Age, Sequences, Depo-Models, and Biofacies: U.S. Mississippian Shale-Gas Basins

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Extended Abstract

As exploration and production in shale-gas plays reach a more mature stage, it is clear that the conventional questions about trap, seal, stratigraphy, depositional facies and geometries, and their relationship to reservoir properties, need to be answered in regards these unconventional reservoirs. This presentation provides an overview of stratigraphic and depositional aspects of four formations, prone to produce shale-gas.

The formations of interest are the Barnett, Caney, Fayetteville, and Floyd, and their local stratigraphic equivalents, that were deposited in four separate basins. These basins were foreland basins that formed near the southern edge of the southward-converging Euramerican craton during the Early to Late Mississippian. They are the Delaware Basin in West Texas (Barnett), the Fort Worth Basin (Barnett) in north-central Texas, the Arkoma Basin in eastern Oklahoma (Caney) and western Arkansas (Fayetteville), and the Black Warrior Basin (Floyd) in Mississippi and Alabama.

The southern edge of the craton bordered the Rheic Ocean located between Euramerica and Gondwana. Through the course of the approximately 40 million-year span of the Mississippian, this ocean narrowed and circulation became increasingly restricted as the two continental plates converged. A volcanic arc formed at the western end of the convergent zone. The four basins opened into the restricted seaway to the south/southeast and were bounded on the north by a broad submarine cratonic platform with localized, subdued, exposed highlands. As a result of this tectonic and paleogeographic setting, the basin centers, where the formations of interest were deposited, would have been filled by a combination of three types of deposits. These are downlapping distal turbiditic deposits that included very fine clastics and fine carbonate skeletal material derived from the highlands and around the basin margins; onlapping pelagic marine sediments; and rare volcanic ash deposits derived from the volcanic arc. Southern trade winds transported the ash from southeast to northwest. This prevailing wind would have also inhibited any upwelling within the basins by continuously driving surface waters toward the cratonic platform.

The published time span of deposition ranges from essentially the entire Mississippian for the Caney Fm. of the western Arkoma Basin to 3-5 million years during the mid Chesterian, represented by deposition of the Fayetteville in the eastern Arkoma. The Barnett in the Delaware Basin is generally correlated to the entire Chesterian. The Barnett's age is extended to the Late Osagean in the Fort Worth Basin. The Floyd is correlated to the Upper Meramecian through the Chesterian. The ages of deposition of the formations of interest are typically determined by sparse biostratigraphic sampling in outcrop and around the subsurface basin margins. Reliable biostratigraphic data from the basin centers are only currently being gathered as a result of deep drilling in the shale-gas trends. Some of these data suggest that undifferentiated shale deposition may have begun in the basin centers, much earlier than previously believed.

Worldwide sequence stratigraphic models applied to these basins suggest that 10 second-order and approximately 17 third-order sequences were formed during the Mississippian. These sequences can be subdivided and age-calibrated through the application of palynomorph (14 zones), conodont (14 zones), foram (10 zones), and mollusk (15 zones) biozonation frameworks. In addition, recent biostratigraphic analysis has evaluated five palynomorph, seven conodont, two foram, and three mollusk biohorizons that are marked by multiple Last Appearance Datums (LAD's). These biohorizons are interpreted to be regionally correlative.

Two example interpretations demonstrate that the Barnett, and likely the other formations of interest, can be meaningfully subdivided and interpreted through traditional sequence biostratigraphic techniques. In the Fort Worth Basin the stratigraphic section between the Marble Falls Limestone and the Viola or Ellenburger is typically divided into the Upper Barnett, the Forestburg Limestone, and the Lower Barnett. In some locations the Chappel Limestone is recognized but in the deeper parts of the basin-center, the Chappel appears to "shale out" and the Barnett consists of undifferentiated shale below the Forestburg. In the Delaware Basin the Barnett is not subdivided and overlies the "Miss Lime" which in turns overlies the Devonian Woodford Shale. Sequence stratigraphic interpretation of wireline log character of wells along two transects in the Fort Worth Basin and Delaware Basin is presented. These interpretations are supplemented and calibrated by nearby biostratigraphic sampling and application of the biozone and biohorizon frameworks. Interpretation of these cross sections suggests that 10 major stratigraphic sequences can be identified in the deep Fort Worth Basin. Downlapping and onlapping stratal units are identified on the Fort Worth Basin cross section as well as on a parallel north-south seismic line. The Delaware Basin Barnett can also be subdivided into four Chesterian sequences.

A variety of depositional processes, fabrics, and fossil assemblages have been documented from the formations of interest by this, and other, studies. Assemblages of conodonts, bivalves, gastropods, and foraminifera can be used to infer benthic conditions and water column properties. An integrated depositional model that builds upon previously published models addresses biofacies, water-column properties, and deposition of olive and black shales. This model combines models of primary productivity, biofacies, and water-column structure to help explain differences in the preservation of organic matter, bioturbation, and depositional microfabrics.

Examples of three end-member microfossil assemblages are given to illustrate the benthic and water-column properties reflected in the planktonic, nektonic, and benthonic biota. A “normal marine” environment with an oxygenated water column and “livable” benthos is interpreted from moderately abundant and diverse foram and conodont faunas recovered with both adult and juvenile gastropods and rare to common bivalves. Ammonoids such as *Goniatites* are also occasionally found in this assemblage. An assemblage that contains common to abundant specimens of one or two foram species and rare to absent conodonts, gastropods, and bivalves is interpreted to reflect a low-oxygen water column and “hostile’, possibly anoxic benthos. A third assemblage that is rich in conodonts but contains rare specimens of forams, gastropods, and bivalves is tentatively interpreted as reflecting a water column that is al least somewhat oxygenated (dysaerobic) but an anoxic benthos.

This overview is presented as an example of how conventional forms of stratigraphic reservoir analysis can be applied to unconventional shale-gas reservoirs. These units can be subdivided for improved correlation and reservoir zonation by a variety of means. Useful models can be applied to characterize shale-gas reservoirs in terms of depositional environment and depo-facies. Seven key conclusions have been made that can guide further study and hopefully lead to improved exploration and production performance. These are:

1. Tectonic Setting and Paleolatitude Have Implications for Sedimentation and Oceanic Circulation
2. Conodont, Palynomorph, Foram, and Mollusk Zonations Can be Used to Subdivide the Mississippian and Applied to the Formations of Interest
3. 17 Last Appearance Datums Have Been Evaluated for Regional Utility
4. Correlation to Worldwide Chronostratigraphic Model Predicts 10 Second Order Sequences in the Miss.
5. Barnett Examples Corroborates the Sequence Stratigraphic Model
6. Water Column and Biofacies Models Can be Applied to Explain Differences in Sedimentation
7. Integrated Data Sets Can be Used to Characterize Stratigraphic Units

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