Microstructural Evolution of Organic Matter Pores in Middle Devonian Black Shale from West Virginia and Pennsylvania, USA

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ABSTRACT

The pore microstructure, porosity, mineralogy and elemental composition of the Mahantango Formation and Marcellus Shale were characterized using a combination of focus ion beam (FIB) scanning electron microscope (SEM), X-ray fluorescence (XRF) and low-pressure nitrogen adsorption methods on core samples acquired from three wells in West Virginia and Pennsylvania, USA. The thermal maturity of examined samples range from Ro (vitrinite reflectance) 1.36% to 2.89%. The nano-scale-resolution FIB- SEM makes it possible to study the pore morphology on both organic and inorganic parts of the unconventional reservoir directly. With the help of advanced image processing software, we analyzed the pore size, organic matter (OM), OM porosity, and porosity developed in inorganic rock matrix. Four pore micro-facies were defined, namely organic-rich, organic-lean, clay-rich, carbonate-rich. Pore micro-facies had a stratigraphic distribution and were strongly affected by the redox and clastic influx history, richness of organic matter, and lithology.

BET, t-Plot, H-K, and BJH models were used to interpret the isotherms of nitrogen-adsorption test, and distinguished specific surface areas (SSA), pore volumes, proportions or micropores and mesopores, and pore-size distributions (pore width down to 2nm) of core samples. The isotherms and hysteresis loops acquired indicate that the pore system in core samples are mainly associated with narrow slit-like pores with both mesoporosity and microporosity, i.e. activated carbons. There is a significant amount of porosity beyond the resolution of SEM (.:Sl Onm in this research), which helped explaining the fact that SEM technology underestimated the porosity values compare to helium porosimeter. With thermal maturity increasing, a significant change in SSA, pore sizes, pore volumes, and pore size distribution was noted. Richness of organic matter (total organic carbon TOC) also affects the pore structures, but this impact appears less important than thermal maturity. The porous system of shale-gas reservoirs composed by organic matter and inorganic matrix are complicated and varies related to both sedimentary environment and hydrocarbon generation and migration. Porosity within OM is the most important secondary porosity in our shale-gas reservoir, and its evolution is mainly controlled by thermal maturity.