Comparison of Thermal Maturity Parameters from Lower and Upper Bakken Source Rocks from Immature Through Late Oil Window Conditions

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Abstract

Thermal maturity is an essential characteristic to understand for evaluation of source rocks and their role in petroleum systems. To address the need for thermal maturity information, a variety of geochemical, petrographic, and spectroscopic tools have been developed to evaluate and quantify the degree of thermal stress sedimentary organic matter has experienced. Reflectance measurements from vitrinite and solid bitumen are widely considered to be the gold standard for thermal maturity determination to which other parameters are calibrated. In this study, source rock samples from the lower and upper parts of the Devonian-Mississippian Bakken Formation were collected from eight cores across the Williston Basin at depths (2,300-3,400 m) representing immature through late oil window thermal maturity conditions, confirmed petrographically by solid bitumen reflectance (%BRo). The BRo relationship with depth followed a non-linear trend with an inflection point at around 3,000 m (BRo ~0.7%), typical of reflectance "dogleg" curves in many basins around the world. Reflectance results were compared to parameters derived from programmed temperature pyrolysis [hydrogen index (HI), Tmax] and total organic carbon analyses before and after extraction, normal hydrocarbon and isoprenoid analysis of extractable organic matter (pristane/n-C_{17}, phytane/n-C_{18}), and infrared spectroscopy (IR) peak ratios (methyl/methylene, aliphatic/aromatic). Significant systematic differences between samples from the lower and upper Bakken source rocks were not observed. BRo values from extracted samples ranged from 0.32 to 1.25% and HI and Tmax values ranged from 80-540 mg/g and 424-458°C, respectively. Using whole rock IR, CH_3/CH_2 and A-factor ratios were calculated and found to be in agreement with extant data, although though there was substantial scatter in the new data and no significant correlations were observed. Values for isoprenoid to n-alkane ratios decreased linearly with thermal maturity (slope = 1.1, R^2 = 0.98), decreasing from 1.4-1.6 (BRo of ~0.35%) to 0.2 (BRo of >1.1%). Despite consistency between these results, many parameters show substantial scatter, especially at immature conditions, indicating organic matter variability likely is attributable to fluctuations in preservation conditions or organic matter sources. This is consistent with petrographic observations of multiple maceral types at immature conditions, including heterogeneous solid bitumen, algal organic matter and bituminite, terrigenous inerts, and granular micrinite. At higher thermal maturity, algal organic matter and bituminite are absent, and solid bitumen is more homogeneous, creating less scatter in comparison to other thermal proxies. The heterogeneity for Bakken organic matter properties observed across datasets in this study indicates that multiple lines of evidence are needed to better understand thermal maturity trends in the Williston Basin.