A model for porosity evolution in shale reservoirs- an example from the Upper Devonian Duvernay Formation, Western Canada Sedimentary Basin

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In order to understand the influence of thermal maturity on porosity evolution in shale reservoirs, samples from five wells (88 core samples) from the Upper Devonian Duvernay shale were examined by integrated methods, including Rock-Eval pyrolysis, inorganic composition analysis, helium pyncnometry, mercury injection analysis, nitrogen adsorption and scanning electron microscopy (SEM) imaging combined with ion-milling technique. The samples span a maturity range from immature to wet gas window and a wide range of compositions.

The Duvernay Formation exhibits an average organic richness of 2.6 wt.% TOC, consisting predominantly marine-derived type Ⅱ with limited terrigenous type Ⅲ organic matter. Increasing maturity from immature to wet gas window of Duvernay Formation exerted many changes in the pore system including porosity from helium pyncnometry, pore volume from nitrogen adsorption technique, pore size distribution, pore morphology and pore type; these parameters are also influenced by mineralogical composition and organic matter content. Total porosity decreases from 7.3% in immature samples to 4.7% in oil window samples, increases to 6.9% in wet gas window samples and then declines to 4.3% in dry gas window samples. Total pore volume measured by nitrogen adsorption displays parallel evolution trend along the increasing maturity.

Visible pores imaged by SEM and He-ion microscopy exist as organic matter pores including pores developed within organic matter and along organic matter grains, intraparticle pores mainly developed within carbonate grains, interparticle pores either within the clay-rich matrix or between rigid mineral grains. In immature samples, organic matter is generally non-porous and interparticle pores between rigid grains as well as mineral-dissolution pores are dominated. In oil window samples, organic matter devolatilization cracks either within organic matter or between organic matter and mineral interface are ubiquitous. Bubble-like OM-hosted pores are developed within gas window samples.

Organic matter maturation is a primary factor controlling quantitative petrophysical properties. Nitrogen adsorption and mercury injection analysis indicate that macropores (> 50 nm) and coarse mesopores (20-50 nm) dominates in immature samples. With increasing maturity, fine mesopores (2-20 nm) and micropores (<2 nm), which are strongly associated with the cracking from organic matter into hydrocarbon, become more abundant, especially in gas window.

Total porosity is also governed by the concentration of biogenic silica, quartz which shows positive correlation to porosity. We speculate that high concentrations of biogenic silica serve to develop mechanical strength in mudstones, retarding mechanical compaction and preserving primary porosity. Other compositional variable such as detrital quartz, carbonate and clay content do not have a significant role in controlling porosity.