Thickness Trends and Sequence Stratigraphy of the Middle Devonian Marcellus Shale, Appalachian Basin: Evidence of the Influence of Basement Structures on Sedimentation Patterns*

Gary G. Lash¹ and Terry Engelder²

Search and Discovery Article #50337 (2010)
Posted October 22, 2010

*Adapted from poster presentation at AAPG Annual Convention and Exhibition, New Orleans, April 11-14, 2010

¹Department of Geosciences, State University of New York, Fredonia, NY (lash@fredonia.edu)
²Department of Geosciences, The Pennsylvania State University, University Park, PA (engelder@geosc.psu.edu)

Abstract

Analysis of more than 900 wireline logs indicates that the Middle Devonian Marcellus Shale comprises two third-order depositional sequences, MSS1 and MSS2, in ascending order. Thickness trends of the sequences reflect the interplay of temporal and spatial variations in accommodation space, the influence of recurrent basement structures, eustatic fluctuations, and proximity to Middle Devonian clastic sources. Thickening of both sequences toward the eastern region of the basin preserves a record of greater accommodation space and proximity to clastic sources at this early stage of the Acadian Orogeny. Moreover, organic-lean late MSS2 highstand systems tract deposits prograded to the west. Local variations in the thickness of MSS1 and MSS2 reflect the reactivation of extensional basement structures, including the Rome Trough, most evident in thickness trends of MSS1 highstand systems tract deposits. Lithostratigraphic units and depositional sequences of the Marcellus Shale reveal variable degrees of erosion in western New York and northwestern Pennsylvania, a consequence of intermittent vertical displacement of crustal blocks bounded by both Eocambrian extensional structures and northwest-striking cross-structural discontinuities, including the Tyrone-Mt. Union, Lawrenceville-Attica, Home-Gallitzen, and Pittsburgh-Washington faults. Episodes of block movement induced by Acadian plate convergence gave rise to northeast-southwest-trending regions of starved sedimentation and/or erosion bounded by cross-structural discontinuities. Block movement appears to have initiated in late Early Devonian time, resulting first in local erosion of the Oriskany Sandstone in northwest Pennsylvania. Similarly, depositional and erosional patterns of the Marcellus Shale and the overlying organic-rich Levanna Member of the Skaneateles Formation in New York and western Pennsylvania were controlled by block movement.
INTRODUCTION

Results reported on this paper are based on our analysis of more than 350 wireline logs from the Appalachian Basin of Pennsylvania, New York, northeastern West Virginia, and southeastern Ohio. Our focus is on the Appalachian Plateau region of the basin for two reasons: the greater density of available wireline logs and fewer structural complications. Specific points addressed in this study include (1) the distribution and thicknesses of the two black shale members (the Cherry Valley and the Union Springs formations) along a northeast-southwest trend across western New York, (2) the development and orientation of the intervening organic-rich Marcellus and Utica Shale formations along a northeast-southwest trend across western New York, and (3) the distribution and stratigraphic relationships of the Utica Shale formations across the basin.

As important as the above points are, however, the most significant contribution of this paper is to sequence stratigraphic frameworks of the Marcellus Formation based on publicly available wireline logs. Partington et al. (1980), Emery and Myers (1980), and others have demonstrated the utility of these more common wireline logs for the recognition of transgressive-regressive cycles and the interpretation of sequence stratigraphic elements as sequence boundaries, systems tracts, condensed sections, and maximum flooding surfaces. Such an approach serves as a means by which basin fill can be examined into unconfined or semi-confined surficially bounded packages of strata that provide a framework for predictive reservoir assessment and correlation between two regions of similar or dissimilar environments.

Thickening trends from northeast to northwest across the region is thought to be due to a combination of factors including: (1) the greater density of available wireline logs along a northeast-southwest trend across western New York and northwestern Pennsylvania, (2) the influence of recurrent basement structures, eustatic fluctuations, and proximity to Middle Devonian clastic sources. Thickening of both the Cherry Valley and the Union Springs formations toward the eastern region of the basin preserves a record of greater accommodation space and proximity to clastic sources at this early stage of the Appalachian Orogeny. Moreover, organic-rich black shale has been identified as a key stratigraphic element in the Marcellus Formation, with major potential for producing natural gas. In contrast, thickening of the Cherry Valley Formation and the overlying Marcellus Formation toward the western region of the basin is likely due to the influence of recurrent basement structures, eustatic fluctuations, and proximity to Middle Devonian clastic sources. Thickening of both the Cherry Valley and the Union Springs formations toward the eastern region of the basin preserves a record of greater accommodation space and proximity to clastic sources at this early stage of the Appalachian Orogeny. Moreover, organic-rich black shale has been identified as a key stratigraphic element in the Marcellus Formation, with major potential for producing natural gas.
A series of sequence stratigraphic cross-sections through the core region of the basin reveals several significant aspects of the stratigraphic architecture of the Marcellus Formation. MSS1 is thickest in northeastern Pennsylvania and southwestern New York where a thick regressive systems tract overlies a submarine fan. In southwestern Pennsylvania, the sequences are thinner and less distinct. MSS2 is thickest in northeastern Pennsylvania and western New York, and becomes progressively thinner to the west. In northeastern Pennsylvania, the regressive systems tract thickens sectionally towards the northeastern region of the basin, matching the geometry of underlying basement tectonics. The regressive systems tract is thickest in northeastern Pennsylvania and further thins to the west. The systems tract thickens towards the northeastern region of the basin, and the bulk of the deposits in this region are of the Acadian highland source region.

**SEQUENCE STRATIGRAPHY**

We adopt the transgressive-regressive (T-R) sequence described by Embry and Johannessen (1992) and further modified by Embry (2002). For example, Johannessen (1992) and Embry (2002) refer to the T-R sequence concept as the transgressive systems tract. We apply the T-R sequence concept to the Devonian succession of the Appalachian Basin, recognizing that it is applicable to a variety of stratigraphic successions. The regressive systems tract is deposited on the transgressive systems tract and records rising base level, whereas the transgressive systems tract deposits are less sensitive to falling base level and consequent washout accommodation space (Emery and Johannessen, 1992; Embry, 1993, 2002). Recognition of T-R sequences is dependent upon the identification of minimally drowning sequence boundary surfaces (Emery, 1992; Embry, 1993, 2002). Recognition of T-R sequences includes the identification of minimal drowning, sequence boundary surfaces, and the onlap of minimal drowning, sequence boundary surfaces.

**Cross-Section 1**

A cross-section through the core region of the basin reveals several significant aspects of the stratigraphic architecture of the Marcellus Formation. The regressive systems tract thickens sectionally towards the northeastern region of the basin, matching the geometry of underlying basement tectonics. The regressive systems tract is thickest in northeastern Pennsylvania and further thins to the west. The systems tract thickens towards the northeastern region of the basin, and the bulk of the deposits in this region are of the Acadian highland source region.

**Cross-Section 2**

![Cross-Section 2](image2)

**Cross-Section 3 west**

![Cross-Section 3 west](image3)

**Cross-Section 3 east**

![Cross-Section 3 east](image4)

**Cross-Section 4**

![Cross-Section 4](image5)
The Middle and Upper Devonian successions of the Appalachian Basin contains the continuous advance of the Catskill Deltaic complex in response to the Appalachian orogenic collision of the ancestral Laurentia and the Avalon Terrane (1847). Rapid synorogenic stacking of MSS1 and MSS2 toward the Appalachian fold and thrust belt is characterized of foreland basin deposits (McGill and Giles, 1994).

An early indicator of forebulge-like dynamics induced by Acadian caunation is the Appalachian Basin to the west by the Tyrone-Mt Union CIS. It is noteworthy that the MSS maximum flooding surface is located at the Tyrone-Mt Union CIS maximum flooding surface.

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