The Barnett Shale - A Sequence Stratigraphic View of Depositional Controls, Reservoir Distribution and Resource Density

Jeffry D. Ottmann[1] and Kevin M. Bohacs[2]
[1]*ExxonMobil Exploration Company, Houston, Texas*
[2]*ExxonMobil Upstream Research Company, Houston, Texas*

Commercial gas production from the Barnett Shale ushered in a new viable resource type that will provide an important energy supply to the U.S.A. for a significant time. Shale gas plays, although described as unconventional due to the scale of reservoir parameters and extraction methods, are still within bodies of rock that were deposited under systematic environmental changes in response to variations in sea level, accommodation and climate. These processes deposit distributed system tracts bounded by surfaces with significant breaks in sediment accumulation.

Detailed examination of a wide range of physical, biogenic, and chemical attributes (molecular to seismic scale) indicates that the Barnett Shale of north Texas accumulated discontinuously in at least two separate intra-shelf basins in various depositional environments with significant variations in primary biogenic production, bottom-energy and oxygen levels, and sediment accumulation modes and rates. Rock properties that influence source, mudstone reservoir, and seal behavior vary vertically at the cm scale and laterally at the km scale in systematic ways that can be deciphered using an integrated sequence-stratigraphic approach.

Thin-section, core, and outcrop images reveal a variety of primary and secondary sedimentary structures, as well as a moderately diverse population of body and trace fossils. Scour surfaces, wave and current ripples, graded beds, fossil and pyrite lags, and wave-enhanced sediment gravity flow bedsets record energy levels in the benthic boundary layer that were episodically capable of transporting sand-sized grains. Some surfaces are overlain by grains that appear to have been transported from shallow-water carbonate platforms. Detailed correlation of closely spaced well logs shows laterally extensive erosion in some intervals with relief up to 10 m over 5 km spans.

In-situ body fossils also occur in some intervals indicating significant and recurring periods of benthic oxygenation-- benthic foraminifera as well as articulated siliceous sponges and epi-benthic and shallow-burrowing bivalves. The epi- and endo-bionts are relatively low in diversity (~3-4 genera) and are of a type especially adapted for life on a soupy substrate under dysoxic conditions. Their size distribution and growth ring count are relatively narrow, suggesting colonization events were somewhat episodic. They co-occur with ichnofossils and sedimentary structures that indicate increased benthic oxygen and energy levels, although their thin-walled and articulated nature indicate minimal transport. Ichnogenera include *Planolites*, *Paleophycus*, *Chondrites*, *Helminthopsis*, *Phycosiphon*, and sparse *Zoophycus*. These ichnotaxa are in commonly recurring associations of lithofacies, sedimentary structures, and body fossils.

These lithofacies associations and depositional environments stack in systematic ways revealed by sequence stratigraphy. Within these rock packages, content of such properties as biogenic silica, TOC/HI, clay, and carbonate that control reservoir character, also vary systematically. Key to identifying these stratigraphic patterns is the recognition of flooding surfaces, sequence boundaries, and systems tracts.

Flooding surfaces are marked by laterally extensive concentrations of burrowing or boring traces, authigenic minerals and nodules, and early lithification or cementation in the interval just below that also typically records an organized change in ichnofauna indicating evolution of the substrate consistency, from soupground to firmground to hardground.

Above the flooding surface are concentrations of pelagic or airfall input, increased continuity of lamina, beds, and bedsets, and accumulations of fossils that are dominated by quieter water taxa than in underlying strata (autochthonous)-- generally lower energy forms with mixed taphonomy (pristine - broken). These fossils represent a range from biocoenosis to moderately time averaged assemblages. This superjacent interval is marked by well-preserved encrusting organisms and a local maxima in pelagic taxa. There is typically a secular change in bioturbation intensity and ichnofossil diversity across the surface. Well-log expression commonly includes higher gamma-ray, decreased resistivity, lower density, and decreased sonic velocity just above the flooding surface (Figure 1).

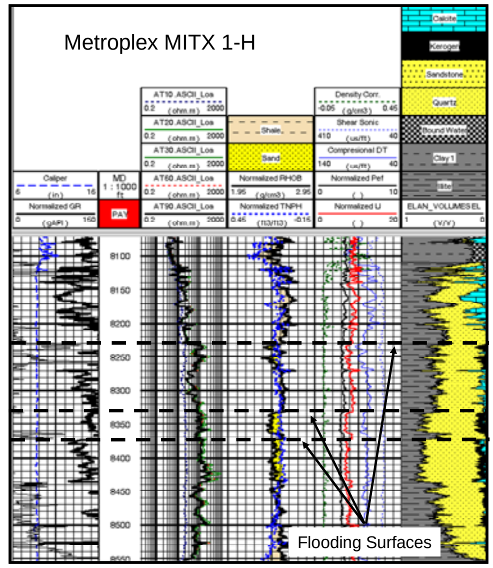

Figure 1-- Flooding surface expression in well logs

Sequence boundaries, in contrast, are marked by laterally extensive erosion, truncation, subaerial exposure, significant change in sediment supply (including a dominance of allogenic over authigenic components, advected clastics & fossils, and secular changes in biogenic lithology), decreased continuity of lamina, beds, bedsets just above, as well as by accumulations of fossils that are dominated by shallower water taxa than in underlying strata (advected or in-situ)--generally higher energy forms that are uniformly poorly preserved thanatocoenosis (fragmented – comminuted). They are minimally encrusted or bored; pelagic taxa are minimal, and there might be an obrution bed at very base of the superjacent interval. Well-log expression commonly includes lower gamma-ray, increased resistivity, higher density, and increased sonic velocity just above the sequence boundary (Figure 2).

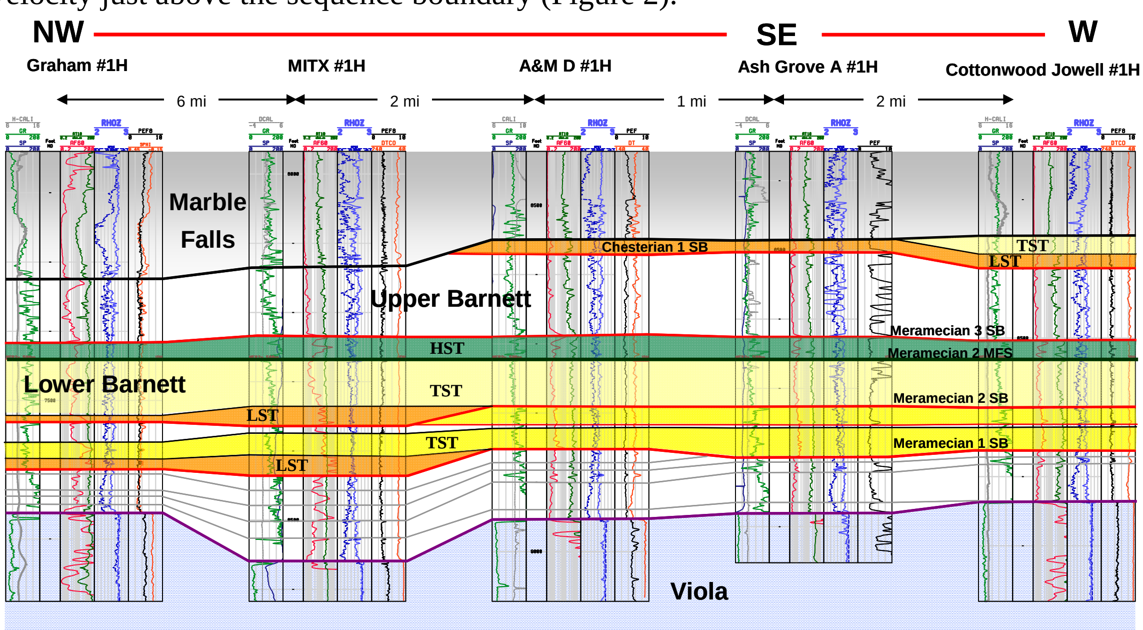

Figure 2-- *Sequence boundary expression in well-log x-section, illustrating more than 30 feet of erosional relief over a 5 mile span, along with onlap of overlying lowstand systems tract strata.*

Lowstand systems tracts (the interval just above a sequence boundary), identified on well-log cross sections by erosion beneath and onlap above (Figure 2), typically contain local maximum of transported shells and sclerites, scours, graded beds, thick bedsets, decreased lamina continuity, and aggradationally stacked parasequences. Transgressive systems tracts can overlie the top lowstand transgressive surface or coincide with the subjacent sequence boundary where no lowstand systems tract accumulated-- in either case, they are bounded above by a maximum flooding downlap surface (commonly marked by a local maximum in total gamma ray). This systems tract typically contains decreased occurrence of transported shells and sclerites, increased nodule development, thinner bedsets, increased lamina continuity and retrogradationally stacked parasequences. Highstand systems tracts are identified by downlap at their base and erosion or truncation at their top. They tend to contain increasingly common clay, scours, and graded beds, thicker bedsets upward, decreased lamina continuity and nodule development, and progradationally stacked parasequences.

Barnett Shale reservoir quality and hence resource density distribution can be tied directly to systems tracts. Porosity development from the enrichment, preservation, and maturation of organic material along with increased brittleness from sponge and radiolarian production occur in the same environments tied to lowstand system tracts. Reservoir potential is greatly diminished within transgressive and highstand systems tracts due to increased clay-mineral content. These system tracts are, however, important elements within the play as they provide hydrocarbon seals and frac barriers for well completions. The development and distribution of depositional facies and system tracts are tied to the bathymetry and configuration of the paleo-basin floor. Positive topography as well as detrital sediment trapping can benefit the development of reservoir in the lowstand systems tracts.

The Barnett Shale accumulated in a dynamic and variable depositional system. Deciphering these variations is key to understanding and predicting the occurrence, character, and distribution of potential reservoir facies at the basin to field scale.