Depositional Control of Organic Content in the Middle Devonian Marcellus Interval of West Virginia and Western Pennsylvania

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In the central Appalachian basin, the multiple organic-rich intervals of the Middle Devonian, including the Marcellus Shale, are an emerging large resource play with high economic potential (estimated 1,307 trillion cubic feet of recoverable gas). This resource play was evaluated by examining the patterns of organic richness, lithology, stratigraphic distribution and other depositional characteristics. Using logs from wells throughout West Virginia and western Pennsylvania (2,266 wells) integrated with core data (whole and sidewall), the subsurface lithostratigraphic boundaries were defined and correlated for the Marcellus and associated units throughout the study area.

Past studies of the Middle Devonian interval have not rigorously defined the lithostratigraphic boundaries in the subsurface and relied on limited petrophysical criteria (i.e. un-scaled gamma ray). In this study, the interval was defined in the subsurface by using a multiple well log approach including the following curves: gamma ray, bulk density, resistivity, photo electric, and neutron porosity (Figure 1). The rock properties analyzed from core data (X-ray diffraction and total organic carbon [TOC]) indicate that the Marcellus Shale is organic-rich (2-20%) and although classified as a shale, it has a relatively high amount of quartz (40-75%) and a low amount of clay (10-45%). The variations in the relative concentration of quartz and clay can affect fracture stimulation and subsequent well performance.

The high amounts of TOC are correlated to more gas-rich intervals and vary significantly, both stratigraphically and spatially. A correlation was observed between uranium content derived from the spectral gamma ray log and TOC. The relationship among gas content, TOC, and uranium in the Appalachian basin was evaluated using multiple petrophysical analyses techniques including modified gas saturation equations (Figure 1). The petrophysical results were use to improve regional and local understanding the distribution and deposition controls on the Marcellus Shale. Numerous maps and cross sections were constructed to better display local and regional depositional patterns of Middle Devonian units across the Central Appalachian basin including the Onondaga, Marcellus Shale, Mahantango Shale, Tully Limestone and Harrell Shale.

A regional net thickness map of the Marcellus Shale with estimated total organic carbon content at seven percent (Figure 2) highlights a regional fairway relatively thick organic-rich shale with distinctive local variations. A well-defined arcurate north-to-south regional trend of increased thickness of shale with high organic content is correlated to underlying paleostructure and paleotopography. These regional features are observed in the deposition of all Middle Devonian units. It appears that a paleotopographic high created a slope break environment and upwelling conditions leading to higher rates of accumulation of organic-rich shale.

Salt tectonics in the underlying strata, and reactivated paleostructures influenced local variations in accumulation of organic-rich Marcellus Shale (10-30 km regions; Figure 2). The accumulation of

thicker intervals of organic rich shale occurred in depositional lows that appear to create favorable conditions for accumulation organic-rich shale.

The correlation between thicker accumulation of organic rich Marcellus and related shale units appears to define a fairway with significant local variations for the highly productive areas of the Marcellus Shale resource. The relatively rapid temporal variations at regional and local spatial scales in the location of oxic-anoxic conditions result in changes in lithology and accumulation or organic-rich shale.

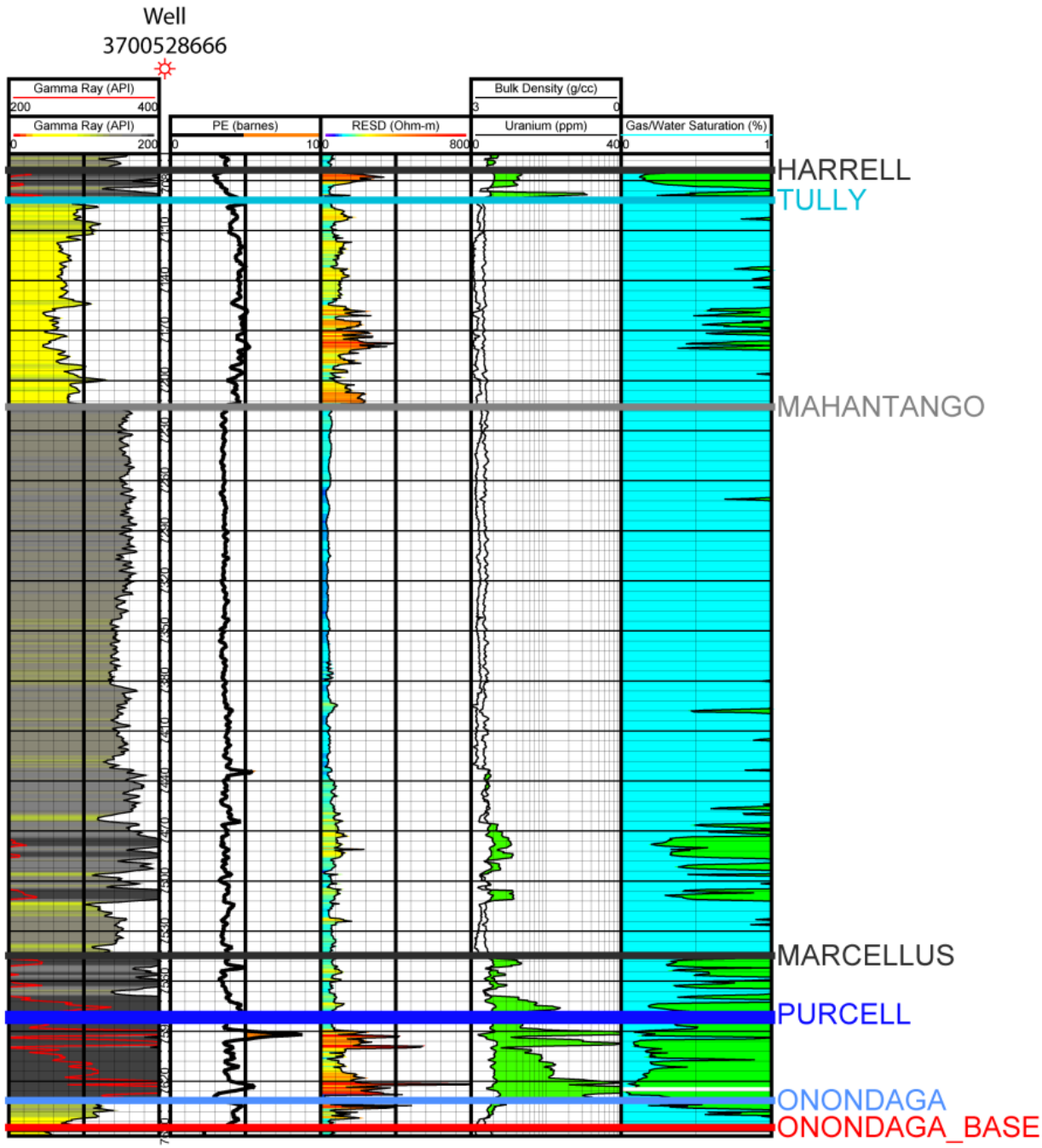

Figure 1. Log for the Middle Devonian in the Matthew Miller (37-006-28666), Armstrong County, Pennsylvania showing gamma ray (Track 1), PE (Track 2), Resistivity (Track 3), uranium (ppm) and Bulk Density with cross-over of gas-rich intervals highlighted (Track 4), and modified computed gas/water saturation using uranium (Track 5). Middle Devonian units listed on right.

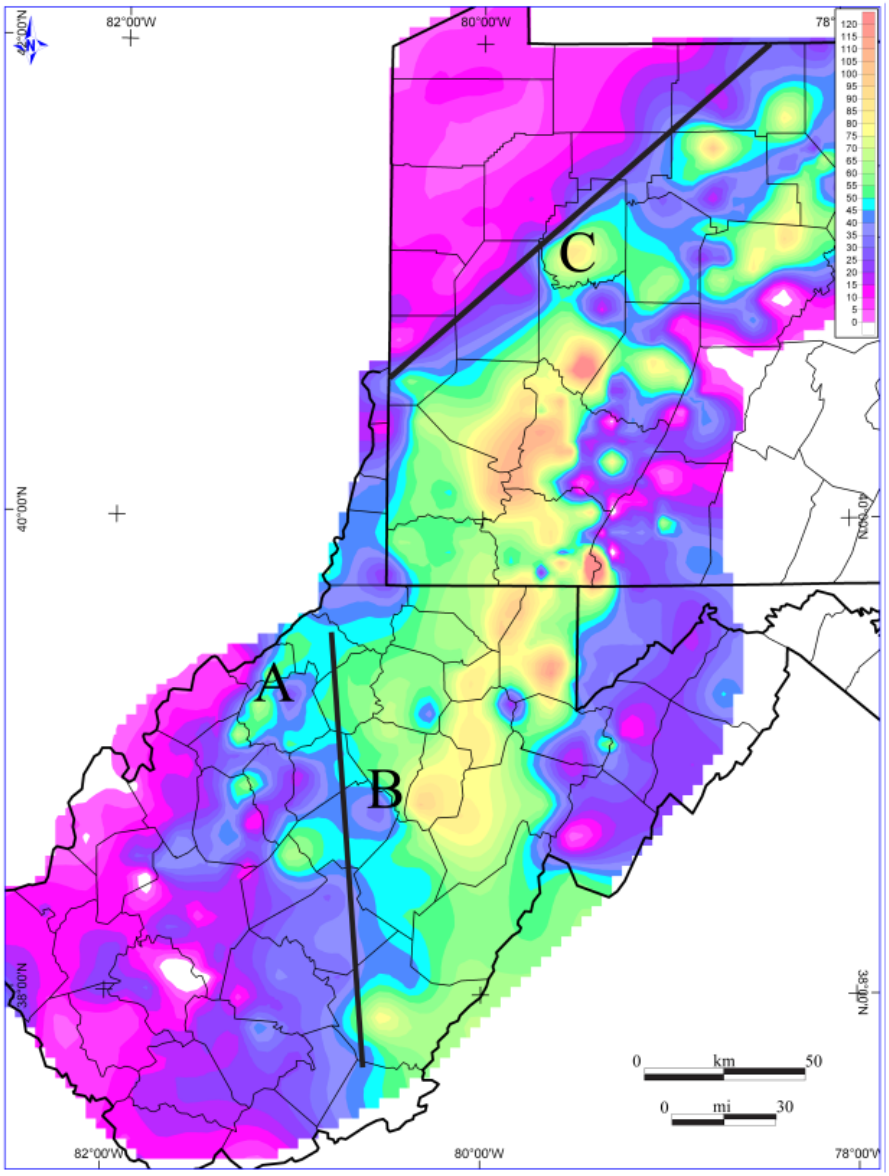

Figure 2. Interpreted organic richness map illustrated by a net thickness map of the Marcellus Shale with total organic carbon content greater than or equal to seven percent. Localized rapid changes in interpreted thick TOC accumulations are tied to local structures that appear to be a result of salt tectonics or reactivated structure during the Acadian Orogeny. The regional trend **A** highlights an area favorable for organic preservation because of a shelf break formed as a result of the uplifted limb of the Rome trough. The arcurate trend **B-C**, oriented northwest to southeast, and northeast to southwest is interpreted to represents a slope break environment during the deposition of the Marcellus. The slope break environment is recognized in all the Middle Devonian units and created a regional area with more favorable conditions for organic matter production and preservation.