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Deterministic and Geostatistical Characterization and Modeling of the Geometry, Heterogeneity, and Connectivity of Lacustrine-Deltaic Sandstone, Green River Formation, SW Uinta Basin, Utah

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During the Early and Middle Eocene, extensive lacustrine strata of the Green River Formation accumulated in Laramide basins of Wyoming, Utah and Colorado. Although famous for well-developed shale and carbonate source rocks, profundal lacustrine facies, and tectonically-controlled cyclicity, the Green River Formation and laterally equivalent strata contain excellent examples of lacustrine and fluvial-lacustrine deltaic sandstone. The Uinta basin of northeastern Utah contains sandstone deposited in two contrasting types of lacustrine shoreline environments, on opposite sides of a profundal lacustrine depocenter that spanned much of the basin. These environments, wave-dominated lacustrine in the northeastern Uinta basin, and lacustrine deltaic in the southern and southwestern part of the basin, each contain a variety of sandstone lithosomes that are productive reservoirs in this basin, and effective analogs for lacustrine sandstone reservoirs in similar systems worldwide. In this study, we focus on sandstone reservoir analogs in the lacustrine deltaic “Sunnyside Facies” in the Nine Mile Canyon and Argyle Canyon area of the southwestern Uinta basin northeast of Price, Utah.

Mixed sandstone-mudstone successions in around the intersection of Argyle Canyon and Nine Mile Canyon were deposited in the Sunnyside Delta Facies of the Green River Formation. This interval consists of relatively coarse strata deposited in a fluvially-dominated delta that was fed by river systems flowing northward and westward off of Laramide uplifts and remnant topography in the Sevier fold-thrust belt. The Sunnyside delta prograded over north- and eastward into the lacustrine depocenter of the Uinta basin, until expansion of lake Uinta drowned the deltaic facies in the area east of Price.

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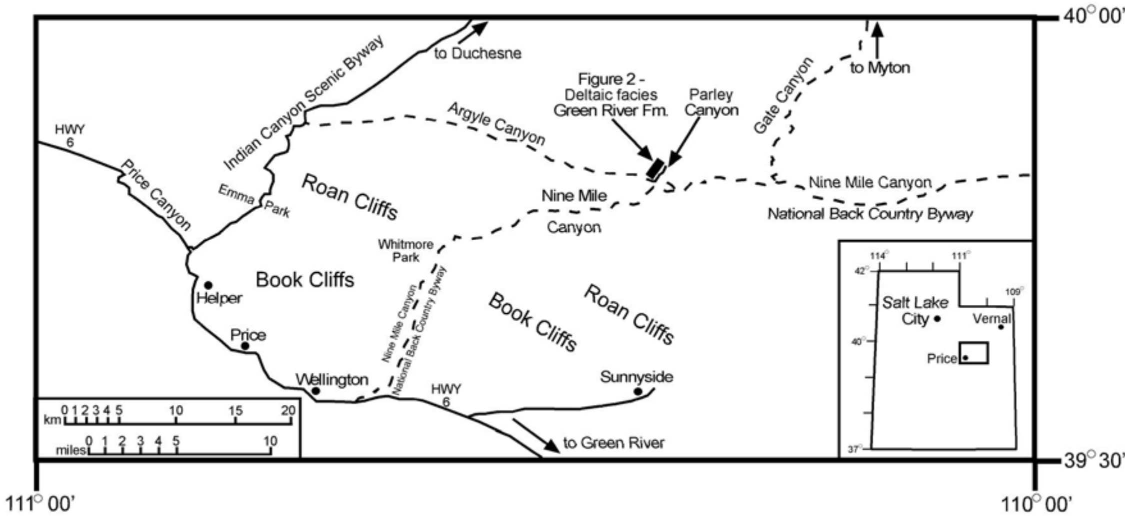

Figure 1. Location map of the Argyle Canyon – Nine Mile Canyon study area east of Price, Utah. Location of Figure 2 in Parley Canyon is shown.

In the area and interval of interest, sandstone was deposited in deltaic sub-environments, including distributary channel and distributary mouth bars, and shallow lacustrine sand sheets. These sand-rich lithosomes are interbedded with offshore lacustrine mudstone and limestone and inter-distributary mudstone. Distributary channel lithosomes occur at either the top of shoaling-upward sequences that represent delta lobe progradation, or incising offshore mudstone, indicating rapid base-level drop. The distributary channel sandstone lithosomes are lenticular over meters to 200 m laterally, and may be either isolated within mudstone or amalgamated vertically and laterally with other sand-rich lithosomes. Individual distributary channel sequences are 2-11 m thick, and, when amalgamated with other sand-rich lithosomes, can yield sections of continuous sandstone up to 15 m thick. Internally, distributary channel facies are characterized by erosional bedding contacts, common occurrence of rip-up clasts, trough cross-stratification, planar lamination, and macroform accretion sets. Distributary mouth bar facies commonly occur beneath distributary channel lithosomes, or as isolated sheets or ribbons encased in offshore lacustrine mudstone. These sheets and ribbons can be traced laterally up to 250 m and range from 2 m to 10 m thick and consist of cross-stratified or rippled sandstone, commonly with down-stream dipping accretion sets and non-erosive basal contacts. Shallow lacustrine sand sheets consist of laterally continuous sandstone beds, commonly less than 50 cm thick, that are composed of graded or rippled sandstone, with a large component of detrital mud and rip-up clasts. These are interpreted to have been deposited primarily be the remobilization of sand during storm or flood events. Of the three sand-rich lithosomes, the distributary mouth bar facies has the highest porosity, followed closely by the distributary channel facies. The shallow lacustrine sandstone has relatively low porosity, and a high component of detrital mud and pseudomatrix, suggesting poor petrophysical properties relative to the other two sand-rich facies.

In addition to the petrophysical characteristics of the lacustrine sandstone, reservoir quality is influenced strongly by the geometry and internal heterogeneity of the sand-rich lithosomes. Internal to the lithosomes, potential baffles or barriers to fluid flow include macroform accretions sets, particularly when mantled by mud clasts or covered by mud drapes, discontinuous mud horizons, and mudchip horizons that occur as lags or along the tops of beds. At the scale of the lithosomes, the lateral and vertical dimensions of each unit, the degree of amalgamation, and the spatial stacking pattern controls the volume and connectivity of reservoir-quality lithosomes. The distributary channel and distributary mouth bar facies have the greatest vertical thickness of sandstone, and similar lateral continuity. Because the distributary channel lithosome has erosive basal contacts, the degree of incision of channel bases into underlying or laterally-associated bar and channel facies controls the connectivity of the better sand-rich lithosomes. These geological attributes are documented deterministically with measured sections and outcrop maps on 2D photomosaics and 3D outcrop models constructed by ground-based LIDAR outcrop scanning.

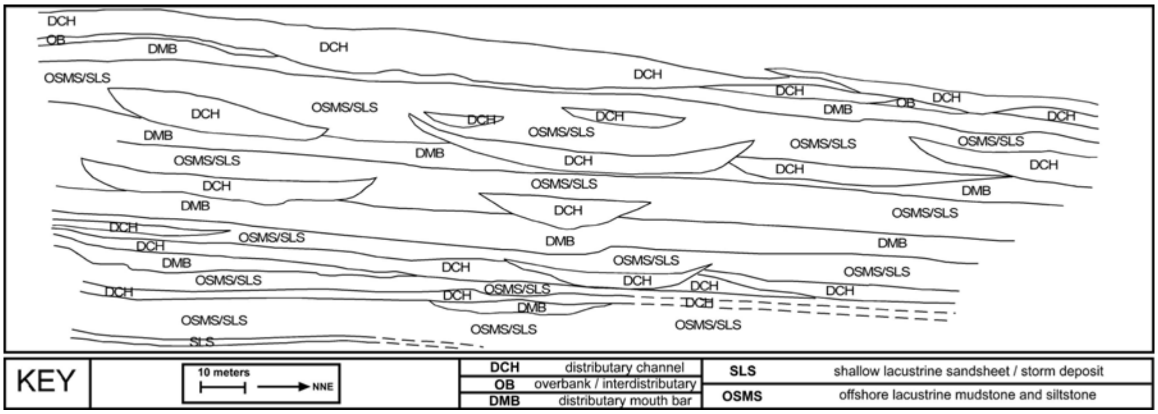

Figure 2. Two-dimensional outcrop map of the interval of interest in Parley Canyon. Location of figure is shown in Figure 1.

Simulation of reservoir analog sandstone lithosomes in the study area was designed to investigate the effects that geometry, stacking, amalgamation and heterogeneity of channelized reservoirs have on fluid flow. Fluid flow simulation was completed using the IMEX black oil simulation software, using geological parameters derived from deterministic mapping of the outcrop area and petrophysical properties from producing fields elsewhere in the Green River Formation of the Uinta basin. Lithosome-scale channel properties found to influence reservoir performance include number of channels, sinuosity, and channel overlap. Greater channel concentration, higher channel sinuosity and channel overlap all correlate to higher production rate, greater cumulative production, and improved production efficiency. Predictably, these results indicate that, because distributary channels are erosive elements that link sandstone compartments, the greater the concentration of channel lithosomes and the greater the number of intersections between them, the better the performance of lacustrine deltaic reservoirs. Internally, lower reservoir anisotropy, and greater interlayer transmissibility correlates to better reservoir performance. Thus, reservoir elements with fewer internal flow barriers, such as mud-draped accretion surfaces, represent better reservoirs.

Continuing studies of the Sunnyside delta facies of the Green River Formation is seeking to construct a working 3D reservoir model that spans multiple canyons near the Argyle Canyon – Nine Mile Canyon intersection. Such a model will improve documentation of the 3D geometry and heterogeneity of this reservoir type, and provide a base for the quantitative investigation of other types of reservoir heterogeneity and compartmentalization on lacustrine reservoirs.