern Louisiana. Using a variety of subsurface data including 2D seismic, well logs, mud logs, core descriptions, and absolute age control based on multi-disciplinary biostratigraphy, detailed depositional models for the Haynesville and Bossier Shale depositional systems have been developed. In both systems, the framework of regional structural elements and antecedent topography strongly influences basin geometries and fill through geologic time.

After initial rifting, the Gulf of Mexico (GOM) basin filled with thick evaporite units of the Louann Group followed by the basinward advance of continental siliciclastics of the Norphlet Formation. Early segregation of the northern shelf was marked by intrashelfal highs and sub-basins such as the East Texas, Northern Louisiana, and Eastern Mississippi Salt basins. Subsequent transgressions established the deposition of stacked Oxfordian to Tithonian carbonate systems with major siliciclastic input from the ancestral Mississippi River and predecessors of the Lone Oak and other deltas.

The antecedent topography shaped by underlying Oxfordian mixed carbonate/clastic systems and subsequent sediment budgets strongly influenced (1) facies development and stacking patterns that vary along the northern rim of the GOM during Haynesville and Bossier time and (2) the depositional processes, type, total organic carbon richness, and preservation of the self-sourcing Haynesville and Bossier Shale units.

Building an integrated geologic model to unravel basin evolution, basin physiography, and sedimentary fill through time aids in our understanding of each time-equivalent depositional sequence and ultimately highlights greatest exploration potential. This approach is particularly important in basins like the northern GOM, where continued structural evolution including basement-involved faulting, inversions, and salt movement and evacuation has led to variations of the structural framework of the geologic past while ancient sub-basins and highs may not mimic the modern structural framework.

Introduction

As shale plays across the American continent keep adding resources to the domestic fossil energy mix, both the Haynesville and Bossier Shale plays in east Texas and northern Louisiana ([Figure 1](#)) have been a focus of renewed hydrocarbon exploration in a prolific petroleum province that has been explored since almost a century ago, has been productive for some 80 years, includes the largest oilfield in the U.S. outside of Alaska, and has seen one of the densest oil developments in the world (Smith, 1996). Major conventional reservoirs in the area include siliciclastic and carbonate depositional systems ranging from Triassic to Cenozoic in age. Today, the shift to unconventional hydrocarbon plays has industry focused on the gas-mature source rock intervals of this hydrocarbon province; namely, the Haynesville and Bossier shales, which has been recognized as gas-bearing intervals long before this shift had occurred. With new drilling and completion technologies, companies are developing hydrocarbon resources directly from these source rock units. Geologic factors driving richness in total organic carbon (TOC) of these rocks, type and preservation potential of kerogen, maturity, and their mineralogic composition need to be understood and put into a geologic context in order to predict areas of highest exploration potential for shale gas. This article addresses the underpinning geologic parameters (basin evolution, geometry, and its sedimentary fill through time) of the Haynesville and Bossier shale plays in east Texas and northern Louisiana.

Methodology

Various subsurface data sets have been combined in the study area to understand the basin physiography of the northern shelf of the Gulf of Mexico (GOM) basin throughout the Late Jurassic and earliest Cretaceous as well as its contemporaneous sedimentary fill. About 600 digital well logs were correlated along regional depositional dip and strike and supported by seismic data. Some 120 mud logs with core and cutting descriptions were used to calibrate log responses to rock types, while some 20 wells with detailed biostratigraphic information helped identify absolute age ranges of depositional sequences and support paleoenvironmental interpretation within them. Aeromagnetic and gravity data were used to underpin the general basin setting and geometry. Depositional environment maps for each of the identified sequences through time were generated.

Geologic Setting

Initial rifting along the back of the Ouachita thrust belt during the Triassic was continued throughout the Jurassic period and led to the formation of the GOM Basin (Marton and Buffler, 1999; Pindell and Kennan, 2009). The northern shelf of the young GOM basin was segregated by

intrashelfal highs and lows or sub-basins according to the geometric relationships of rifted basement blocks along the northern margins of the basin ([Figure 2](#)). Various proximal and distal structural fault grains exerted a combined influence on the overall basin geometry and complexity of its subdivision, which, in conjunction with sediment budgets, governs spatial geometries of facies distribution in successive depositional systems filling the basin. During Late Jurassic time the East Texas Salt Basin was separated by a series of basement highs from the Haynesville Basin to the east. The latter appears more restricted by a series of basement blocks to the south and southeast (e.g., Ewing 2001). A proxy for Late Jurassic basin physiography ([Figure 2](#)) is based on thickness variations of sediments between the Pettet Limestone/Sligo and the Cotton Valley/Gilmer Lime but is not corrected for penecontemporaneous salt movement and evacuation, which accentuate intrabasinal isochore thins and thicks in the areas of increased halokinesis. Well control, seismic and gravity data support this map.

Geometries of the basin fill through time in response to basement movement and basin evolution are interpreted using well control and seismic data ([Figure 3](#)). A chronostratigraphic framework ([Figure 4](#)) links sedimentary sequences and their internal facies distribution to absolute ages based on biostratigraphic analyses of nannofossils and palynology, while benthic foraminifera aided in the interpretation of depositional environments. A type log from Harrison County is also shown.

A geologic cross section oriented to depositional strike from west to east across the northern GOM shelf depicts the diachronous nature of maximum flooding surfaces (or intervals of highest TOC enrichment and preservation potential) of higher order sequences within the Haynesville/Bossier shale package ([Figure 5](#)). This diachronous nature is due to the differences in interplay of subsidence and sediment budget in various geographic areas ([Figure 6](#)). The ancestral Mississippi River accounted for a large siliciclastic sediment budget throughout the Late Jurassic even during deposition of the older carbonate depositional systems of the Smackover and Cotton Valley/Gilmer Lime, which both tended to develop shallow water build-ups and shoals along basement highs and basin margins and included mixed carbonate/siliciclastic and siliciclastic deposition toward the mouth of the ancestral Mississippi River.

The Haynesville Shale is interpreted as a continuation of the overall transgressive Upper Gilmer Lime carbonate depositional system (Goldhammer 1998), which includes high-energy carbonates in shallow areas of the shelf and dark laminated marly mudstones within the intrashelfal sub-basins. Only around the mouth of the Mississippi River is the Haynesville mostly progradational after an initial transgressive phase. The Bossier depositional system inherits a less complex northern shelf of the GOM basin, while antecedent basement highs and lows may still persist as bathymetric undulations of the shelfal seafloor. The depositional system of the Bossier Shale is marked by a substantial shift from a more carbonate-rich system of the Haynesville Shale to one with considerably more siliciclastic input, including an increased clay fraction in its sub-basinal mineralogy and drop in carbonate content. Carbonate build-ups still persisted on the western shelf of the East Texas Salt Basin until very late in Bossier Shale deposition, while the ancestral Mississippi River delta expanded westward and prograded to the south. Additional siliciclastic input points developed along the proximal northern and western margins of the northern GOM shelf. Ultimately, carbonate deposition ceased as the Taylor Sands of the Lower Cotton Valley Sandstones prograded southward, across an increasingly annealed shelf topography. Distal parts of the Taylor Sand siliciclastic depositional system make up the uppermost Bossier lithostratigraphy, while dysoxic bottom water conditions persisted in the deepest parts of the intrashelfal subbasins.

A series of depositional environment maps ranging from the Upper Gilmer Lime to the Taylor Sands shows the evolution of facies belts within respective stacked sequences and render an overall impression of the transgressive and regressive nature of sequences areally as well as through geologic time ([Figure 7](#)).

Implications

Rock types and properties favorable to shale gas exploration, like TOC content and internal mineralogy, are functions of facies development of, and preservation potential in, a given depositional sequence. They are closely linked to the relative position in a basin or sub-basin, sediment type, and budget, as well as bottom and pore water conditions above and below the depositional surface, respectively, with respect to oxygenation. Understanding the spatial geometries of the depositional sequences is an integral part of predicting these rock types and properties that allow for high-grading areas of highest hydrocarbon concentrations, most economic drilling (ROP), especially when landing the lateral section of a well, and most effective stimulation of gas shales. Building an integrated regional geologic framework including basin evolution and physiography that includes the internal architecture and make-up of its associated sedimentary fill through time is a cornerstone in the predictive tool kit for hydrocarbon potential in shales.

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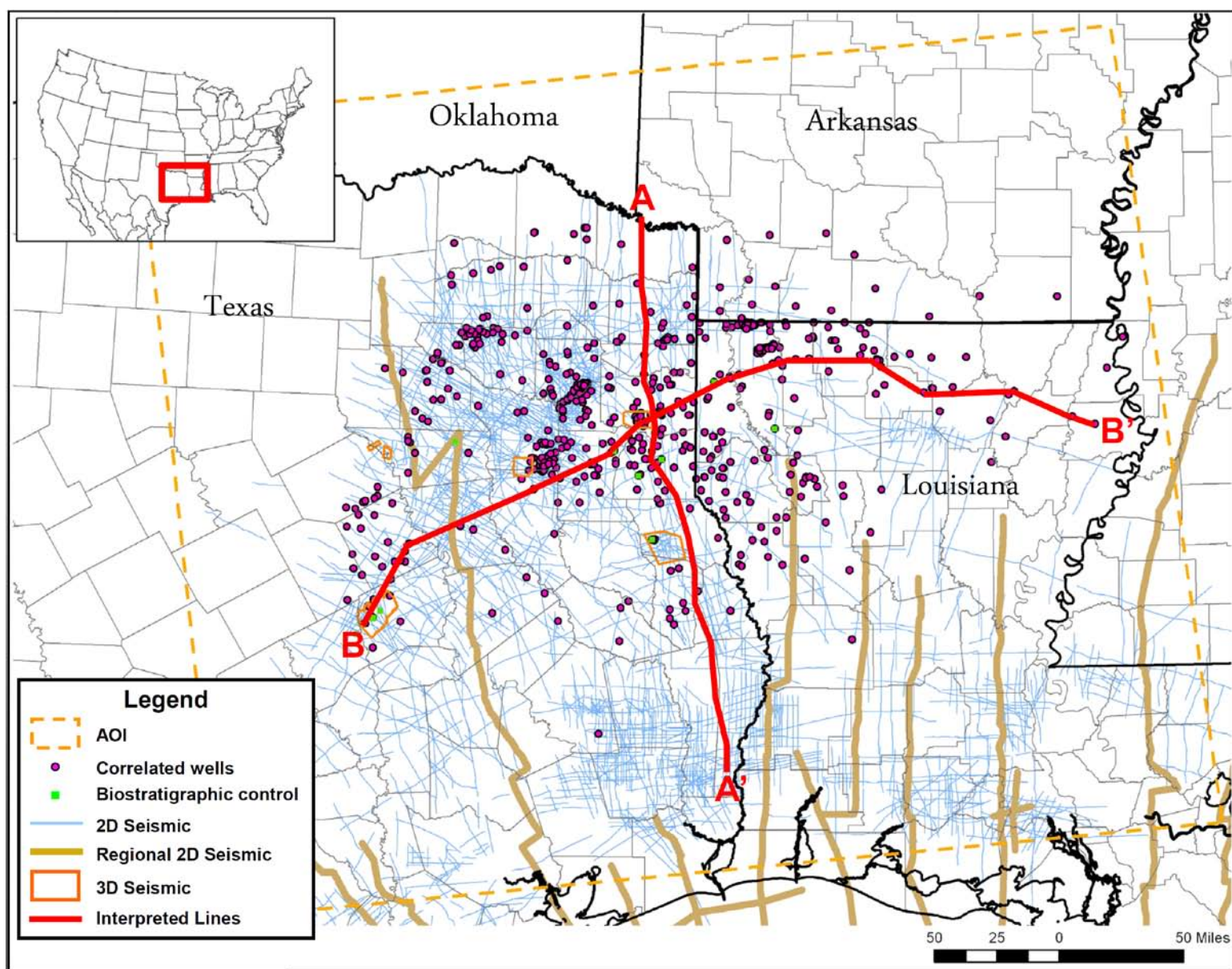


Figure1. Location map of study area.

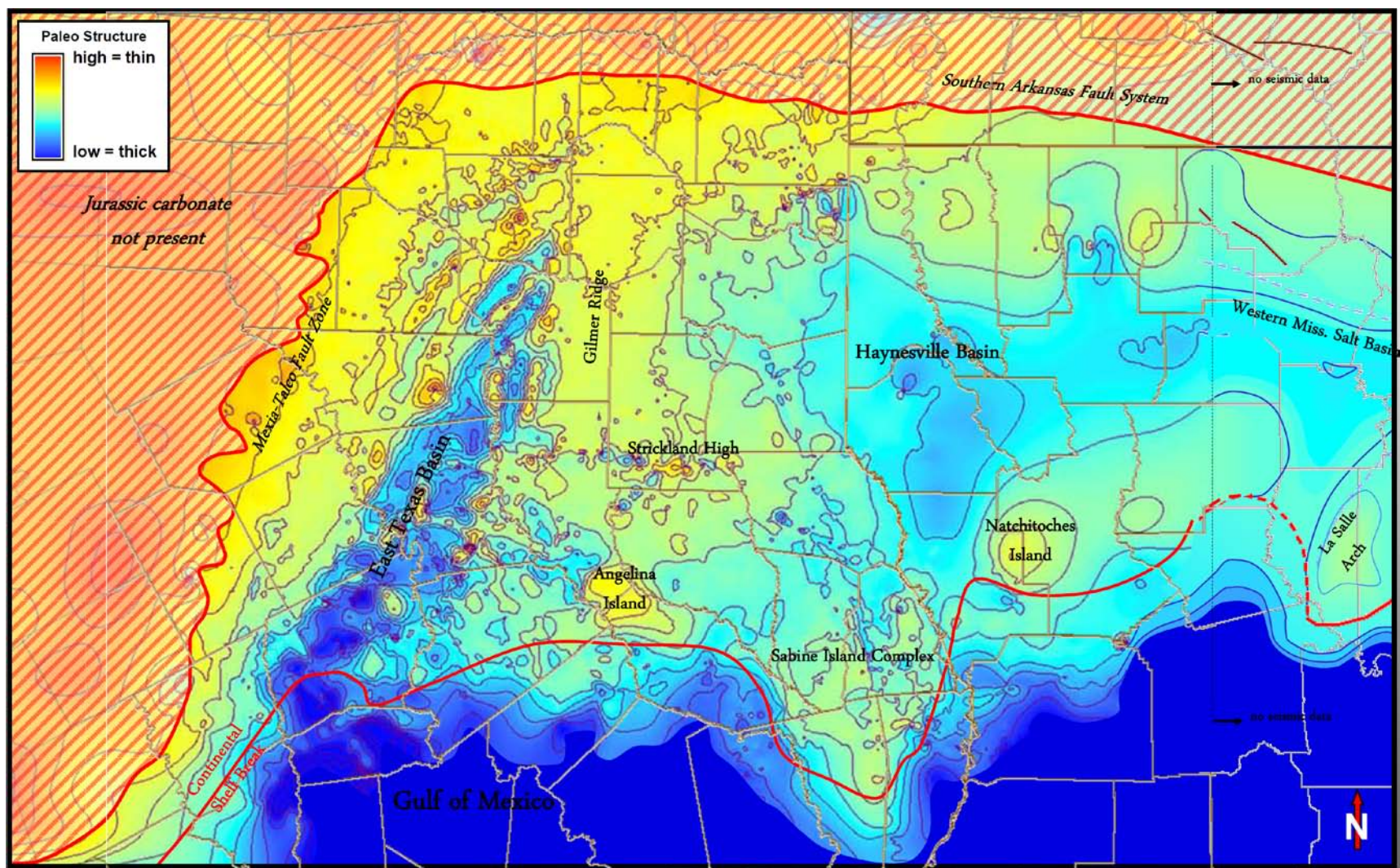
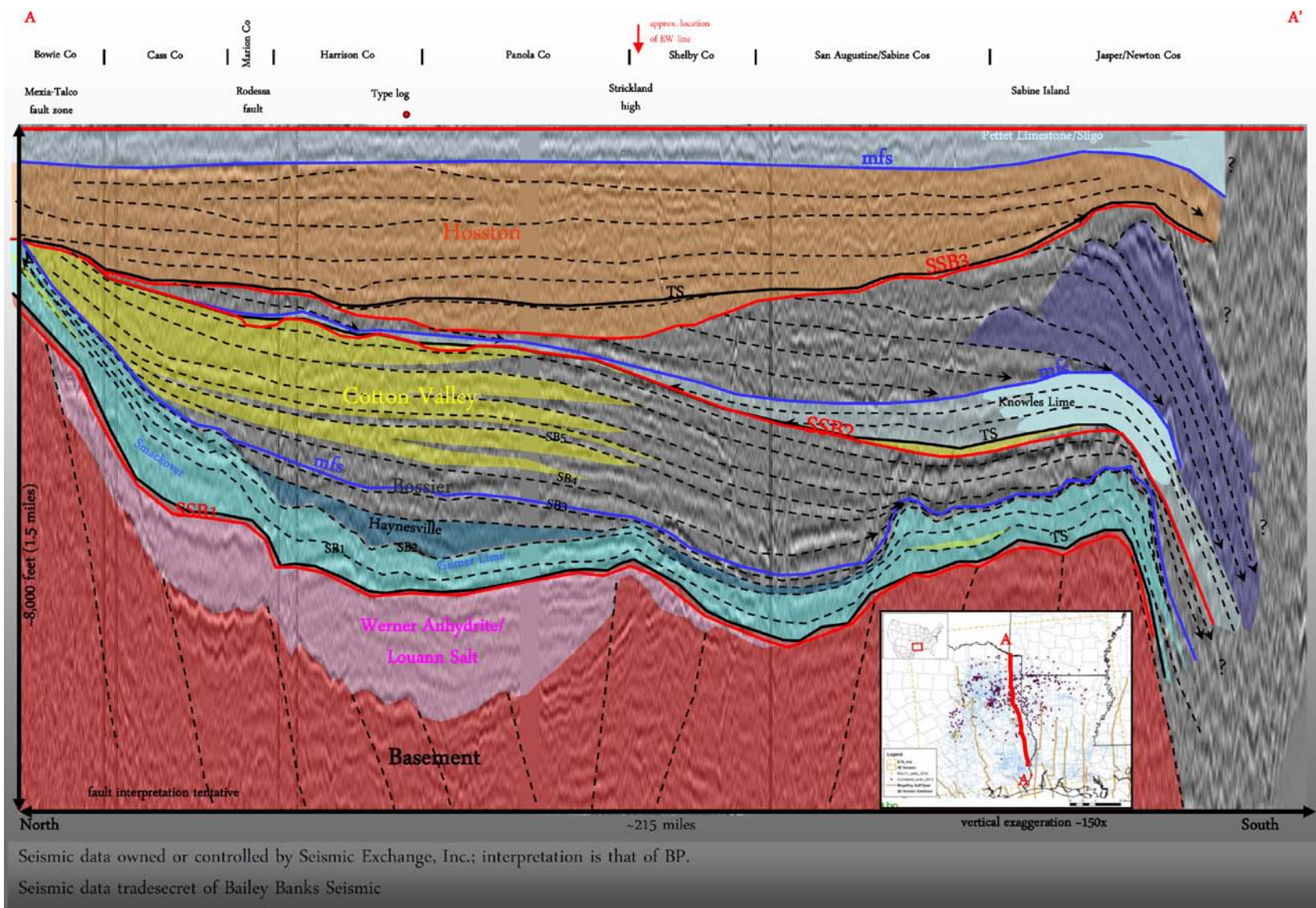


Figure 2. Basin physiography map (based on Pettet to Gilmer Lime thickness) with geographic references.



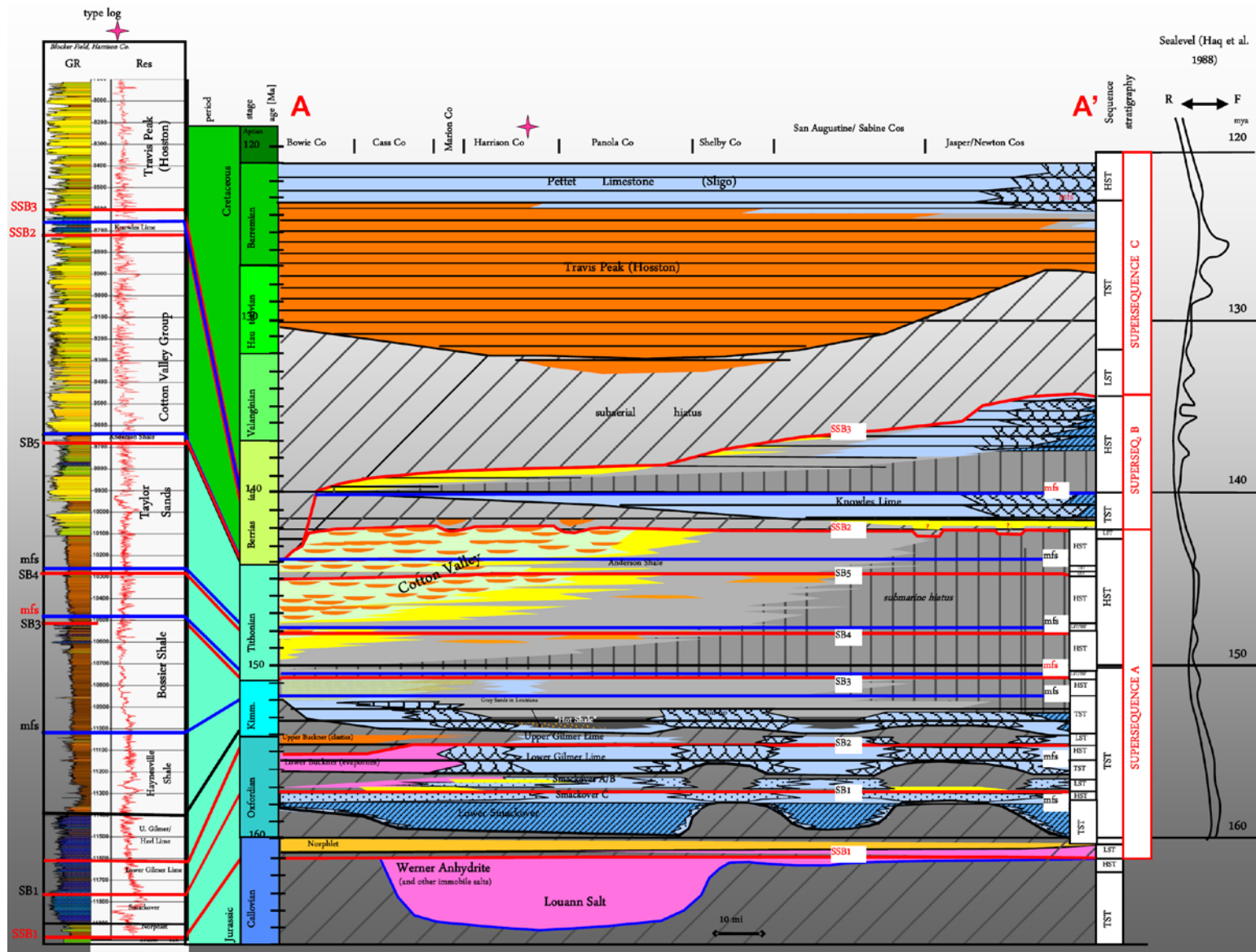


Figure 4. Chronostratigraphic representation of same line shown in Figure 3 based on biostratigraphy, including sequence stratigraphic interpretation.

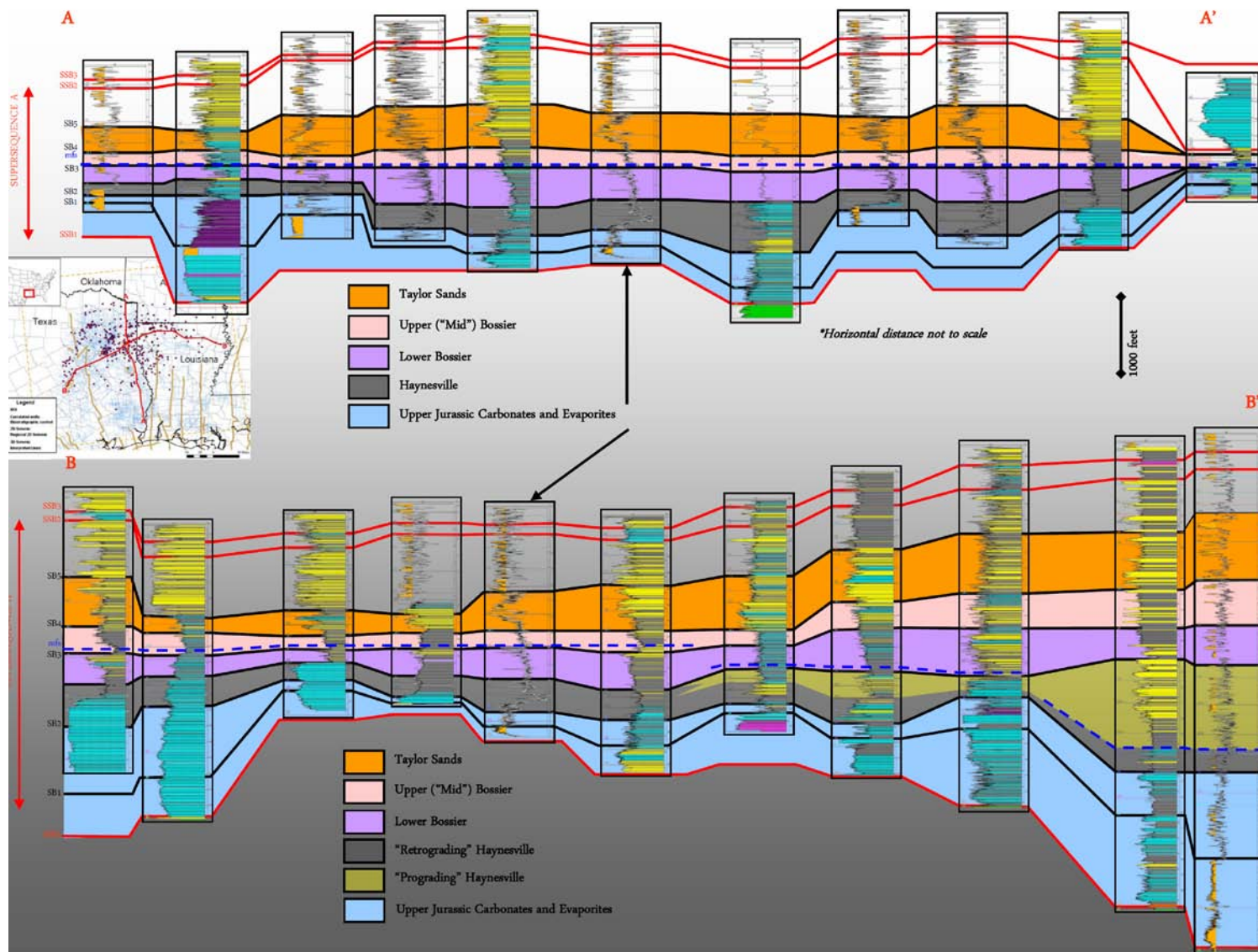


Figure 5. Well log cross sections in dip (A-A') and strike (B-B') direction indicating shift in retro- versus progradation through time and with varied sediment input across the area.

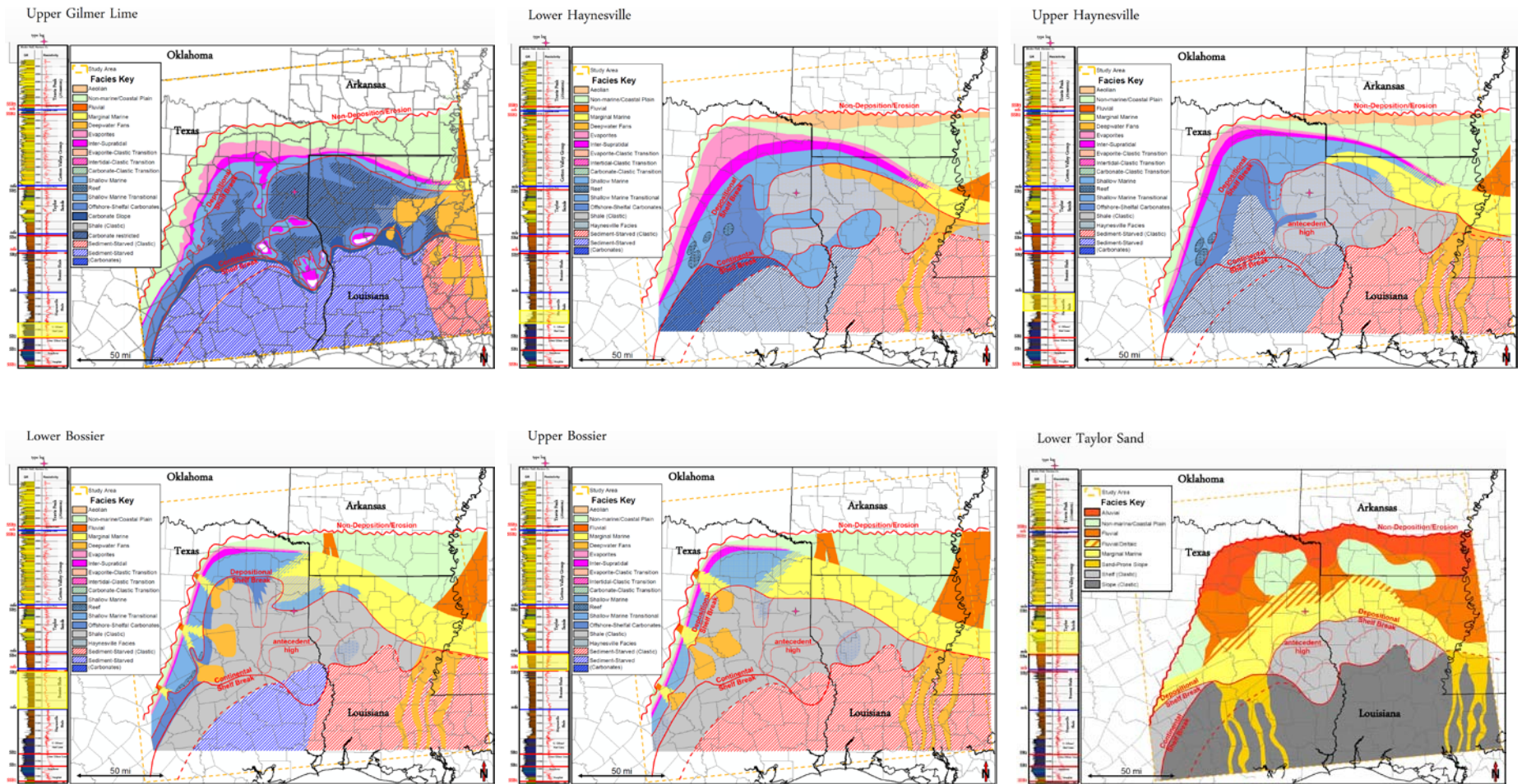


Figure 7. Depositional facies maps from Upper Gilmer Lime to Lower Taylor Sand (see type log for mapped interval) showing the shelf evolution during Haynesville and Bossier shale deposition.