Methodology for Multi-scale Shale Lithofacies Modeling: Case Study from the Bakken Formation in North Dakota

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ABSTRACT

Integrated shale lithofacies models are important to analyze multi-scale variation of geologic and petrophysical parameters of shale formations to interpret depositional and diagenetic environments, and manage the petroleum system. This study presents the results from the upper and lower shale members in the Bakken Formation of the Williston Basin in North Dakota. The major objectives of this study are to better understand geologic controls on mineralogy and organic matter content, and provide a quantitative framework for shale lithofacies characterization at core, well, and regional scales. Shale lithofacies is defined using a quantitative workflow based on mineralogy, Total Organic Carbon, and various petrophysical parameters derived from core (XRD, XRF, pyrolysis, and secondary X-ray emission spectroscopy) and advanced geochemical spectroscopy logs from 37 wells. Next, machine learning algorithms are used to recognize the pattern of different shale lithofacies and corresponding petrophysical parameters from ubiquitous conventional well logs from ~500 wells. After core and well log-based classification of shale lithofacies, geostatistical algorithm, such as Sequential Indicator Simulation, is used to generate 3D stochastic shale lithofacies models at regional scale (~13,000 sq. miles). The results show that upper and lower Bakken shale members are vertically and laterally heterogeneous at core, well, and regional scales, but can be classified into five different lithofacies. Organic-rich shale lithofacies outweigh the proportion of organic-lean gray shale lithofacies. Several factors, such as source of elements, paleo-redox conditions, and organic matter productivity appear to have controlled the depositional pattern of shale lithofacies. Silica in the Organic Siliceous Shale lithofacies is derived from both biogenic and eolian actions. Organic-rich shale lithofacies show positive correlation with hydrocarbon production.