Computational Rock Physics

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Description: Earth sciences is undergoing a gradual but massive shift from description of the earth and earth systems, toward process modeling, simulation, and process visualization. This undertaking is challenging because the underlying physical and chemical processes are often nonlinear and coupled. In addition, many processes occur in strongly heterogeneous systems. An example is two-phase fluid flow in rocks, which is a nonlinear, coupled and time-dependent problem and occurs in complex porous media. To understand and simulate these complex processes, the knowledge of underlying pore-scale processes is essential. This research project focuses on building physical property simulators in realistic pore microstructures. These pore-scale simulators, such as fluid flow, elastic, electrical and NMR property simulators, are modules of a computational rock physics framework (Figure 1), which is a new paradigm of quantitative models for coupled, nonlinear, transient and complex behavior of earth systems. This computational environment can significantly complement the physical laboratory, with several distinct advantages: (1) rigorous prediction of the physical properties; (2) interrelations among the different rock properties in a given pore geometry; and (3) simulation of dynamic problems with coupled and nonlinear physical processes.

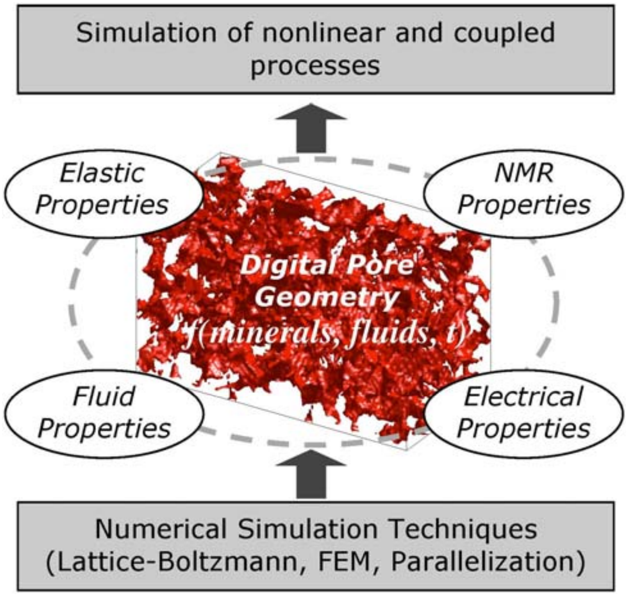

Figure 1. Computational Rock Physics Framework.

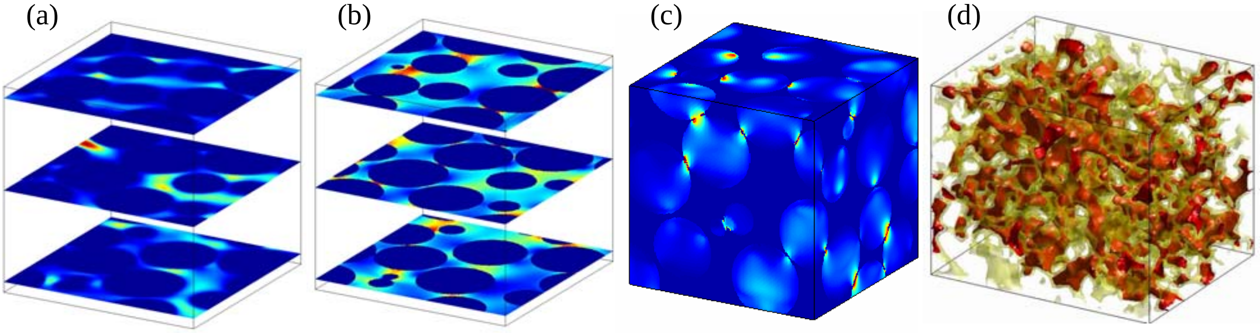

Figure 2. Pore-scale simulation results: (a) fluid velocity; (b) electrical current; (c) local stress concentration; and (d) two fluids (red-nonwetting/green-wetting) from 2-phase flow simulation.

A rigorous pore-scale simulator requires three important traits: reliability, efficiency, and ability to handle complex micro-geometry. We have implemented single-phase and two-phase flow simulators using the Lattice-Boltzmann (LB) algorithm, since it handles very complex pore geometries without idealization of the pore space. Parallel single-phase and two-phase flow simulators have been also implemented for fast and accurate calculation of fluid flow properties of rocks. Finite-element method (FEM) is used for elastic and electrical property simulators, and a random-walk technique is used for NMR simulation (Figure 2).

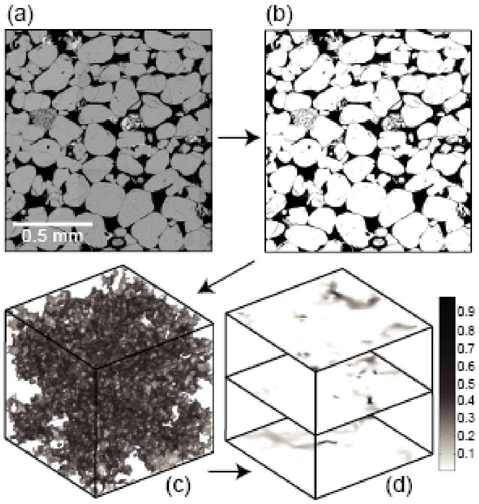

Figure 3. Permeability estimation from thin sections. (a) thin section, (b) binary image, (c) stochastically reconstructed 3D, (d) flow simulation results.

Permeability estimation from thin sections consists of two components – stochastic 3D porous media reconstruction, and flow simulation using the LB method (Figure 3). This technique successfully predicted the permeability of several sandstones samples. We have used a sequential indicator simulation technique with porosity and the two point correlation function; currently, we are working on using higher statistics, such as multipoint correlation functions and pattern simulations. We are also pursuing this technique for relative permeability estimation.

The diagenesis modeling is a basic framework for quantifying trends of physical properties for a given diagenetic process (Figure 4). The immediate application of this method will be incorporating more realistic diagenetic mechanisms, such as chemical deposition and dissolution, by altering digital rock samples in the computer, e.g., depositing diagenetic cement, dissolve minerals, or deposit small shale particles. By so doing, geologically-plausible variations in the depositional environment as well as diagenesis can be represented in the computer without having direct access to a multitude of physical samples. The porosity and permeability of the altered samples can be calculated to assess how these properties may vary laterally and vertically in the field. This approach places a computational rock physics lab at the fingertips of a practitioner.

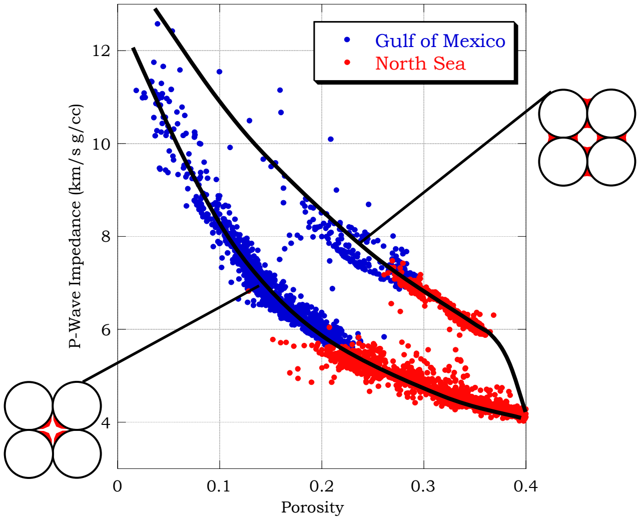

Figure 4. Two typical diagenesis trends and their impact on physical properties of rocks.

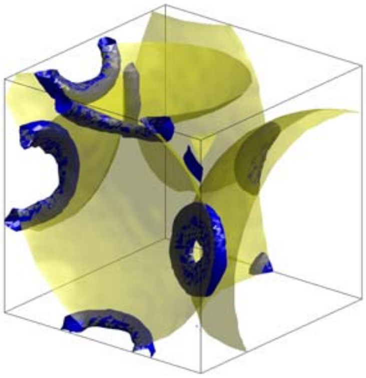

Figure 5. Partial saturation modeling. Yellow surfaces denote grain boundary and blue area denotes partial water saturation. Due to wettability and surface tension, small water saturation forms torus shapes around grain contacts.

For CO_2 sequestration or gas flooding in oil reservoirs, partial saturation of water is of great importance (Figure 5), since it is directly related to the injection and sweeping efficiencies. In addition, the partial water saturation causes changes in rock properties, such as gas permeability and electrical resistivity. We are conducting partial saturation modeling in various scenarios – gas surface area calculation during CO_2 injection in porous media, gas and water percolation in different pore structures, and electrical resistivity changes in different water saturation. These modeling will give us great understandings about what is happening at the pore scale when we deal with CO_2 sequestration and enhanced oil recovery with gas flooding.

Status: This work continues, sponsored by the DOE and Stanford Rock Physics Project.

Publications:

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