Porosity variations in the Upper Ordovician Utica Shale, southern Quebec, Canada

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Abstract

The Upper Ordovician Utica Shale in the St. Lawrence Platform of southern Quebec (eastern Canada) has been a potential target for unconventional shale gas and shale oil exploration and development since 2006 (Haeri-Ardakani et al., 2015; Lavoie et al., 2014; Lavoie et al., 2016). Based on the recent resource assessment by Geological Survey of Canada, the Utica Shale has significant gas-dominated hydrocarbon resources (Chen et al., 2014) that warrant a better understanding of controlling factors on the Utica Shale reservoir characteristics. This study presents pore type variations and possible controlling factors on porosity in the studied as-received samples using helium pycnometery, scanning electron microscopy (SEM) and X-ray diffraction (XRD) mineralogy. Selected samples from three wells at depths of ~400, 700, and 2000 m cover a range of thermal maturity from late peak oil window ($VRo_{eqv.}$ ~ 1%) to dry gas zone ($VRo_{eqv.}$ ~ 2.1%). The predominant organic matter (OM) constituents are bitumen, chitinozoans, and minor graptolites with mean total organic carbon (TOC) content of 1.1 wt. % (0.07 to 2.25, n = 408; Haeri-Ardakani et al., 2015).

The mean helium porosity values for oil and gas window samples are 3.9 and 2.6%, respectively. Oil window samples show a weak correlation (R^2 = 0.25, n = 14) between TOC and porosity, while there is no correlation (R^2 = 0.06, n =10) between the two parameters for samples in the dry gas zone. Porosity has a correlation (R^2 = 0.87, n = 14) with total clay content for samples in the oil window, but no correlation (R^2 = 0.02, n = 10) for samples in the dry gas zone. A negative correlation (R^2 = 0.40, n = 14) between carbonate content (i.e., calcite and dolomite) and porosity suggests its detrimental effect on porosity for samples in the oil window, while there is no correlation (R^2 = 0.06, n = 10) between these parameters for samples in the dry gas zone. Based on SEM petrography, pore types in the Utica Shale can be divided into three major groups in decreasing order of abundance: (1) matrix porosity that can be further divided into inter-granular, inter- and intra-crystalline porosity; (2) organic porosity that is limited to pore developed in OM (i.e., bitumen); and (3) fracture porosity. The SEM images illustrate that chitinozoans have a non-porous structure, except limited isolated fractures. However, bitumen that is generally associated with clay minerals has pore spaces, although clogged bigger intergranular and crystalline pore spaces that affects its overall positive impact on porosity.

Our entire data set demonstrates that OM, especially in dry gas window, is not the major controlling factor on overall porosity in the Utica Shale, whereas matrix porosity and mineralogy have more significant control. Textural, mineralogical and facies changes have a dominant impact on controlling reservoir properties in the studied Utica Shale samples. Decrease in overall porosity from shallower samples (i.e., oil window) to deeper samples (i.e., dry gas window) suggests that matrix porosity is the dominant component which decreased with burial compaction. In addition OM (i.e, bitumen) can potentially clog the available matrix porosity and reduce the overall porosity (e.g., Sanei et al. 2015). Our results suggest that in a single unit at various thermal ranks, variable organofacies, and diagenetic changes can have a significant effect on reservoir quality and could affect OM contribution in the overall porosity of the rock. Furthermore, a precise knowledge of original and dominant OM type is critical as potential for generation of OM porosity differs significantly between various types, thus affecting the overall porosity of shale reservoirs.

References

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