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.

Selected References


Websites


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This map shows the shale gas basins of the US including the Haynesville/Bossier Shale area in E Texas and Northern Louisiana, the object of this study.
Presenter’s Notes: A stratigraphic profile for the generalized area shows the position of the interval studied; the type log from Harrison County, Texas, displays more lithostratigraphic detail and nomenclature within Supersequence A, which includes both the Haynesville and Bossier shale packages.
Presenter’s Notes: Continental-scale paleogeography at 170 Ma (after Scotese) depicts the base of Louann Salt deposition. The Scotese reconstruction shows the beginning of the opening of the Gulf of Mexico (GoM) and the invasion of hypersaline water into Texas.
Presenter’s Notes: This Scotese reconstruction shows additional opening of the Gulf and the basin framework of the Haynesville Shale and Cotton Valley Lime at 151 million years. The restricted evaporite basin has developed into an ocean basin with a moderate amount of oceanic crust formation associated with seafloor spreading.
Presenter’s Notes: The East Texas Regional Assessment utilized Pindell’s (2004) plate reconstructions for additional insight into the formation of basins in the East Texas study area. The blue line south of the Appalachian-Ouachita-Marathon thrust front in the north depicts the maximum extent of Louann deposition. This interpretation shows that the Sabine Uplift and Wiggins Arch received little if any salt deposition. The yellow arrows show the direction of the opening of the Gulf (NE-SW) along the oceanic spreading center.
Presenter’s Notes: Zooming into the study area in East Texas, Northern Louisiana, and Southern Arkansas, this map, as a data base map, shows the location of the 584 wells that were used for regional correlations and the about 2000 2D seismic lines that were also used for regional structure and thickness mapping of the various stratigraphic units of interest. The 20 green dots denote locations of wells with biostratigraphic age control. Limited 3D seismic data was used to calibrate the regional mapping effort. The red lines mark seismic and well cross sections in dip (A-A’) and strike (B-B’) orientation across the northern shelf of the young Gulf of Mexico Basin (to be noted subsequently).
Presenter’s Notes: An example of the biostratigraphic age control used to identify the ages of the lithologic rock units, tie various facies belts to the correct time interval, and generate respective depositional environment maps for the Haynesville and Bossier shale units. In this case nanno fossils, benthic foraminifera, palynology, and ammonites have been combined to identify absolute ages and environmental conditions across the Haynesville through Cotton Valley sand units.
Presenter's Notes: Regional geologic N-S X-section through East Texas based on well logs showing the section from top of Norphlet (which is picked as a projection in some of the wells) to Pettet. Geographic subareas are marked at the top of the structurally oriented section.

The section is shown both structurally and stratigraphically (Pettet marker as datum -- lower X-section). Small black arrows mark internal stacking patterns of individual units as retro-, aggra-, and progradational.

Sub-basins on the northern shelf of the GoM basin as inherited from, and/or accentuated by, the underlying Upper Jurassic carbonates (Smackover and Gilmer Lime) appear filled with thicker Haynesville and Bossier Shale units (gray units around the middle of the cross section and toward the south).
In this study, great care was exercised to include as much actual rock data as possible -- of core where available and cutting material from some 124 wells across the study area. This slide shows examples of some of the stratigraphic intervals included in the study.
Mudlogs - improve temporal and environmental (GDE) relationships

Lithology

Bossier Shale

Haynesville Shale

Cotton Valley Lime

Presenter's Notes: Example well indicating the value of incorporating mudlog information with the standard wireline log suite for its calibration to lithology and with the benefit of a more robust regional well log correlation.

Mud logs from more than 120 wells were selected and entered into the Openworks database to improve regional correlations in the study area.

This particular example shows a large variety of lithologic units in the Haynesville shale section, ranging from sandstones at the bottom of the section (directly overlying the Gilmer (=Cotton Valley) Limestone) to shaly units in the middle of the section to carbonates toward the top of the Haynesville.
**Presenter’s Notes:** Geologic well cross section of the Gray Sands in the Haynesville Basin, showing thickness and facies variations of the Upper Jurassic carbonate and shale intervals in tandem with local basin evolution along the Rodessa Fault system, including production data from some of the wells chosen for the cross section (most notably from the Gray Sands in the well marked with the blue dot on the map and in the cross section).

The well marked with the purple dot (next to the well with production) is the same well shown in the previous slide, whereas its mudlog (only for Haynesville unit) is posted to the right of the last track. In this case, the rock description in the mudlog is a powerful tool to discern the lithology of the various units deposited along the Rodessa Fault zone.

Examination of thin-sections from the well at far left on the half-graben shoulder of the Rodessa Fault system calibrates the log response as carbonate rather than siliciclastic deposits in the “Bossier Shale” section.
Presenter's Notes: Well cross section along the lines A-A' and B-B' where GR track and mudlog information for each well are shown where available. In the dip-line (A-A') a maximum flooding surface (mfs) of Supersequence A is identified fairly easily and can be recognized as a single time line across a condensed section present in every well along the section. Formations are color-coded.

Cross section B-B' is a strike section across the northern shelf of the paleo-GoM Basin, in which the mfs of the same sequence appears diachronous, based on the relative timing of retrogradational to progradational stacking patterns. To the right of the section (toward the ancestral Mississippi delta), siliciclastics extended into the basin early during the Late Jurassic due to an elevated sediment budget, occupation of available accommodation space, and resulting progradation of the shoreline in a regressive pattern. Toward the left of the section (western shelf of the East Texas Salt Basin), subsidence and relative sea-level rise have kept pace with the occupation of accommodation space by basin-filling sediments, and retrogradation and the associated transgressive signal lasted longer through the Late Jurassic, placing the mfs of Supersequence A higher up in the stratigraphic section.
**Presenter’s Notes:** Schematic diagram depicting the relationship of stacking patterns observed in Supersequence A along with respective plots (not to scale) of retrogradation and progradation as a function of rate of sediment input and the creation of accommodation space due to subsidence. The three diagrammatic plots below the schematic cross section show the relationship of retrogradation and progradation for time horizons T0 through T5 in the three areas on the cross section immediately above the plots. They show very different stacking architectures in the three respective areas, where progradation dominates in the area of the ancestral Mississippi delta, whereas retrogradation dominates on the western shelf of the East Texas Salt Basin.
Presenter's Notes: Dip section A-A' in seismic domain showing the rugose nature of the “basement” including sedimentary rocks older than Louann Salt; this is a function of a developing rift and ultimate opening of the GoM Basin. Deposits of the Louann Group annealed the established topography to some degree where the Upper Jurassic carbonates (Smackover through Gilmer Lime) overlie the evaporites. Basement topography and subsequent carbonate development across it had a strong influence on segregation of sub-basins and highs on the northern GoM shelf in general and the facies development of the Haynesville shale and, later, to a lesser extent, the Bossier shale unit, in particular. The Cotton Valley sands prograded across a fairly annealed shelf topography (bathymetry), while the coarser material did not reach the continental shelf edge in this position. The transgressive Knowles Limestone caps the Cotton Valley sandstones and forms the majority of the transgressive systems tract of the next Supersequence B (not part of this study).
Presenter’s Notes: Dip section A-A’ with all its chronostratigraphic units shown in time domain (Wheeler diagram) and referenced to the type log of the area, which ties in the lithostratigraphic nomenclature and GR log signature. In this profile, the Haynesville package appears in the uppermost transgressive systems tract (TST) of Supersequence A, whereas the Bossier includes the mfs of the supersequence with the Lower Bossier marking the top of the TST and the Upper Bossier representing the first higher-order sequence of the early highstand systems tract (HST) above the mfs of the supersequence. Placement of the mfs of Supersequence A may vary along strike of the northern GoM shelf as a result of interplay of basin subsidence and rate of sediment fill. Facies variations in all chronostratigraphic units become apparent in this 2D rendition of the shelfal basin fill.
Detailed structure mapping was performed for some 8 main horizons of the stratigraphic column to unravel basin evolution through geologic time. Shown here is the present-day structure of the Gilmer (Cotton Valley) Lime.
Presenter's Notes: To arrive at a proxy for basin physiography at the time of deposition of the Upper Gilmer Lime, an isochron between the Gilmer Lime and Pettet seismic reflector was used. Thicks were interpreted as relative basins, thins as relative intrashelfal highs during time of deposition.
Presenter's Notes: Proxy for Gilmer Lime (= pre-Haynesville) basin physiography based on isochron between Gilmer Lime and Pettet with geographic nomenclature of intrashelfal basins and highs. NOTE: No correction was applied for syndepositional salt movement; this accentuates intrabasinal features in examples like the East Texas Salt Basin.
**Presenter’s Notes:** Depositional Environment map of the Upper Gilmer Lime (yellow box on type log for reference). In general, the map supports the basin physiographic map shown in the previous slide. General basin geometries as shown on this map were inherited by the overlying Haynesville and Bossier shales.
Presenter’s Notes: Depositional Environment map of the overall transgressive Lower Haynesville (yellow box on type log for reference). The ancestral Mississippi River delivered siliciclastics onto and maybe even beyond a carbonate-prone shelf, parts of which form the Gray Sands along the growth axis of the Rodessa Fault zone toward the west into the Haynesville Basin. Central parts of the Haynesville Basin seem relatively (extrabasinal) sediment-starved and appear to have been prime areas of potential (intrabasinal) TOC enrichment, provided that biogenic productivity in the shallower oxygenated water column and favorable preservation potential around the depositional surface due to basin restriction were sufficient.
**Presenter’s Notes:** Depositional Environment map of the Upper Haynesville (yellow box on type log for reference) showing the southward progradation of the siliciclastic wedge around the ancestral Mississippi delta and a continued westward push of siliciclastics, while the western shelf of the East Texas Salt Basin continued to experience retrogradation of carbonate-dominated facies belts. The central parts of the Haynesville Basin apparently remained sheltered from extrabasinal sedimentation, with continued basin restriction relative to the East Texas Salt Basin and the central GoM to the south of the former carbonate islands (Strickland High, Angelina Island, the Blox Island Complex, and Natchitoches Island) which may still have appeared as bathymetric highs.)
Presenter’s Notes: Depositional Environment map of the Lower Bossier (yellow box on type log for reference), during the deposition of which siliciclastics continued to expand westward, while several additional point sources of siliciclastics formed across the western shelf of the East Texas Salt Basin. Southern parts of the Haynesville Basin and the sub-basin between the Stickland High and the former Blox Island Complex farther south appear to have been relatively sheltered from an extrabasinal sediment budget, while retaining some degree of restriction.
**Presenter’s Notes:** Depositional Environment map of the Upper Bossier (yellow box on type log for reference), during which siliciclastics continued to expand westward into East Texas and southward in Mississippi and Louisiana. Siliciclastic point sources in the west gained further momentum and slowly caused the cessation of carbonate production there. The areas between the Stickland High, Angelina Island and the Blox Island complex may still have received the smallest amount of extrabasinal sediments and retained some degree of restriction, although the areal extent, in which this combination of depositional condition prevailed, was continually shrinking.
Presenter’s Notes: Depositional Environment map of the Lower Taylor Sand (yellow box on type log for reference). Carbonate deposition had ceased on the northern shelf of the GoM. Major clastic wedges delivered sediment to the continental shelf break (and possibly beyond) around the ancestral Mississippi delta and through the axis of the East Texas Salt Basin. Coarse clastics seem not to have reached the continental shelf break in between those two areas, having left this part of the shelf relatively (extrabasinal) sediment-starved but increasingly less restricted. The favorable interplay of intrabasinal biogenic production, relative intrabasinal organic carbon enrichment, and TOC preservation diminished, if not mostly shut down.
Presenter's Notes: Isopach maps of the Haynesville and Bossier shales in comparison. The Haynesville shale (above) shows thickest overall deposits around the mouth of the ancestral Mississippi delta and in a narrow band along the Rodessa fault zone into East Texas in the northern and western Haynesville basin. Extrabasinal detritus in the areas of higher sedimentation rates may have had a diluting effect on the accumulation of intrabasinal organic matter.

The lower map shows the thickness development of the Bossier shale. While similar patterns to those observed in the Haynesville are still apparent, the belt of thickest accumulations seems to expand southward, and the southern East Texas Salt Basin collected a relatively thick section of Bossier shale equivalent deposits. Small areas south of the Strickland High along the southern fringes of the main Bossier thick in the Haynesville Basin still remain sediment-starved, having not received as much extrabasinal detritus as the northern areas of the Haynesville Basin.

The expansion of areas of thick sediment accumulations from Haynesville to Bossier times, especially in the Haynesville Basin, is believed to have driven, in part, the progradational stacking patterns observed during the Haynesville/Bossier time increment.

Thicker parts of both the Haynesville and Bossier Shale-equivalent rocks include a larger proportion of siliciclastic sediment, which, through geologic time, replaced carbonate deposition on the shelf from East to West.
Conclusions

- Antecedent geology (structure and stratigraphy) influenced depositional patterns of the Haynesville and Bossier Shales

- Integration of age constraints, lithologic information, seismic data, and stratigraphic principles help predict depositional facies of the Haynesville and Bossier Shales which point to:
  - relative rates of deposition
  - degree of restriction of shelfal subbasins
  - potential rock fabric:
    - mineralogic composition, rock properties
    - detrital dilution vs. TOC enrichment

- Understanding the evolution and depositional make-up of the subcrop and capping stratigraphy helps setting the stage for and confirming internal facies interpretation and stacking patterns in a chronostratigraphic continuum.
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