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TITLE: POROUS ROCKS WITH FLUIDS:
SEISMIC & TRANSPORT PROPERTIES

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VIRTUAL ROCK PHYSICS LABORATORY

We have optimized the numerical Lattice-Boltzmann flow simulation method such that a single run for a 500,000-cell sample takes a few minutes on a laptop PC. This is more than 100-fold acceleration of the previous benchmark. This result allows us to digitally simulate viscous flow in a pore space of any complexity with the turnaround time of just a few minutes. This drastic improvement became possible due to using an implicit representation of the Lattice-Boltzmann equations on a finite grid, which eliminated the need for many convergence iterations required by the explicit method. Then powerful linear solvers have been used to rapidly resolve the implicit system of equations. We have combined this new code with (a) an image processing code that allows the user to highlight and digitize the pore space in a thin section image; and (b) a statistical indicator simulation code that uses the statistical properties of a 2D image to simulate a 3D pore space with the same statistical properties. The combined work flow includes: (a) taking a thin section image with a digital camera; (b) processing the image to highlight the pore space and calculate the first and second statistical moments; (c) recreating a 3D pore space; and (d) conducting a viscous flow numerical experiment and outputting absolute permeability. Several trials on sandstone samples show a good correlation between the calculated and measured permeability. The method can be used to estimate permeability from small chips of rock where intact samples are not available.

The image manipulation tools have been added to this package that include erosion and dilation and also median filtering to remove stand-alone pixels.

We have also created a two-phase Lattice-Boltzmann flow simulation algorithm and successfully used it to produce relative permeability curves of a realistic pore space. The results are encouraging. This method can complement and even replace the costly and time-consuming relative permeability laboratory measurements.

We have also conducted first tests of a newly developed NMR simulation code that show encouraging results.

MEASURING AND MODELING THE ELASTIC PROPERTIES OF GAS HYDRATE AND SEDIMENT CONTAINING GAS HYDRATE.

Natural gas hydrates are nonstoichiometric crystalline solids comprised of a hydrogen bonded water lattice and entrapped guest molecules, predominantly methane. Gas hydrate with methane as the guest species is stable at the pressure and temperature conditions present in the sediments beneath most of the world s continental margins and deep inland seas and also in arctic sediments below the permafrost layer. Enormous amounts of methane are believed to be trapped in nature by hydrates; both in the hydrate crystal structure itself and also in sediments beneath hydrate deposits. This large reservoir of natural gas may be a future energy resource and may play a significant role in global climate change. The formation of melting of gas hydrate also has a strong effect on sub-sea slope stability. Unfortunately, all distribution and hydrate-related methane estimates are very inexact because accurate estimates of the amount of methane hydrate in situ are not currently available on a regional or site specific basis. A remote sensing technique which can accurately assess the amount and distribution of hydrate in natural deposits is needed to improve these distribution and hydrate-related methane estimates.

The best technique for remotely probing sediments several hundred meters below the surface or beneath deep bodies of water is seismic reflection profiling. Interpreting seismic data to deduct the amount of gas hydrate in place requires a relation between the hydrate fraction in the sediments and the elastic properties of the hydrate-sediment composite.

To address this lack of data, we conducted experiments on artificially made methane hydrate. The method used to prepare pure methane hydrate was to fill a holder with water ice, then fill with methane, and gradually increase the temperature above the melting point. Then the resulting porous methane hydrate was compacted to essentially zero porosity. Careful velocity measurements gave very accurate results and, for the first time, the S-wave velocity data in methane hydrate have been obtained. Also, theoretical velocity calculations in methane hydrate have been conducted based on thermodynamics theory. The results appear to be consistent with the experimental data, which gives us confidence in the robustness of the new results.
We have also conducted micro mechanical numerical modeling of gas hydrate generation in a realistic pore space. The template used was a thin section of a sandstone sample. Part of the pore space was filled with gas hydrate and a 3D realization was created. Viscous fluid flow numerical experiments have been conducted on this 3D object to estimate permeability in hydrate-filled reservoir.

PORE PRESSURE PREDICTION.

One of the most important problems in crustal tectonics and reservoir geophysics is pore fluid type and pore pressure prediction. Aside from basic scientific value, overpressure prediction can save billions of dollars of drilling and blowout prevention costs. The traditional way of overpressure prediction from seismic is via P-wave velocity. Typically, abnormally low P-wave velocity corresponds to elevated pore pressure. However, P-wave velocity also depends of pore fluid compressibility, porosity, mineralogy, and other factors.
We have conducted ultrasonic pulse transmission experiments on unconsolidated sands, room-dry and water-saturated in a range of confining and pore pressures. The emphasis has been on very small effective pressure results. The new data allow us to quantitatively approach overpressure estimation in shallow sand/shale sequences and estimate the potential of shallow water flow in deep water sediments.
Also, ultrasonic pulse-transmission experiments have been conducted on sand samples subjected to anisotropic triaxial loading. The new data allows us to quantitatively describe the effect of realistic anisotropic state of stress on the elastic properties of unconsolidated sediments.