4-D permeability in a gas shale: when 10 nm voxels are too large

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Reactive-transport models used to study the nano-to pore-scale geochemistry of shales and mudrocks must satisfy a number of demanding requirements. Two of these are verisimilitude—being sufficiently similar to real rocks, and spatial resolution—capturing the surfaces and flow pathways found in nanoporous Earth materials.

One common method used to populate grid-based models is to translate high-resolution imagery directly into binary maps of void and non-void space. Such efforts have yielded much progress in recent years, but continue to suffer from the inability of most imagery to map the flow pathways between clay folia and other nanoscale objects.

This gas shale study therefore employs an alternative workflow. The base dataset is a series of images acquired with a Helios dual-beam FIB/SEM at Thermo-Fisher Electron Microscopy, from a sample of a Utica Shale core stored at the Ohio Geological Survey Core Repository. The images show BSE intensity at 2 keV accelerating voltage, revealing both pores and minerals at a voxel size of 10x10x10 nm. Even the industry-leading resolution and signal to noise ratio of this dataset, however, cannot visualize the spaces between clay folia that dominate potential flow pathways between porous, gas-forming organic matter (OM) in this formation.

Using image greyscale value, local greyscale anisotropy tensor, and local greyscale variability, a quaternary map of non-clay matrix (a), non-porous OM (b), open pores (c), and clay folia (d) is generated. A map of high permeability connectedness is created by running a burning algorthm on the binary map formed of open pores versus everything else. A map of low-permeability connectedness is created using the same method on the binary formed by combining phases a and b, and c and d. Regions accessible only through clay folia are mapped by subtracting the first map from the second.

The organic matter is then progressively removed from the volume, beginning immediately around a model fracture, to simulate chemical dissolution (as with CO_2) or thermal bake-off of local hydrocarbons, and the above workflow repeated. The permeability of clay folia made accessible in this way is calculated using data from neutron scattering and other techniques. The end result is a 4-dimensional video of sub-image-scale local permeability evolution in the near-fracture zone of an unconventional hyocarbon reservoir.