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Upscaling of Relative Permeability on a Laminated Sandstone after Pore-scale Rock-typing Using Minkowski Functionals

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Relative permeability is an essential parameter to describe flow and transport in porous media, which is a vital process throughout various underground engineering and environmental projects. Traditional laboratory measurements for two-phase flow in rock samples are rather time-consuming and financially expensive. Digital physical analysis, on the other hand, provides a convenient alternative with the assist of advanced X-ray imaging technology. Nevertheless, limited by computational resources, pore-scale numerical simulations are normally conducted on a homogeneous cubic digital sample with a side length of a few hundred voxels. For a highly resolved image, the physical size may even be smaller than a cubic millimeter, which is inadequate to serve practical purposes. Hence, upscaling of pore-scale numerical simulation to continuum scale has attracted extensive interest, which is challenged by severe structural heterogeneity of reservoir rock and the limitations on imaging and computational aspects. Towards the issue, we offer a novel approach of pore-scale rock-typing and relative permeability upscaling. Integral geometry is applied on a 3D segmented tomogram of a laminated sandstone to compute regional Minkowski measures of volume, surface area, the integral of mean curvature and the integral of total curvature. The feature maps are then utilized for the recognition of relatively homogeneous regions/pore-scale rock-types through Support Vector Machine method. A few subsamples are then extracted from each rock-type to compute the representative capillary pressure and relative permeability curves using Pore Network Model, which are assigned back to corresponding regions of the rock-type distribution map before fast upscaling of the whole image applying van Genuchten model. The upscaling results are then compared with full-scale computation on the original tomogram. The excellent agreement has indicated great potential of this approach to bridge the gap between pore-scale and continuum-scale two-phase flow research under the guarantee of accuracy and computational efficiency.

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