Pore-scale Simulation Tools for Understanding and Predicting Physical Properties of Rocks

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The earth sciences are undergoing a gradual but massive shift from *description* of the earth and earth systems, toward *process modeling and simulation*. This shift is very challenging because the underlying physical and chemical processes are often nonlinear and coupled. In addition, we are especially challenged when the processes take place in strongly heterogeneous systems. One example is multiphase fluid flow in rocks, which is a nonlinear, coupled and time-dependent problem and occurs in complex porous systems. To understand and simulate these complex processes, the knowledge of underlying pore-scale processes is essential. To this end, we have initiated computational rock physics to rigorously simulate rock/reservoir properties. The computational rock physics framework is based on digital representations of rocks, which consist of minerals and fluids, and may evolve with time. It also contains modular physical property simulators, with which we directly simulate physical properties of rocks. This computational environment significantly complements the physical laboratory: (1) rigorous prediction of the physical properties, (2) interrelations among the different rock properties using shared digital porous media, and (3) simulation of dynamic problems with multiple physical responses. The primary objective of the framework is building rigorous pore-scale simulators for predicting physical properties of rocks with realistic pore microstructures. We pay special attentions to three aspects in developing the rigorous pore-scale simulators: reliability, efficiency and ability to handle complex micro-geometry.

We have shown results for single-phase and two-phase flow simulations using the Lattice-Boltzmann method in the last meeting. To overcome the long calculation time of flow simulation, we have now implemented efficient parallel flow simulators by creating four optimization techniques customized for the Lattice-Boltzmann algorithm. The optimized two-phase code runs 12 times faster with 14 processors than its serial counterpart, while the generic parallel code is only 4 times faster. With the parallel simulators, we can perform flow simulations on more realistic, complex and bigger pore geometry. Pore-scale simulators for elastic and electrical properties using the finite-element method were also added to the computational rock physics framework. We made extra efforts for the new simulators to handle the same microgeometry used for fluid flow simulations without modification or simplification. The new computational modules were tested against the lab data, and showed very good agreement. These pore-scale simulators give us a better link to reservoir management. We investigated interrelations of physical properties under different diagenesis histories. We found that the relations between electrical conductivity and permeability show very distinct trends in different diagenetic models. Partial saturation was also modeled using the pore-scale simulators, and we will present the results with permeability and electrical conductivity. Diagenesis and partial-saturation modeling showed that the pore-scale simulation environment provides rigorous links to understanding and modeling geological processes.