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Relating tortuosity and permeability in tightly cemented and fractured sandstone

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Permeability estimates are important to any subsurface flow prediction. Although permeability estimates exist for formations that can be modeled as packings of spherical grains, models to estimate permeability in fractures formations are limited. In this study, we focus on correlating permeability with geometric tortuosity of both the pore space and individual fluid phases for Torridonian sandstone, a Precambrian lithic sandstone from the Late Proterozoic Torridon Group in the foreland of the Moine Thrust Belt, NW Scotland. We consider this sandstone an outcrop analog for tight fractured sandstone reservoirs. Fractures of the Torridonian sandstone are frequently partially cemented with quartz lining the fracture walls and creating a complex fracture porosity geometry. We use a combination of lattice-Boltzmann simulation and the level set method based progressive-quasistatic (LSMPQS) algorithm to characterize the capillary dominated flow properties (capillary pressure-saturation and relative permeability-saturation relationships) of the matrix and fracture. At the same time, we use image analysis tools to characterize the connectivity and tortuosity of the pore space, as well as individual fluid phases at different saturations.

Tortuosity distributions in the Torridonian sample were observed to vary when compared to samples from unfractured formations. Fractures provide the most direct path across the sample (when aligned) and have the narrowest tortuosity distribution, followed by granular packings. Consolidated media and carbonate samples have the widest distribution. The higher the amount of rock cementing material, carbonate or quartz overgrowth, the higher tortuosity (and ultimately the fluid retention time) in both consolidated porous media and partially cemented fractures. When analyzing tortuosity of different fluid phases in the matrix, we observe the non-wetting phase as being more tortuous than the wetting phase. This behavior is reversed, however, for flow between fracture and matrix if they behave as a connected system.

Keywords: Fractures, Lattice-Boltzmann, permeability, tortuosity, tight sandstone reservoirs.