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Porous Rocks with Fluids: Seismic and Transport Properties

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Objectives: In this study we develop techniques for simulating viscous fluid flow in realistic pore space of sedimentary rock. These algorithms are combined in a Virtual Rock Physics Laboratory (VRL) that is used to simulate rock elastic and transport properties depending on the diagenetic process that is responsible for the pore space topology (specifically, cementation and sorting). This effort continues our past research in numerical rock physics. The ultimate reason for the proposed effort is to predict permeability by altering the pore space consistent with spatial variations of porosity, grain sorting, and diagenesis.

Project Description: Porosity and permeability are sediment properties most relevant to petroleum industry and environmental applications. A 3D space occupied by porous rock is represented by a three-dimensional matrix of zeros and ones where zeros are for the pores and ones are for the solid. We combine new efficient algorithms of simulating viscous fluid flow (Lattice-Boltzmann method), with various pore-filling schemes to explore how various diagenetic pore-altering mechanisms affect rock elastic and transport properties. We compare the numerical results with existing empirical relations and data sets.

Results: We have conducted initial numerical experiments on a medium-porosity coarse-grained sandstone sample. The sample was CT-scanned (the UT Austin facility). The variation in color intensity reflects variations in density. Because of the large density contrast between the mineral phase and the pore space (even where the pore space is filled with epoxy), it is straightforward to convert a CT image into a 3D binary pore space representation in the computer.

The sandstone sample is a moderately well-sorted sand with average grain size of 0.68 mm. The core was 20 mm in diameter and approximately 9 mm in length. The sample is 99.7 % sand size and consists of quartz, and has 0.3 % silt size particles (clay minerals).

The 3D pore space was numerically altered to represent, e.g., a uniform deposition of cement on the surface of the grains. Fluid flow simulation was carried out within the complex realistic pore geometry using the Lattice-Boltzmann method. From the sample size and fluid flux, it was possible to numerically estimate the permeability. The permeability was calculated as a function of diagenesis and grain sorting. The permeability from the numerical experiments was found to match the values physically measured on the prototype sample.

The measured permeability for this sandstone is 5699 mD, whereas computation of permeability on the 3-D pore geometry from CT scan produced permeability of 3300-9600 mD, depending on CT-scan resolution. We also used two of the 2D slice images from the CT-scanning and applied indicator geostatistics to simulate 3D digital rocks (Figure 5). The output, 3D reconstruction of a digital rock, reproduces porosity of the input, a 2D binary image. The permeability computed on the 3D digital rock built from 2D image with porosity of 16 % was 3560 mD. The permeability for the digital rock built from 2D image with porosity of 21 % was 7520 mD. The porosity of the actual sample was 20 % and therefore the second image was better suited to model permeability of this sample using statistical simulation. Choosing the correct input --2D image with porosity that reflects the overall porosity of the rock sample-- is an important step for this particular method of creating pore topology. In general, permeability of (a) actual sandstone sample (5699 mD), (b) CT-scan generated 3D digital rock (3300-9600 mD) and (c) statistically simulated 3D digital rock (3560 mD, 7520 mD) all corresponded well.

We have started preparing high-porosity sand prototypes. The sample made of well-sorted grains stabilized by epoxy has been CT scanned. The image clearly shows the sand grains that stand out of the pore space partly filled with epoxy.

The ultimate reason for the proposed effort is to link permeability to deposition and diagenesis, which can be estimated from seismic via rock physics. This approach will lead us to estimating permeability from seismic and also forward modeling permeability depending on the burial history.