# Geologic Evolution of the Marcellus Shale and Its Effects on Reservoir Architecture and Production

**Randy Blood[1] and Gary Lash**

[1]EQT

## Abstract

Placement of a lateral and production optimization in the Middle Devonian Marcellus Shale necessitates consideration of the reservoir architecture. Here we exam the evolution of Marcellus deposits and the affects bottom-water conditions, early diagenesis and hydrocarbon production have on the location and modification of the reservoir. Core calibrated petrophysical analysis of Marcellus Shale logs was conducted to deter-mine total organic carbon (TOC) content, gas-filled porosity, clay volume, and both free and adsorbed gas-in-place volumes. The distribution of in-place hydrocarbons is controlled by the sequence stratigraphic framework and subsequent diagenetic and catagenic modifications of the Marcellus Shale.

In general, the Marcellus gamma-ray signature on geophysical well logs displays two T-R sequences, each comprised of lower transgressive systems tract (TST) and overlying regressive systems tract (RST) deposits separated by a maximum flooding surface (MFS) delimiting the change from deepening-upward strata to shallowing-upward deposits (Fig. 1; Embry, 2002; Embry et al., 2007). Individual T-R sequences are bounded by maximum regressive surfaces (MRS), which mark a change in depositional regime from regression to transgression (Fig. 1; Embry, 2002; Embry et al., 2007). A third T-R sequence occurs at the base of the Skaneateles Formation directly overlying the T-R sequences of the Marcellus Shale (Lash and Engelder, 2011).

Variations in the concentration of redox sensitive elements combined with pyrite framboid size distribution trends documented from the Marcellus Shale elucidate the depositional history of this fine-grained succession in this region of the basin. Uranium (U) and molybdenum (Mo) enrichment, coincident with diminishing Thorium/Uranium (Th/U) upward through the initial Marcellus transgressive systems tract (Fig. 2), in association with abundant small, (<5-6μm) pyrite framboids record rapidly deteriorating benthic conditions (Fig. 3). However, strongly anoxic to euxinic conditions were occasion-ally interrupted by episodes of dysoxia. Reduced Mo and U enrichment and increasing Th/U of the overlying regressive systems tract (RST) deposits (upper Union Springs Member) record a modest improvement of redox conditions (Fig. 2). A subsequent base level rise and consequent worsening of benthic conditions is reflected in the lower, organic-rich interval of the Oatka Creek Member by diminished Th/U and sharp increases in Mo and U enrichment (Fig. 2). Further, the mix of abundant small (< 5 μm) and subordinate large (> 10 μm) framboids preserves the record of oxygen deficient to sulfidic bottom conditions occasionally interrupted by (dys)oxia (Fig. 3). Inferred condensed intervals are defined by minimal clay and especially abundant quartz, principally diagenetic.

Opaline quartz tests of planktonic organisms such as radiolarians are unstable and commonly dissolve in bottom water undersaturated with respect to silicon. Upon dissolution, and under conditions of enhanced productivity export, silica precipitates in a more stable form often intimately associated with organic matter which, upon burial, ultimately becomes the reservoir for gas in many of these organic-rich deposits. Further, the newly precipitated silica permeates the clay fabric of mudstones providing a continuous high-modulus medium that is conducive to

the initiation of, and maintenance of, high conductivity hydraulic fractures. Petrographic analysis, including thin section and SEM, and chemostratigraphic analysis of the Marcellus Shale provide evidence of recurrent patterns of biogenic silica enrichment in these organic-rich deposits in which elevated Mo/TOC coincide with excursions in silica to aluminum (Si/Al) ratios, and occur most commonly in condensed sections about the MFS of each T-R cycle (Fig. 4). We suggest that during times of transgression the Mo reservoir is resupplied via connection with the global ocean, resulting in elevated Mo/TOC. In addition to Mo, transgression provides silica and nutrients needed to stimulate primary productivity in the photic zone.

Organic richness throughout much of the Marcellus basin appears to have been controlled principally by a combination of bottom water conditions conducive to preservation of organic macerals and dilution by clastic detritus (Fig. 1). Given that the Marcellus accumulated rapidly (~1.5my), condensed intervals are dominated by TOC that is largely undegraded. Deposits of the Union Springs Member often illustrate the best reservoir development. However, the link between TOC and Marcellus gas production is more than one of gas adsorption onto macerals; organic grains are the dominant hosts of porosity development within the Marcellus Shale.

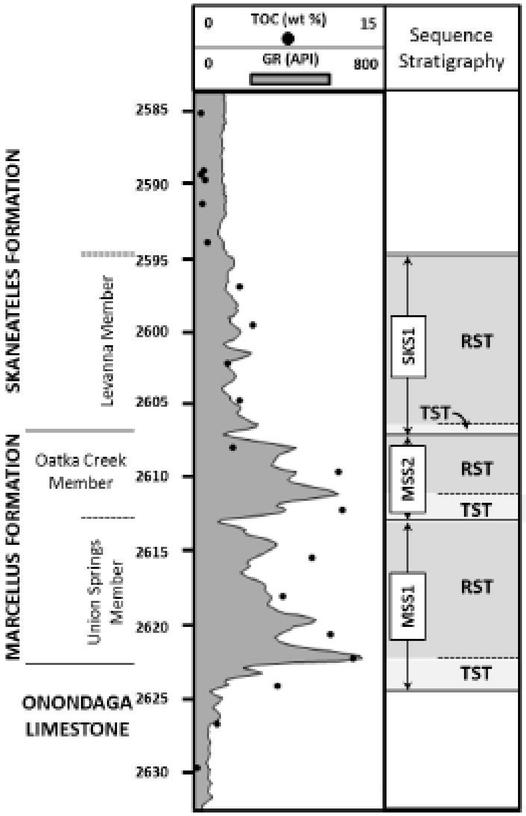

Figure 1. Gamma-ray log and TOC profile of the Marcellus Shale showing sequence stratigraphy inferred from gamma-ray signature (refer to text for discussion).

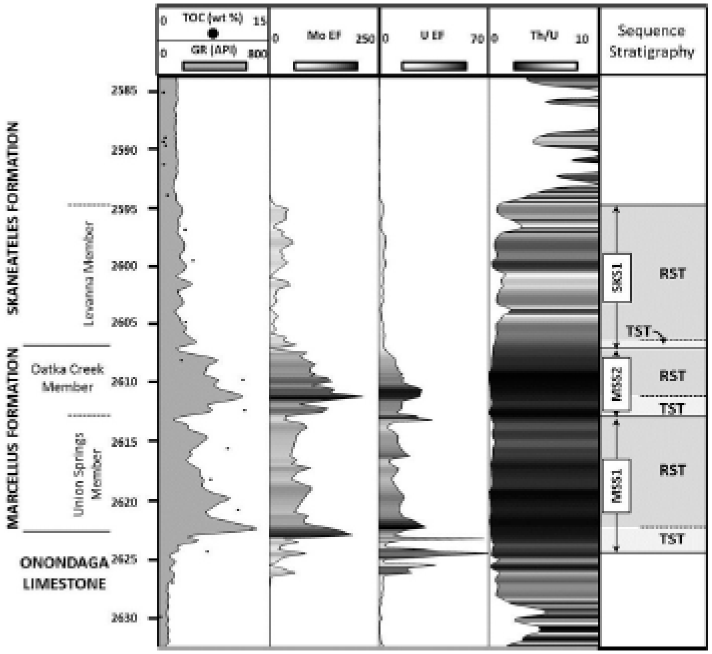

Figure 2. Gamma-ray log and TOC profile of the Marcellus Shale showing chemostratigraphic trends in Mo and U enrichment, and Th/U.

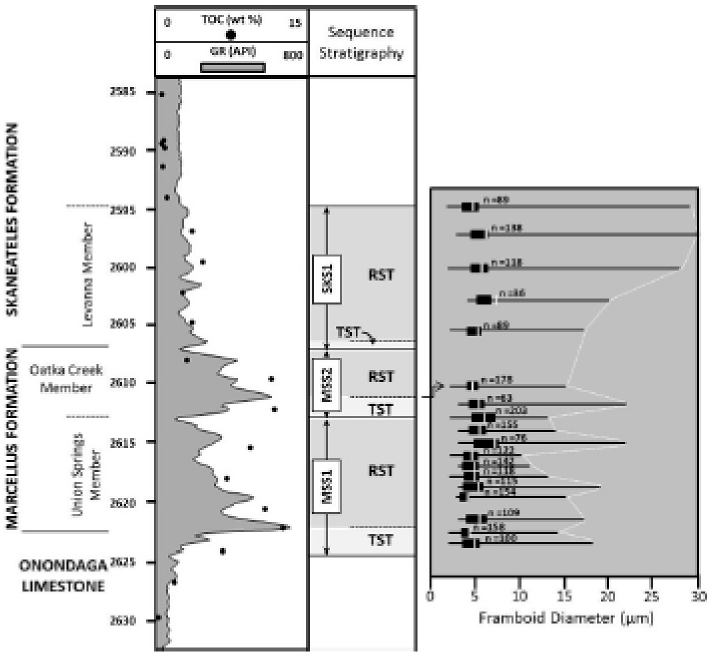

Figure 3. Gamma-ray log, TOC profile, and box-and-whisker plots of pyrite framboid diameter data of samples recovered from the Marcellus Shale.

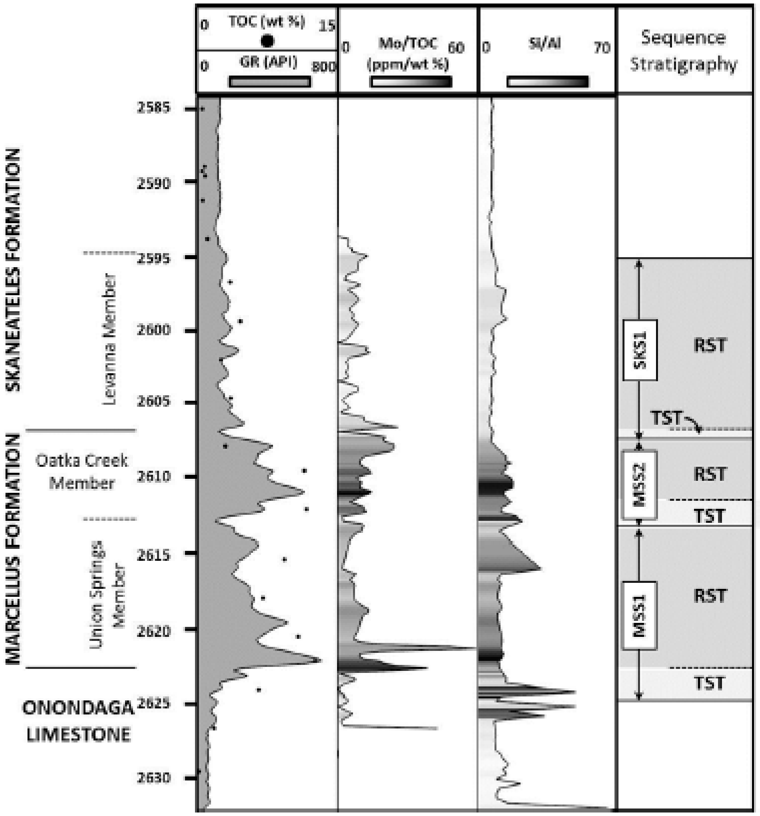

Figure 4. Gamma-ray log and TOC profile of the Marcellus Shale showing chemostratigraphic trends in Mo/TOC and Si/Al.