Lithofacies, Organic Facies and Thermal Maturity Relationships in the Upper Cretaceous Niobrara Formation, Rocky Mountain Region, USA

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Low-permeability organic-rich chalks, marls, and shales in the Upper Cretaceous Niobrara Formation are the target of unconventional reservoir exploration and development in the Rocky Mountain portion of the Western Interior Seaway. Microbial gas in the eastern Denver basin and oil/thermogenic gas in deeper (> 1500 m) portions of the basin along the Front Range are clearly defined by lithology, diagenesis, porosity, tectonics, and petroleum geochemistry.

The resource play characteristics of the Niobrara Formation between these two extremes are not as well constrained, particularly for oil prospects. The type of organic matter and thermal maturity of the petroleum source rocks can be particularly difficult parameters to define. Siliciclastic shale source rocks in the Niobrara Formation contain mostly mixed marine algal and Type III terrigenous organic matter, and biomarker parameters derived from bitumen extracts and petroleum suggest deposition under suboxic conditions. The relative amount of terrigenous kerogen in these rocks defines two organic sub-facies in the shales. Carbonate lithofacies in the Niobrara Formation (marl and chalk) contain variable amounts of amorphnite, alginite, liptinite, inertinite, and vitrinite. Most of the latter is oxidized and recycled.

The combined use of organic petrography, biomarker analysis, and programmed pyrolysis provides concise analytical criteria for defining organic facies in the Niobrara Formation independent of lithology. The most oil-prone sediments belong to organic facies B. These rocks are laminated to well bedded, contain mostly amorphous organic matter, and have respective hydrogen index (HI) and oxygen index (OI) pyrolysis yields of approximately 350 – 700 mg hydrocarbon generated/g TOC and 20 – 60 mg CO2/g TOC. The least oil-prone sediments belong to organic facies D which contains highly oxidized and reworked kerogens, has HI values < 50 mg hydrocarbon generated/g TOC, and presents OI values between 20 and 200 mg CO2/g TOC. Niobrara organic facies D often exhibits a high normalized oil ratio in the carbonate lithofacies warranting caution in interpreting source versus reservoir parameters.

The determination of thermal maturity in the Niobrara Formation is complicated by three factors: 1) a lack of autochthonous and representative vitrinite; 2) bitumen formation and early oil generation which suppresses Tmax measured during programmed pyrolysis; and 3) petroleum migration within the Laramide basins. A reasonable interpretation of thermal maturation in these rocks requires the integrated application of organic petrography, programmed pyrolysis, isotope geochemistry, and biomarker analysis during resource assessment.