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Structural Heterogeneities and Paleo-Fluid Flow in an Analog Sandstone Reservoir

Structural heterogeneities can both retard and enhance fluid-flow in reservoirs and aquifers. Optimal resource management thus depends on properly accounting for these effects. We present an integrated program of field, laboratory and numerical modeling studies of the Aztec Sandstone at the Valley of Fire, Nevada, which offers exceptional exposures of deformation bands, joints, faults and diagenetic alteration patterns in an exhumed sandstone reservoir/aquifer.

Extensive arrays of compactive deformation bands comprise the oldest structural fabric present. We calculate that these can induce bulk permeability reductions and anisotropies of up to two orders of magnitude. Individual bands—thin, tabular features of localized pore-loss compaction—can be modeled as brittle, elastic "anti-cracks" that interact to form systematic patterns. Joint arrays and joint-based strike-slip-faults formed later at length scales ranging from meters to kilometers. The faults, formed by progressive linkage of joints via shearing, can cause up to three-order-of-magnitude reductions in fault-normal permeability and one-order-of-magnitude increases in fault-parallel permeability. We propose a model for the geometric evolution of these fault networks based on splay fracture kink angles. To assess the cumulative impact of these structural heterogeneities on fluid flow, we infer paleo-flow directions and conditions from patterns of diagenetic alteration, such as reduction-front shapes, in this hematite-cemented sandstone.

This integrated approach enables us to quantify the magnitudes, scales and patterns of paleo-flow effects induced by a complex suite of structures, and provides a rigorous framework for extrapolating similar structural geometries and hydraulic properties into active reservoirs based on sparse subsurface data.