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Understanding fluid transport through the multiscale pore network of a natural shale

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Natural shales have a complex pore structure, which is only partly understood today. In the present contribution, a combination of different techniques is used to get information on three different scales. On each scale, the relevant flow equation is solved and provides input for the flow equation of the next higher scale.

More precisely, micro-CT, FIB/SEM (Focused Ion Beam/Scanning Electron Microscopy) and TEM (Transmission Electron Microscopy) provide a full representative 3D pore space on the macroscopic scale, the mesoscale and the nanoscale. The corresponding typical voxel sizes are 0.7 [U+F06D]m, 10 nm and 1 nm, respectively. The porosity on the micro-CT images is 0.5 %, and it is not connected. One can distinguish between the pores, the porous clay matrix and non porous minerals; the volume percentages of these last two phases are 0.6 and 0.395, respectively.
Samples of the porous clay matrix were analyzed by FIB/SEM which yields 3D information. They have a porosity ranging from 2 to 6 %. In some of them, the pore space is connected. Finally, TEM provides 2D images with a porosity of about 10 to 25 %.

These information were used in the following way to estimate the macroscopic permeability which has been measured independently and found equal to 6 x10-20 m2. At the nanoscopic scale analyzed by 2D TEM, in the absence of 3D images, the pore structure
is reconstructed by using a technique based on truncated Gaussian fields. Then, the Stokes equations are solved by using a 3D Lattice Boltzmann method. The resulting velocity field is averaged and this provides the permeability K_n. The permeability of the nanoscale structure varies between 0.7x 10-20 and 1.8x10-19 m2. As expected, the material is anisotropic.

At the mesoscale, percolation of the FIB/SEM pore volume occurs only along a single direction. The Stokes equations are again solved by the same method and the mesoscopic permeability K_m varies between 3.3 10-20 and 1.20 10-18 m2, depending on the nature of the percolating volume.

The influence of the nanoscale porosity on the mesoscopic permeability is also studied. Two examples show that despite the scale ratio between the mesoscopic and nanoscopic pores, the nanoscopic pore structure cannot be neglected to estimate the permeability of the pore clay matrix.

Finally, the sample provided by micro-CT is considered as a porous medium composed of three phases with permeabilities 0 (for the non porous minerals), 1 (for the porous clay matrix) and infinity (for the macroscopic pores). The overall permeability Kmacro is obtained by solving the Darcy's equation with a variable local permeability with spatially periodic boundary conditions. Kmacro is found of the order of 0.4 and the medium is relatively isotropic on this scale. This estimation of Kmacro is in agreement with the measured value.