Deciphering Fluid Flow and Mass Transfer in a Carbonate Reservoir

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Although detailed stratigraphic investigations have elucidated many aspects of carbonate reservoirs, reservoir-scale fluid flow and mass transfer have seldom been characterized. These processes produce reservoir-scale porosity heterogeneity. This study quantifies the degree of intergranular pressure solution, measures percentages of cements, and analyzes trace elements and stable isotope compositions of cements and grains to unravel fluid flow and mass transfer of the Upper Jurassic Smackover Formation grainstones at Black Creek Field, Mississippi. This investigation relates preferential cementation and pressure solution to complex patterns of reservoir-scale fluid flow and mass transfer of idssolved calcium carbonate.

Marine diagenesis of the reservoir was limited to a few marine-cemented hardgrounds, leading to minor porosity occlusion. Bulk carbonate $\delta^{13}C$, $\delta^{18}O$, and Sr compositions reveal paleo-vadose, paleo-meteoric lens, and paleo-mixing zones. Meteoric cementation was limited to minor meniscus cement. The porous and permeable reservoir entered burial realm with constituent grains stabilized to low Mg-calcite. There, organic-inorganic interactions resulted in three distinct stages of burial diagenesis. Pre-oil window diagenesis was dominated by pre-bitumen calcite cement. Oil window diagenesis was characterized by precipitation of saddle dolomite and anhydrite. Gas window diagenesis was dominated by anhydrite dissolution and post-bitumen calcite cementation.

Although burial processes reduced intergranular porosity of these ooid grainstones from an original value of 40% to the present value 0%, the degree of intergranular pressure solution and cementation was not uniform throughout the grainstone. Fine-grained intervals at the top of the reservoir experienced high degrees of intergranular pressure solution and contain only small amounts of cement. Coarse-grained intervals containing abundant cement and low degrees of pressure solution occur in the middle and basal parts of the reservoir. Fine-grained samples acted as sources of calcium carbonate and coarse-grained ones as sinks.

Evaluation of several fluid flow models suggests that mass transfer of pressure solution-generated calcium carbonate from the top of the unit to precipitation sites in the middle and basal parts of the reservoir could have occurred by a non-Rayleigh type convection cell. Due to calcite's reverse solubility with respect to temperature, the cooling, upward-moving limb of the convection cell would become progressively more undersaturated, and hence able to transport more dissolved calcium carbonte released by intergranular pressure solution in the upper portion of the reservoir. Pore fluids descending in the downward-moving limb of the cell would become progressively more supersaturated, and calcium carbonate would tend to precipitate as cement in the middle and basal parts of the reservoir as fluids become progressively hotter.

The study indicates that quantitative analysis of cementation, pressure solution, and porosity variation of carbonate reservoirs can reveal reservoir-scale fluid flow and mass transfer mechanisms.