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Combining laboratory and computational rock physics

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Summary

Identifying and understanding the physical processes taking place in a reservoir rock is an important step towards a more detailed and accurate characterization of a subsurface hydrocarbon reservoir from a seismic data set, and is the subject of our research. We show that the integration of laboratory studies with numerical modeling is a powerful tool to achieve an unbiased comprehension of the physical processes at different scales. Such integration is demonstrated using examples of two challenges in rock physics, which are subject to ongoing research in The Rock Physics Network at ETH Zurich (Quintal et al., 2011a):

(1) understanding the influence of the rock microstructure on effective elastic properties;

(2) identifying the dominant physical mechanism responsible for intrinsic attenuation in saturated rocks at seismic frequencies.

In the first example, we show how the coupling between laboratory and numerical methods help better understand the effect of the rock microstructure on the effective P-wave velocity. Additionally, this procedure enabled the numerical computations to yield an accurate prediction of the P-wave velocity with confining pressure.

In the second example, we demonstrate that in numerical models a single physical process for seismic wave attenuation can be studied while in the laboratory various processes take place at the same time. This allows better interpret the laboratory results and we show that laboratory or numerical studies alone can lead to misconception or misinterpretation of the obtained results.

Generally, we conclude that a persistent combination of laboratory and numerical methods is essential for successful rock physics research.

(1) Laboratory and Numerical Methodology

Two comparable methods (experimentally and numerically) are used to determine the P-wave velocity, V_P, at 3 MHz in a dry Berea Sandstone, i.e. the pulse-transmission technique. V_P is calculated from the traveltime of a source pulse through the sample and the length of the sample.

Laboratory measurement
Measurements are conducted in a Paterson gas-medium rig (Fig. 3; Burlini et al., 2005) at different confining pressures.

Numerical method
The Berea Sandstone sample is scanned using micro-CT to obtain a 3D rock model (Fig. 1), which is subsequently used in a 3D finite-difference elastodynamic wave-propagation model (Fig. 2; Saenger et al., 2011).

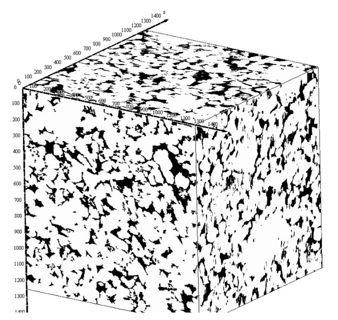
Fig. 1: Micro-CT scan.

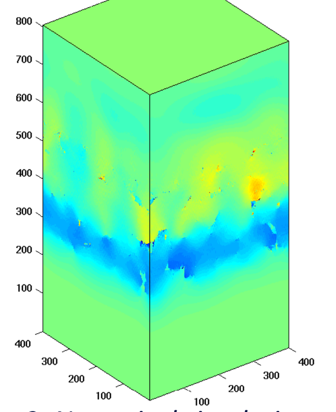
Fig. 2: Numerical simulation.

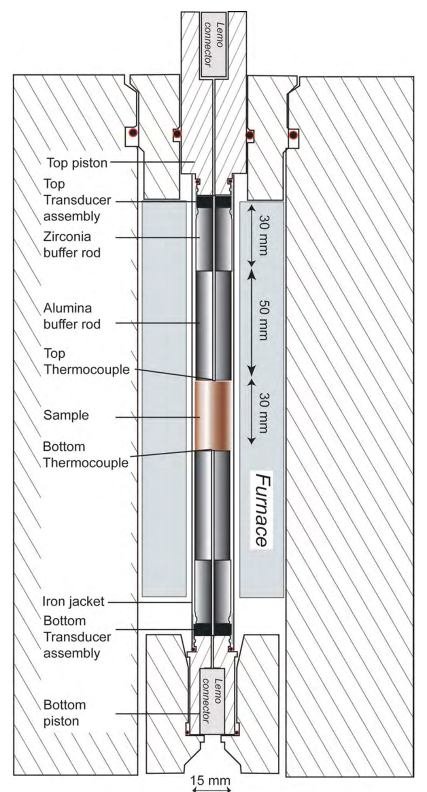

Fig. 3: Sketch of the Paterson rig.

(1) Results and Interpretation

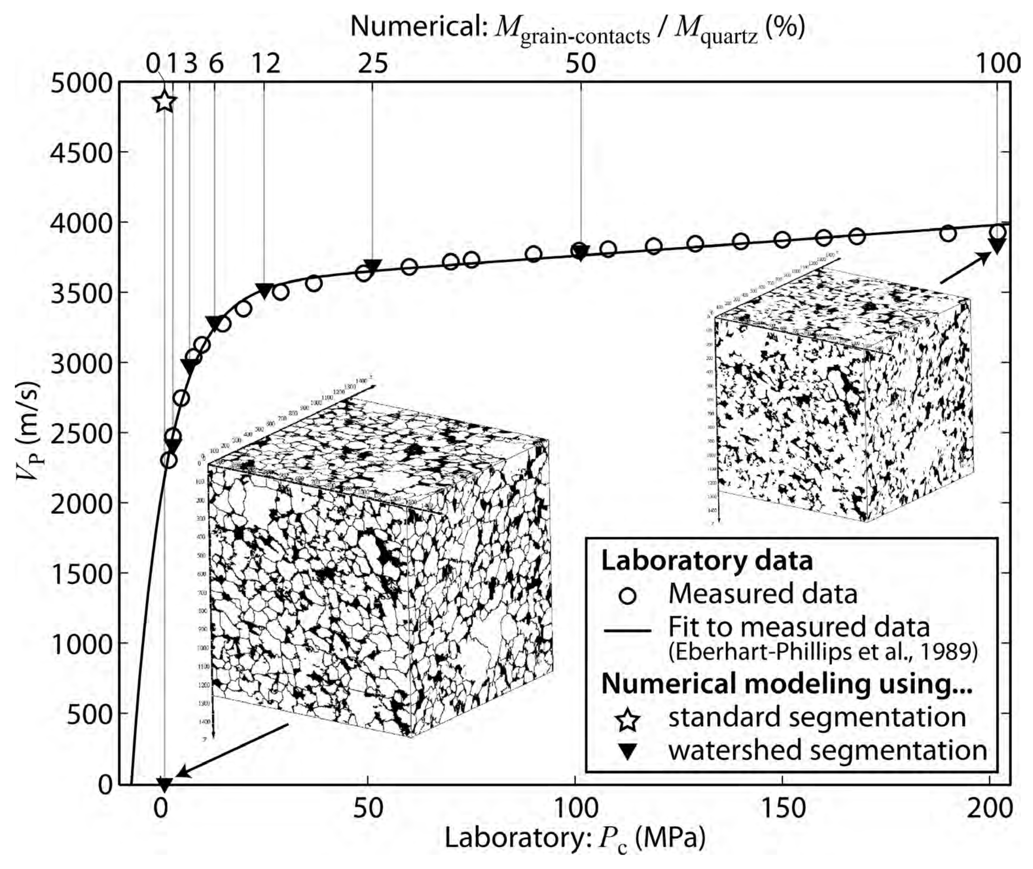

Fig. 4: P-wave velocity, V_P, for varying confining pressure, P_c, and varying grain-contact modulus.

Laboratory results show a pressure-dependent V_P (Fig. 4). Using standard techniques for segmenting the micro-CT data results in a single value for the numerically calculated V_P (star in Fig. 4). However, watershed-segmentation allows identifying grain contacts below the resolution of the micro-CT (Fig. 5). In the simulations, a P-wave modulus, M, between 0 and M_{Quartz} is assigned to this additional phase (top axis in Fig. 4). The resulting numerical V_P-curve is almost identical to the laboratory data after scaling, i.e. $V_{P,lab} \approx a \cdot V_{P,num}$. This procedure allows insight into the effect of the rock microstructure on the seismic properties.

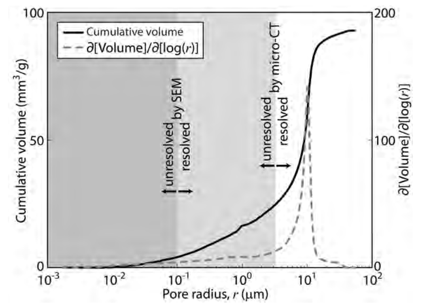
Fig. 5: Mercury-intrusion porosimetry

(2) Laboratory and Numerical Methodology

Laboratory measurement
For measuring attenuation in partially saturated Berea Sandstone, the Broad Band Attenuation Vessel (BBAV; Fig. 6) is used. The self-developed machine delivers accurate bulk attenuation values from 0.1-100 Hz by inducing sub-resonance harmonic excitation on the sample. From the phase shift between stress (input) and strain (output) the quality factor, Q, is determined.

Numerical method
The finite-element method is used to solve Biot's equations for consolidation (Quintal et al., 2011b) in a heterogeneous poroelastic medium representing the laboratory sample. Only one physical mechanism, i.e. wave-induced fluid flow is modeled numerically.

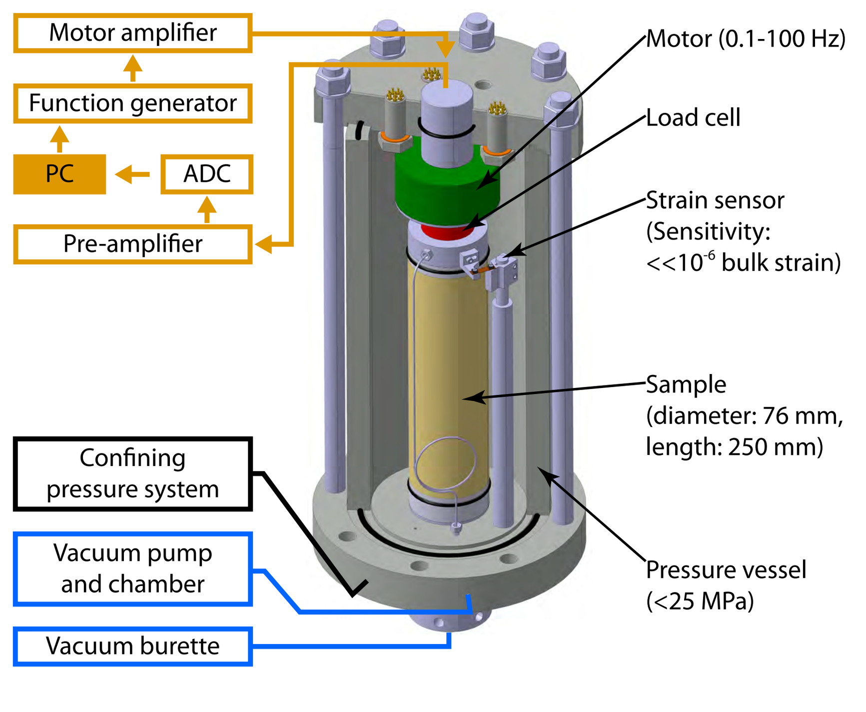

Fig. 6: CAD-drawing of the BBAV.

(2) Results and Interpretation

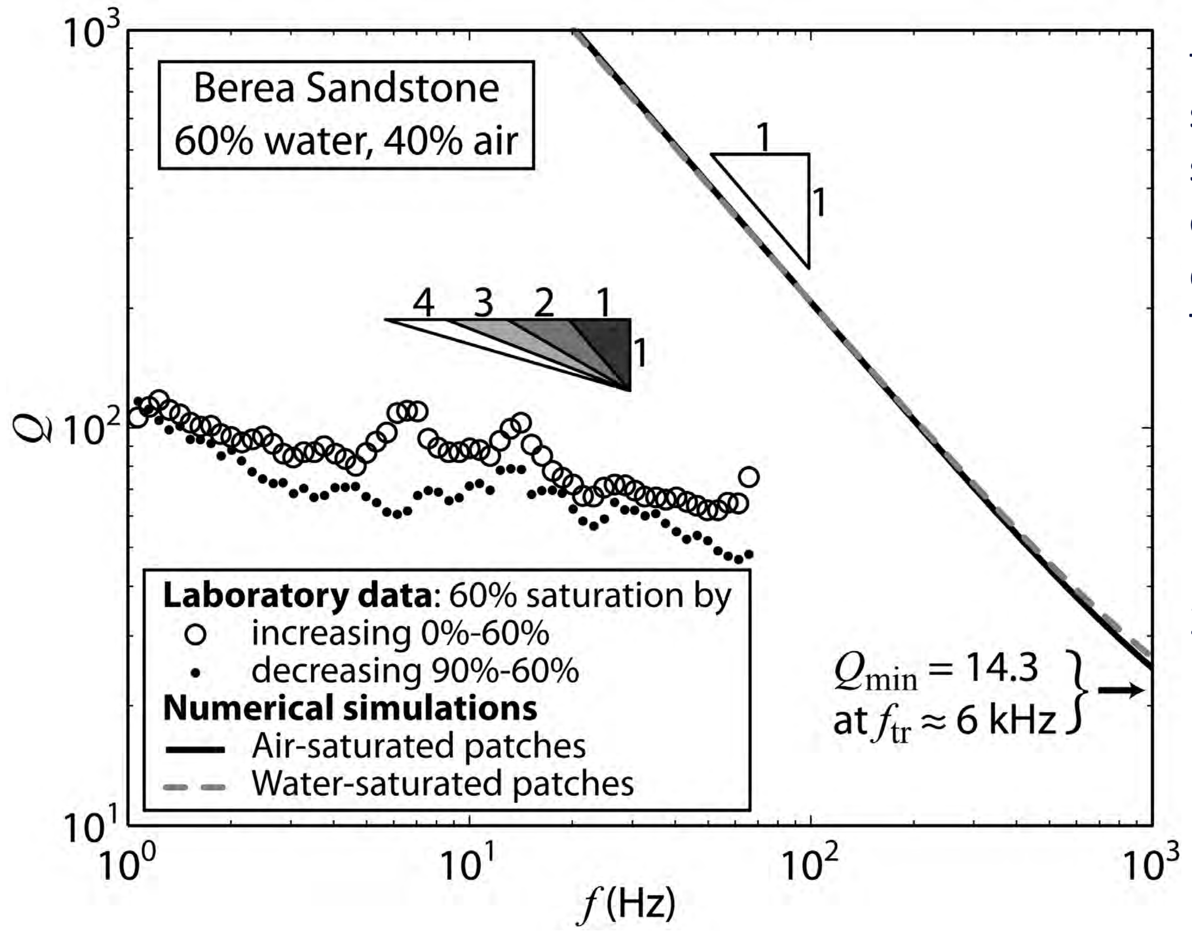

Fig. 7: Laboratory and numerical frequency-dependent attenuation values, Q, for Berea Sandstone 60% saturated with water at ambient pressure.

Two saturation methods were used in the laboratory to obtain 60% water saturation, but both of them give very similar attenuation results (Fig. 7). However, the numerical equivalent is very different from the laboratory results. This mismatch may have two reasons:

1) The assumed distribution of fluids in the numerical model is too simple to represent the real partially saturated situation (Fig. 8).
2) Wave-induced fluid flow is not the major cause of attenuation in the laboratory and other physical processes have to be considered.

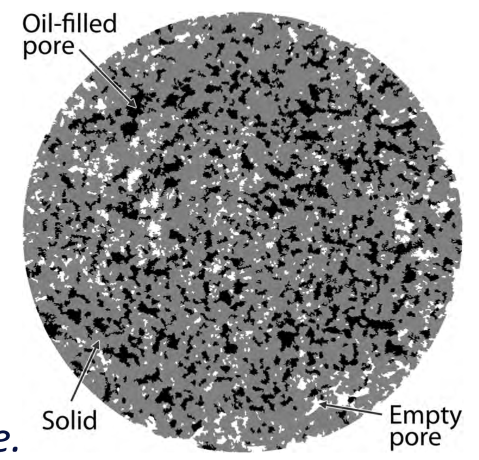

Fig. 8: Micro-CT slice of a partially saturated Berea Sandstone.

Conclusions

We compared rock physical laboratory measurements with computer modeling for two examples.

In the first one, a strategy was presented to identify and investigate the influence of rock microstructure on the propagation of seismic waves.

In the second example, we illustrated how a single physical process can fail to completely explain attenuation measured in the laboratory.

The examples illustrate the advantage of integrating laboratory and computational rock physics.

References
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