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Geometrical and transport properties of Bentheimer sandstone under deformation

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During industrial, geoscientific or environmental drilling campaigns, rock samples are often extracted few km below surface under large pressures p and their in situ properties may significantly differ from the ones measured in the lab close to atmospheric pressure p_a. Our first objective is to derive from measurements made at p_a the geometric and transport properties at p.

In petroleum industry, during production, the vertical effective stress in the reservoir increases as the pore pressure decreases from few hundreds to few tens bar; in average the horizontal effective stress increases as well, but at a lower rate along an oedometric path, favoring shear stress and reservoir depletion; a complex geology induces locally a variety of stress paths between the two extreme hydrostatic and uniaxial paths. For storage, CO2 might be injected into deep geological formations; such a re-injection will decrease the effective stress. Therefore, our second objective is to test numerically the sensitivity of transport properties to stress path.

The methodology can be summarized as follows. First, the rock geometry on the pore scale is obtained by microtomography. The major geometric characteristics are derived by extracting the pore skeleton. Second, the sample is submitted to hydrostatic, oedometric or uniaxial deformations. Then, the permeability K is derived by routines based on finite volume discretization operating on cubic or on unstructured tetrahedral elements.

This methodology is applied to a real Bentheimer sandstone of porosity E close to 0.23-0.24. It is binarized with 500^3 and 1000^3 voxels equal to 6 and 3 microns. E, the correlation function, the specific area, the hydraulic radius, the skeleton and the percolation properties of the pore space are calculated.

The influence of various boundary conditions on K in the uncompressed sample is studied; K is slightly anisotropic.

Then, the sample is submitted to the overall deformations and the influence of the loading path analyzed; two deformations of 1% were successively applied and their results compared to a single step of 2%; results were practically identical. During deformation, the relative volume changes in the solid and pore space are of the same order of magnitude. The relative variation of E is -1.20e for hydrostatic and oedometric compressions, and -1.28e for uniaxial compression where e is the trace of the mean strain tensor.

During deformation K [Darcy] can be approximated by power laws, 1164 epsilon^{4.13} for hydrostatic, 709 \epsilon^{3.79} for oedometric and 2005 \epsilon^{4.49} for uniaxial compressions, respectively.

The numerical results were compared to lab data. Bentheimer samples were compressed according to different stress paths while K is measured. Due to frictional end-effects, standard permeability measurements on full sample length can be seriously affected leading to an underestimation of K and erroneous evolutions. Numerical results for K and evolutions are more compatible with improved measurements on an intermediate length using local pore fluid samplers.