Sweet Spotting the Haynesville-Bossier Shale Gas Play, Northwestern Louisiana, an Integrated Study

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Shale gas plays are emerging as significant contributors to global gas reserves. The matrix permeability of these self-sourcing plays is extremely low, which limits play productivity unless as well-connected fracture network exists, either naturally or through cost-effective hydraulic fracturing. The ability to identify the stratigraphic zones that are naturally fractured, or those that have sufficient stiffness to stimulate, enhances a play's success. However, prediction of subtle changes in shale facies and their petrophysical properties to enable this success is difficult, contributing to variable production rates and the complexity of sweet-spotting shale gas plays.

In order to define the vertical and lateral variability in Jurassic Haynesville-Bossier shales, we conducted a two-part integrated study in the greater Sabine area of northwestern Louisiana (USA). The first part focused on defining the depositional environment, reservoir characteristics, and facies variation through inorganic element analysis (i.e., chemostratigraphy), XRF, XRD, petrography, and the biostratigraphic classification of macro, micro, and nano fossil species. The second focused on interpretation of present-day stresses and characterization of the natural fracture systems by reviewing core, image logs, and micro-seismic data. Both parts were then integrated to assist in sweet spot definition and well planning and optimization.

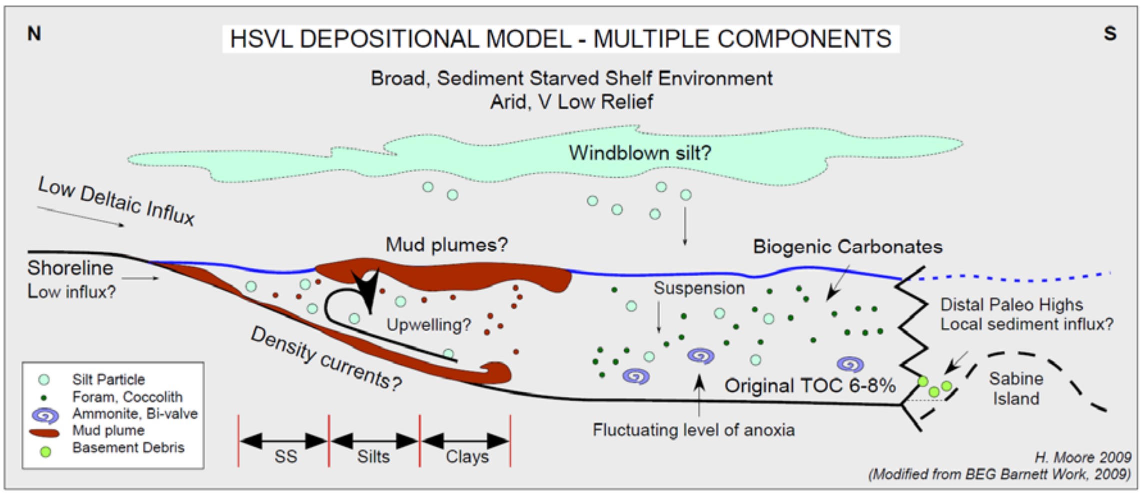
Jurassic Bossier – Haynesville depositional environment, NW Louisiana

Evidence from this study suggests a gradual change in depositional environment throughout the Haynesville-Bossier. A sharp boundary separating the Haynesville from the Smackover formation marks the introduction of significant clays into an environment previously dominated by carbonates. XRD and XRF data suggest clay content is lowest in the Haynesville, which is predominately an argillaceous to calcareous silty mudstone. Clay content increases steadily up section throughout the Bossier as clastic systems build and mature, resulting in a more diverse clay distribution. Despite the relatively low clay content in the Haynesville, a distinct series of TST-HST cycles is clearly identified through gamma ray signatures across the study area. The lower and middle Haynesville each contain a full cycle, whereas the upper Haynesville, coupled with the basal-most Bossier, completes a third. At the base of a cycle, a transgression results in a relatively "cleaner" system over time as more carbonate growth occurs but gradually, the system becomes more clay rich during the high stand at cycle top. Local biostratigraphic flooding surfaces fall approximately at the top and lowermost Haynesville and are in agreement with the TST-HST cycles, which also continue throughout the Bossier. Each flooding surface represents a relative sea level rise with respect to the rate of clastic sedimentation and carbonate growth in the basin, with the mid-Bossier marking the maximum flooding surface observed throughout Haynesville-Bossier deposition. Maximum flooding surfaces highlight the richest organic zones in both the Haynesville and the Bossier.

Chemostratigraphic and biostratigraphic studies were completed on cuttings from several wells and proved to be regionally correlative. Chemical stratigraphy provides distinct geochemical packages, which correlate with the TST-HST cycles above. Relative enhancement or depletion in geochemical ratios, such as EFV (enrichment of vanadium) and Th/U, distinguish Haynesville from Bossier shales.

These ratios tend to be associated with redox and anoxic conditions. Th/U ratios within the Haynesville average < 2.5 indicating extreme anoxia. These ratios gradually increase up section, reaching about 4 in the uppermost Bossier. These values may suggest a gradual increase in water depth and circulation, and/or pulses of biological productivity. Burrowing in the lower Haynesville observed in thin sections suggests some degree of biological productivity did persist during this extremely anoxic time.

Spatially, the Haynesville thins over pre-existing basement topography. The lack of significant Haynesville shale on these paleo structures suggests some impact to the distribution of terrigenous and biogenic material throughout the basin, water circulation patterns, and suspension settlement rates, particularly immediately adjacent to and between the paleo highs. These areas may have been shielded from significant clay inundation, contributing to the euxinic/anoxic stagnant water conditions prominent during early Haynesville time.

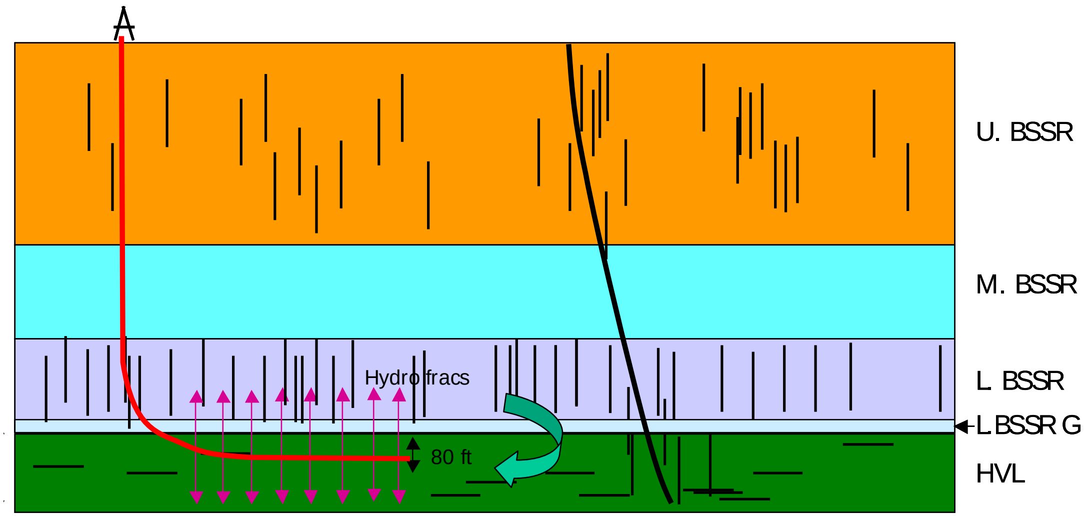


A multi-component depositional model for Upper Jurassic Haynesville (Kimmeridgian) shale is inferred from integrated data in the Greater Sabine area of Northwestern Louisiana and East Texas.

The above results imply that the depositional environment of the Haynesville shale (Figure 1) is one of low deltaic/shoreline influx, suspension settling, wind-transported silt, upwelling, and density currents. These components contribute to the deposition of calcareous and argillaceous mudstone during a period of extreme anoxia. Stratigraphically, the lowermost Haynesville transitions upward from a shallow, anoxic to euxinic, sediment starved shelf environment to a deeper, more oxygen-enriched, shallow marine sag basin dominated by retrograding deltaic deposits in the overlying Bossier.

Fracture distribution in the HVL-Bossier system

Examination of core and FMI data in the study area identified three distinct fracture types associated with over-pressures or tectonics, namely, pre-compaction, early diagenetic, and post-consolidation fractures. While other cements are also observed, the majority are carbonate filled, and are not likely to contribute to production unless re-opened during stimulation. The data also, contrary to conventional wisdom, show that Haynesville shale within the study area is not significantly fractured, except for small bedding-parallel cemented veins. This is in contrast to the Upper and lower Bossier members where high angle tectonic fractures are abundant (Figure 2). Our observations indicate that this vertical fracture distribution in the Haynesville-Bossier system is controlled not only by the tectonic/basin history, but also by mechanical layering. Slight variations in rock stiffness, corresponding to changes in clay, silt, carbonate, and organic carbon content, determine fracture density and lead to variable spacing and length relationships.



A fracture model of the mechanically layered Haynesville Bossier system showing vertical fracture distribution. Fracture density is highest in the lower and upper Bossier and is lowest in the Haynesville and Mid Bossier.

Microseismic data shows that events in the lower Bossier are typically generated in consequence to reactivation of pre-existing fractures whereas those in the Haynesville are generated in situ. This distinct pattern of event distribution supports core and FMI observations that the Haynesville-Bossier is a mechanically layered system, which results in a unique vertical fracture distribution. Spatially, the Upper and Lower Bossier maintain their high fracture densities throughout the study area. However, the Haynesville shows a slight increase in fracture density to the north and northeast of the study area. This change in the Haynesville fracture density is attributed to the change in its facies character that determines it stiffness, and to proximity to increased faulting to the north.

Concluding remarks

The goal of this integrated study was to understand the nature of the Haynesville-Bossier system and to identify sweet spots. The Haynesville-Bossier has all the hallmarks of a shale gas play: high TOC, good porosity, high gas saturations, low clay content and nanoDarcy permeabilities. Early conjecture based on comparisons with the Barnett play initially suggested that the Haynesville is also a fracture play. This would require the presence of open fractures that are connected to the borehole or to the stimulated fractures. Evidence from the above studies does not support this concept. Instead, it shows that even if fractures are present in the Haynesville-Bossier shale system, they are typically cemented and hence cannot directly contribute to the productivity of a well unless some can be reactivated during the stimulation. Those reactivated fractures are typically limited to the vicinity of the stimulated fracs and do not extend far. In addition, the mechanically layered nature of the system poses its own challenges to play development because the less fractured layers are organic rich whereas the highly fractured layers are lean. Thus, while one could target a high TOC layer, the lack of open fractures could hinder productivity. At the same time, the lack of natural fractures often produces better frac jobs because the presence of natural fractures in the path of a stimulated frac dissipates its energy and produces short or segmented fractures. This competition between stimulated frac efficiency and value of natural fractures is critical, but not well understood.

Reservoir properties of the Haynesville and Bossier determined from analyses in this study show defined and mapable trends. A rough correlation exists between these properties and IP rates. However, on a well-to-well basis, it is unclear what the contribution of a single property is (e.g., TOC, porosity or calcite content) to productivity, and hence the predictability of future well delivery or location. A key part of this complexity is the multitude of non-geological variable that can influence IP rates, such as choke size, length of lateral, number of stages, and frac efficiency. Facies maps were helpful in upgrading acreage and focusing development-well sequencing on upgraded areas.

We conclude that the definition of a "sweet spot" in these systems is questionable and requires a good balance between the right choice of reservoir properties to optimize stimulation success, and reactivation of pre-existing fractures to assist in productivity. This study contributes to the fundamental understanding of the Haynesville-Bossier system, and to some extent provided an initial predictive tool. However, long-term development of these "reservoirs" requires further multi-disciplinary integration to demonstrate the interplay between the subsurface, drilling, and completions to increase the chances of successfully identifying a sweet spot and improve economics.