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Dual Mineral Matrix and Organic Pore Textures in Thermally Mature Niobrara Formation (Upper Cretaceous) Rocks, Rocky Mountains Region, USA – Implications for Tight-Oil Carbonate Reservoir Modeling

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We studied core of the Niobrara Formation recovered from the central portion of the Upper Cretaceous Western Interior Seaway in the northern Denver basin to determine what factors control porosity and permeability in these compacted fine-grained tight-oil carbonate reservoirs. The Smoky Hill Chalk member of the Niobrara recovered in the core consists of pelagic marine carbonates, hemipelagic marine marlstones, and offshore to shallow marine mudstones. Tight-oil reservoirs in the Smoky Hill Chalk include elements of both hybrid/interbedded and porous mudstone fine-grained reservoir systems. Our work focused on three specific lithologies: 1) relatively porous and permeable, argillaceous, moderately organic-rich, pelletal impure chalk (“B Chalk”); 2) relatively porous, low permeability, moderately organic-rich pelletal chalk (“Upper B Chalk”); and, 3) relatively porous, low permeability, very organic-rich pelletal impure chalk (“A Marl”). Mechanical and chemical compaction significantly modified porosity and permeability, and controlled diagenesis in these rocks.

Geochemical parameters indicate the rocks belong to Organic Facies B (oil-prone) and B-C (oil/gas-prone), and have reached the transition zone of early to peak thermal maturity. Normalized oil ratios ($[S1/TOC] \times 100$) range from 55 to 315 indicating that the Smoky Hill interval contains interbedded mature, tight oil-stained source rock and tight-oil reservoir rocks. The highest oil saturations occur in moderately to very organic-rich, foraminifera/ pelletal wackestone and packstone. Lower oil saturations occur within moderately organic-rich impure chinks and marlstones.

We recognize three principal mudstone pore types in the Niobrara Formation reservoirs: 1) mineral matrix pores, 2) organic-matter pores, and 3) fracture pores. Mineral matrix pores include (A) interparticle voids between carbonate grains and cements, between authigenic silicates and clay platelets, and pores at the edge of rigid grains, and (B) intraparticle carbonate pore textures and intraparticle voids within pyrite framboids and clay aggregates. Intraparticle carbonate pores dominate void space in all of the rocks we examined; storage capacity is primarily controlled by effective nano- to micro-scale interparticle and intraparticle mineral matrix pores preserved within compacted pelletal allochems. *i. e., intraparticle carbonate pores consist of much smaller interparticle/intraparticle pores preserved inside individual pellets.* Organic porosity consists of primary voids related to original kerogen structure and secondary voids related to petroleum generation and expulsion. Organic porosity within kerogens in the rock matrix is rare and poorly connected. Organic pores in kerogens preserved within individual pellets are more common and contribute to the observed intraparticle porosity of the rocks.

Intraparticle pore geometry is readily determined by 3D FIB/SEM segmentation and modeling. In some samples, modeling calculations approach the bulk volume porosity values measured by laboratory core analysis of crushed rock samples. However, correlation is poor in other samples. Laboratory NMR measurements of selected samples modeled by FIB/SEM analysis appear to discriminate discrete pore and fluid distributions in the tight Niobrara Formation reservoirs.

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