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SEM image-constrained process-based modeling for relative permeability estimation of carbonate-rich mudrock

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Abstract. Here we present a digital rock physics approach to estimating the hydrocarbon-water relative permeability of carbonate-rich mudrocks. Bench-scale ‘plug’ steady-state relative permeability measurement of mudrocks (i.e. lithologies with sub-microdary permeability) typically requires weeks to months to reach convergence which limits the number of measurements available, while providing limited information of the fluid distribution (i.e. a ‘black box’ type issue). We investigate the relative permeability of oil-water flow in a carbonate-rich lithology from the Eagle Ford formation in southeast Texas using a digital rock physics approach. We utilize high-resolution large-area SEM image mosaics to collect bulk measurements of porosity, primary porosity, and porous solid bitumen (PSB) volume fraction, as well as pore size and shape distributions of the primary porosity (grain-scale) and porous solid bitumen (PSB-scale). These measurements are used to constrain process-based primary porosity (grain-scale) and PSB-scale three-dimensional models pore space. The distribution of PSB in the primary pore space, as well as the absolute and relative permeability of the pore space models were measured using pore-scale lattice Boltzmann methods (LBM). The primary porosity measured from SEM images is estimated by the grain-scale models to be well connected. For the primary porosity, and PSB volume fractions measured from SEM images the grain-scale models estimate the primary porosity to be obstructed by the PSB, therefore pore connectivity (at SEM resolution: ~5-10 nm pores, 1-3 nm pixel side-length) would require a connected path through the pores in the PSB. The porosity of the PSB falls below the percolation threshold of the PSB pore models. The pores of the SEM images are not estimated to be connected by the process-based models; however, it can be speculated that there is a connected molecular-scale pore network that exists below the resolution of the SEM images. Considering our ‘large-area’ images are approximately the size of the cross-section of a human hair, we explore the hydrocarbon-water permeability of the imaged lithology without PSB. The models predict a permeability jail for water saturations between 0.42 and 0.85, 0.46 and 0.76, 0.55 and 0.67 for primary porosity of 11.7, 14.5, 17.7%, respectively.