Comparative Sequence Stratigraphy and Organic Geochemistry of North American Unconventional Gas Shales: Commonality or Coincidence?

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Increased interest in North American, unconventional gas shales (i.e. the “Magnificent Seven”) as a major energy source has led to a plethora of recent published (and unpublished) geologic studies, including sequence stratigraphic and geochemical characterization. In this paper, we compare these characteristics of the shales to determine if there are commonalities which may lead to a unifying geologic model for their formation and characteristics.

Traditional and conventional sequence stratigraphic principles and analysis have been applied to the Barnett Shale (Loucks and Ruppel, 2007; Singh, 2008; Slatt et. al, 2009; Abouelresh and Slatt (in press); the Woodford Shale (Slatt et al., in press); New Albany Shale (Bohacs and Lazar, 2010), Marcellus Shale (Lash, 2008), and Haynesville Shale (Hammes and Carr, 2009). Comparison of typical stratigraphic sequences and gamma ray logs from these shales reveals a commonality in their characteristics---most notably a basal unconformity atop the underlying stata (transgressive surface of erosion or TSE), upon which sits a fining-upward shaley interval capped by an organic-rich, high gamma-ray shale, which in turn is overlain by a ‘decreasing upward’ (i.e. decreasing API) gamma ray pattern. (Fig. 1). This commonality among different-aged shales suggests a generally similar mode of formation even though specific mineralogic and lithologic compositions may differ.

Although sequence stratigraphic frameworks have now been proposed for the North American gas shales, the inability to age-date high-frequency stratigraphic surfaces or intervals in most cases precludes the ability to definitively correlate strata within a time-stratigraphic framework.

The lower interval of the Cretaceous Fox Hills-Lewis Shale strata in Wyoming exhibits the same stratigraphic pattern as illustrated by the gas shales (Fig. 2). These strata overcome the lack of high-frequency age control of the older gas shales owing to a good ammonite zonation, which has revealed a number of 4^{th} order time-stratigraphic intervals, within a 3^{rd} order progradational highstand or regressive systems tract. This systems tract downlaps onto the organic-rich, aerially extensive “Asquith Marker” across much of the Greater Green River Basin (Pyles et al., 2009; Slatt et al., 2009). The resulting stratigraphy and gamma ray log pattern consists of a basal fining-upward transgressive marine shale resting on a TSE at the top of the underlying Almond Formation, an organic rich condensed section forming the top of the fining-upward sequence, and overlying coarsening-upward progradational strata. Thus, the Lewis Shale provides an age-constrained outcrop-subsurface analog to the sequence stratigraphy of the North American (and other?) gas shales.

Similar geochemical characteristics have also been reported among the prolific North American gas shales. Average organic richness is typically greater than 3% TOC with hydrogen index values greater than 350 mg HC/gr.TOC indicative of type II kerogen.

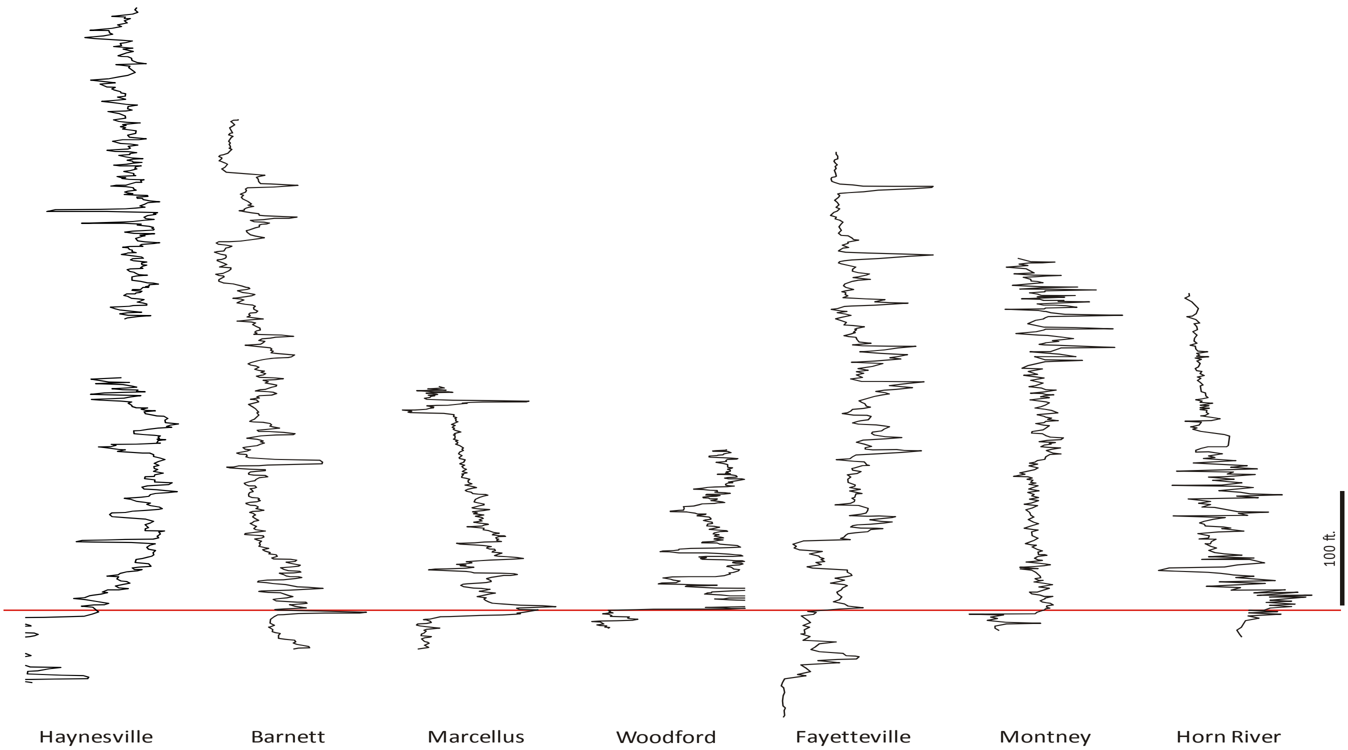

Figure 1. Gamma ray logs of North American gas shales, datumed on a common transgressive surface of erosion (TSE).

Presence of pyrite has been reported in the Barnett, Haynesville, Marcellus, Woodford and Horn River shales, attesting to reducing conditions in the depositional environment. Phosphatic nodules are also present in the Barnett, Woodford and Montney shales, probably associated with transgressive conditions during deposition. Woodford organic biomarkers also reveal dysaerobic to anaerobic environments for the organic-rich strata and more aerobic conditions for the 'cleaner, more organic-poor' strata (Miceli-Romero, 2010).

Also, thicknesses of the organic-rich strata vary considerably, but are usually > 200 feet. Thicker source rocks have reduced expulsion efficiencies so that more hydrocarbons are retained during the initial stages of hydrocarbon generation, which are ultimately available for gas generation at later stages of source rock maturation.

Core producing areas in gas shale fields are usually delimited by organic maturity values > 1.1% Ro. By correlating isotopic and compositional data with maturity in the Barnett Shale, Rodriguez and Philp (in press) determined that better producing wells are associated with higher maturity values, wetness reduction in gas composition and presence of an ethane isotope reversal (Figure 3). This isotope reversal has also been reported in other North American gas shales (Ferworn, 2008) and is thought to be associated with secondary cracking of hydrocarbons.

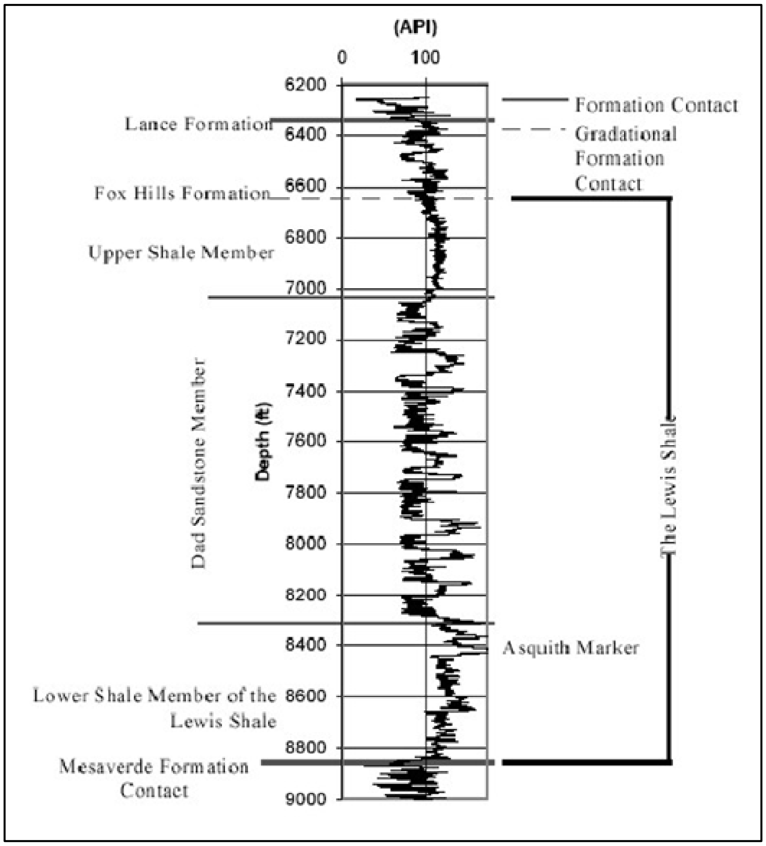

Figure 2. Gamma ray log of the Almond Formation, Lewis Shale and Fox Hills Sandstone. The top of the Almond Formation is a TSE, which is overlain by the fining-upward Lower Lewis Shale which is capped by the Asquith Marker, an organic rich condensed section. Above the Asquith Marker is a coarsening- and cleaning-upward interval.

Although the geochemistry of the Cretaceous Lewis Shale Asquith Marker has not been studied as much as the gas shales mentioned above, kerogen falls within the range of Type II and III, TOC values are upwards of 10%, and maturity levels are similar to those of the older gas shales.

Based upon these observations we conclude that a unifying sequence stratigraphic model can be applied to the North American gas shales even though ages and compositions vary among them. The model consists of basal strata which became sub-aerially exposed to produce a capping sub-aerial exposure surface (sequence boundary), followed by marine transgression to form a TSE and overlying fining-upward strata capped with an organic-rich condensed section, then progradational highstand or regressive marine deposits downlapping onto the condensed section (Fig. 4).

The significance of this model is two-fold. First it demonstrates that conventional sequence stratigraphic principles can be applied to shales. Second, it places potential gas-prone rocks (organic rich shale) in a predictable stratigraphic position within a depositional sequence stratigraphic framework, so it is amenable to regional mapping. Some of the North American gas shales, for example the Montney (Fig. 1) also exhibit organic rich horizons higher within the stratigraphic section, These horizons could represent a higher-frequency sequence stratigraphy within the highstand deposits, as is also the case in the Lewis Shale (4^{th} order) (Fig. 4).

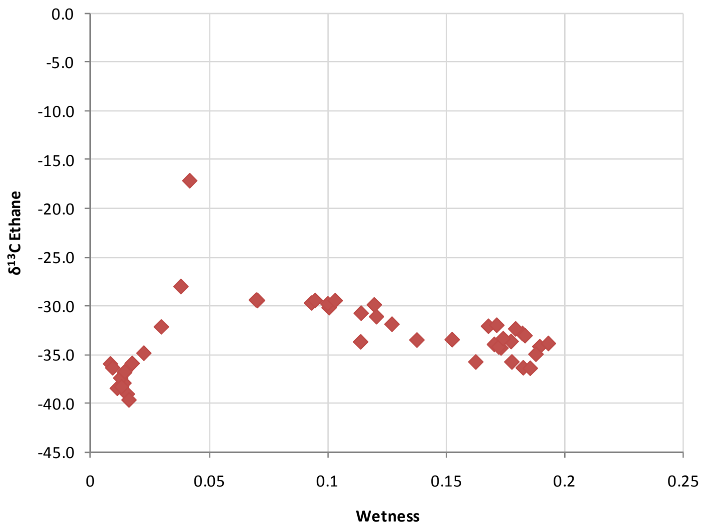

Figure 3. Wetness vs. δ^{13}C Ethane in the Barnett Shale.

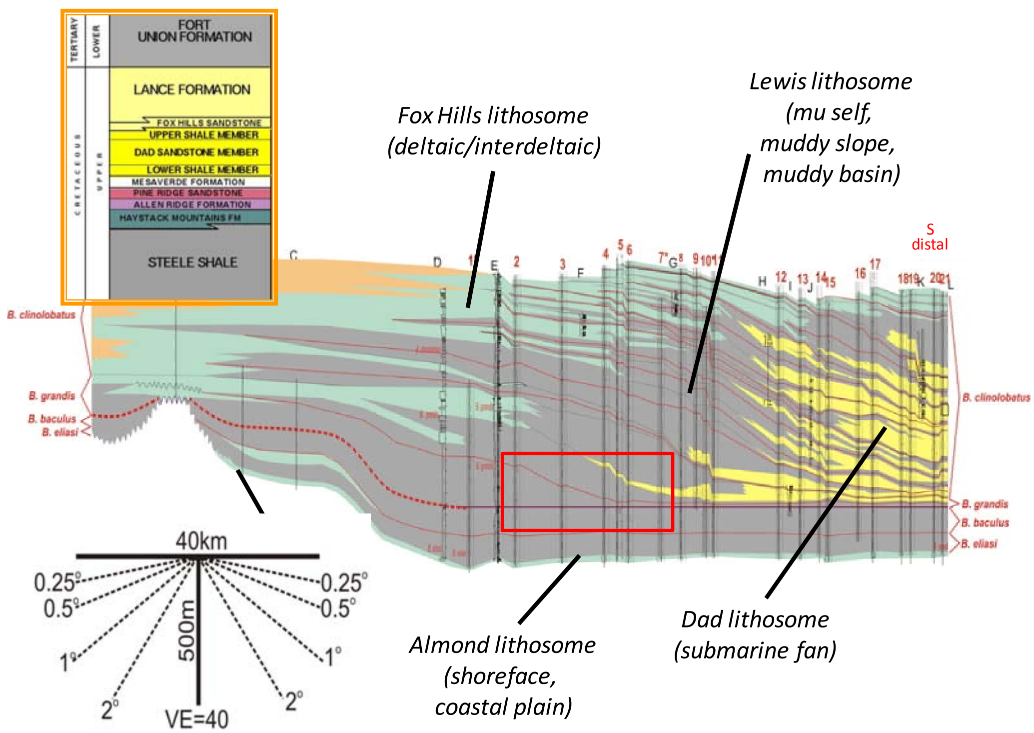

Figure 4. Lance, Fox Hills, and Lewis lithosomes across a 140 km, north-south stratigraphic cross section. The organic-rich Asquith marker shale is the datum. After Pyles (2005). The red rectangle shows the relation between the Asquith Marker and the overlying progradational downlap pattern onto the Marker. Red lines delineate several 4th order depositional sequences superimposed upon the 3rd order highstand (regressive) systems tract.

References

Abouelresh, M. O., and Slatt, R.M., in press, Lithofacies and high-frequency sequence stratigraphy of the Barnett Shale in the east-central Fort Worth Basin,Texas, AAPG Bulletin.

Bohacs, Kevin M., Lazar, Ovidiu R., 2008, The role of sequence stratigraphy in unraveling and applying the complex controls on mudstone reservoir properties, In: Abstracts: Annual Meeting - American Association of Petroleum Geologists, 2008.

Ferworn, K., J. Zumberge, J. Reed, and S. Brown, 2008, Gas Character Anomalies Found in Highly Productive Shale Gas Wells, <http://www.papgrocks.org/ferworn_p.pdf>, Accessed October 5, 2009.

Hammes, Ursula and David L. Carr, 2009, Sequence Stratigraphy, Depositional Environments, and Production Fairways of the Haynesville Shale-Gas Play in East Texas , Search and Discovery Article #110084.

Lash, Gary, 2008, The influence of basin dynamics from depositional patterns of the Middle Devonian Marcellus Shale, western New York and northwestern Pennsylvania, In: Abstracts: Annual Meeting - American Association of Petroleum Geologists, 2008.

Loucks, R. G., and Ruppel, S. C., 2007, Mississippian Barnett Shale: lithofacies and depositional setting of a deep-water shale-gas succession in the Fort Worth Basin, Texas: AAPG Bulletin, v. 91, no. 4, p. 579–601.

Miceli-Romero, Andrea, 2010, Geochemical characterization of the Woodford Shale, central and southeastern Oklahoma. M.S. Thesis, The University of Oklahoma.

Pyles, D.R., J. Syvitski, and R.M. Slatt, 2005, Graded versus out-of-grade basin-margin morphologies and their relationship with basin-scale stacking patterns and local attributes of submarine-fan strata: Lessons learned from outcrops of the Cretaceous Lewis Shale of Wyoming and the Carboniferous Ross Sandstone of Ireland, AAPG Ann. Conv., Calgary, Abs.

Pyles, D.R. and Slatt, R.M. , 2009, Stratigraphic evolution of the Upper Cretaceous Lewis Shale, southern Wyoming: Applications to understanding shelf to base-of-slope changes in stratigraphic architecture of mud-dominated, progradational depositional systems, , in T. Nilsen, R. Shew, G. Steffens, J. Studlick, Atlas of Deepwater Outcrops, American Association of Petroleum Geologists Studies in Geology 56.

Singh, Prerna, 2008, Lithofacies and sequence stratigraphic framework of the Barnett Shale, northeast Texas. Ph.D. Dissertation, The University of Oklahoma.

Slatt, R.M., Minken, J.,, Van Dyke; S.K., Pyles,D.R., Witten, A.J., and Young, R.A. ,2009. Scales of heterogeneity of an outcropping leveed-channel system, Cretaceous Dad Sandstone Member, Lewis Shale, Wyoming, USA, in T. Nilsen, R. Shew, G. Steffens, J. Studlick, Atlas of Deepwater Outcrops American Association of Petroleum Geologists Studies in Geology 56.

Slatt, Roger M.; Philp, R. Paul; O'Brien, Neal R.; Abousleiman, Younane; Singh, Prerna;.; Eslinger, Eric V, Perez, Roderick; Portas, Romina; Baruch, Elizabeth; Marfurt, K.J.; and Madrid-Arroyo, Steven; in press, Pore- to regional-scale, integrated workflow for unconventional gas shales, AAPG book on Unconventional Gas Shales (ed. J. Breyer).