Introduction to this special section—Rock physics

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Rock physics addresses the relationship between measurements of elastic parameters made from surface, well, and lab equipment; and intrinsic properties of rocks, such as mineralogy, porosity, and pore shapes; pore fluids; pore pressures; permeability; viscosity; stresses; and overall architecture such as laminations and fractures. Rock physics provides the understanding necessary to optimize all imaging and characterization solutions based on elastic data and was the subject of the SEG Summer Research Workshop held in Galway, Ireland in 2008. This workshop included sessions on laboratory methods, rock physics of reservoir rocks, rock physics of carbonate rock, rock physics of unconventional and fractured reservoirs, mudrock rock physics and pore-pressure prediction, 4D (time-lapse) rock physics, theoretical rock physics and anisotropy, and upscaling and integration. Several presentations from the workshop are available at http://research.seg.org/2008_SRWS_Ireland.htm.

An important goal of rock physics is to help us understand the physical properties of the reservoir. Usually, at the location of a drilled well, we have measurements that give us a good idea of the elastic and physical properties of the subsurface rocks (velocity, density, lithology, porosity, confining stress, pore pressure, saturation, fracturing, etc). However, to understand these properties away from the well, we use the seismic data. Rock physics helps us link these properties to the seismic data and infer the variation of reservoir properties in a lateral or vertical sense. Rock physics today forms an important component of most reservoir characterization studies.

Rock physics developments in the last five decades can be broadly divided into five main areas: (1) laboratory measurements (made on rock samples under different conditions); (2) interpretation of borehole measurements (including well logging and borehole seismic); (3) modeling (theoretical models developed for establishing elastic properties of rocks under appropriate conditions and also upscaling methods to estimate the expected seismic properties from the available reservoir properties); (4) deforming analysis (studies aimed at quantifying the sensitivity of rocks to stress); and (5) seismic reservoir characterization (application of rock physics knowledge to seismic data for characterization of reservoirs).

Interestingly, the papers submitted for this special issue on rock physics cover all of these five areas.

**Laboratory measurements**

Ahmadov et al. (“Confocal laser scanning and atomic-force microscopy in estimation of elastic properties of organic-rich Bazhnov Formation”) demonstrate the use of AFM coupled with CLSM for visualization and identification of the organic-rich shales and for nanoscale elastic-property measurements. Using these tools, the authors successfully image the kerogen within the matrix of Bazhnov Formation and estimate the variation of Young’s modulus and shear and bulk modulus of kerogen using a nanoindentation technique.

Lebedev et al. (“Direct laboratory observation of patchy saturation and its effects on ultrasonic velocities”) discuss measurements of P-wave velocities and rock sample X-ray computer tomography imaging to infer the distribution of water saturation in rock samples. They show that, at low saturation, the velocity-saturation dependence can be described by the Gassmann-Wood relationship. A transition behavior at intermediate saturations depends on the fluid patch arrangement and its size, and in turn is controlled by the injection rate. For large fluid injection rates, the transition from homogeneous to patchy saturation occurs at lower saturation.

In “Digital rock physics: 3D imaging of core material and correlations to acoustic and flow properties,” Knackstedt et al. combine digitized images from 3D X-ray microtomographic imaging with numerical calculations to predict petrophysical properties of core samples from reservoir sands and carbonate samples. While the reservoir sand cores may be homogeneous, the heterogeneous nature of carbonates requires probing oil structures at finer scales (tens of nanometers to centimeters) by methods that the authors describe.

Prasad et al. (“Rock physics of the unconventional”) stress that improvement in exploration and monitoring would lead to results directly related to material properties in situ, which in turn become complex or “unconventional.” In the hope of stimulating discussions on where the technology is headed and what resources would be required to address such challenges, the authors discuss the challenging aspects related to heavy oil and tar sands, organic-rich shales and oil shales, and coals and gas hydrates, and suggest that their analysis techniques would need information usually not associated with “rock physics.”

In “Cracks in porous rocks: Tiny defects, strong effects,” Guéguen et al. report measurements of mechanical behavior, acoustic emission, and elastic wave velocities as a function of applied stress for several rock samples in the laboratory. Very different rocks, such as sandstones, marbles, and shales, show very different acoustic signatures at rupture and have been investigated using these methods. Sandstone compaction is accompanied by the formation of microcracks and accordingly exhibits a clear drop in compressional and shear wave velocity, together with an increase in $V_p/V_s$ ratio (both in dry and wet samples). In the case of shales, the variation in elastic wave anisotropy is partly due to crack-like pores that are very sensitive to mean pressure and to deviatoric stress.

**Interpretation of borehole measurements**

Smith et al. (“Rock properties in low porosity/low permeability sandstones”) focus on the microstructure of the pore
space in low-porosity/low-permeability sandstones and its impact on velocity behavior. Using their core and petrographic observations for tight quartz-rich sandstones, the authors interpret the high variability in compressional velocity and the poor correlation to porosity in these rocks to be the result of highly variable pore geometries and the presence of low-aspect ratio pores and microcracks. On the basis of dipole sonic log data, it is concluded that these microcracks could have preferential alignment, giving rise to velocity anisotropy and a possible manifestation in anisotropic permeability and perhaps resistivity.

In “Lithology and fluid differentiation using rock physics template,” Chi and Han use rock physics templates derived from log data in association with the elastic attributes derived from seismic data to interpret reservoir properties accurately. The authors generate the template by first constructing dry bulk moduli of the rock at zero porosity and determining the Hashin-Shtrikman bounds and fluid substitution using Gassmann’s equation. This rock physics template is then overlain on all crossplots of elastic attributes generated from seismic data in the area.

Modeling
Xu and Payne (“Modeling elastic properties in carbonate rocks”) present a rock physics model for carbonates that includes the effects of both rounded pores and microcracks. The authors show that the pore fluid in microcracks tends to be unrelaxed, at least at ultrasonic frequencies, probably due to the low local permeability. A mixed-mode fluid substitution, assuming the microcracks are isolated while the rest of the pores are perfectly connected, is also a good match between calculated and measured P-wave velocities. The authors also develop a fracture model that handles both fracture anisotropy and shale anisotropy. Application of the model to an East Texas well shows that the use of azimuthal seismic anisotropy for fracture detection is most effective in the case of a single set of fractures.

In “Constrained rock physics modeling,” Dræge proposes a strategy to evaluate numerous rock physics models in an efficient manner. The method finds the best prediction for each model, which makes it easy to see which models are suited for further modeling. The strategy is applied to a data set from the North Sea Brent group. A selection of the rock physics models with optimal input parameters is further tested to evaluate the ability to predict data outside the calibration data set.

Glover (“What is the cementation exponent? A new interpretation”) suggests an interpretation of the cementation factor $m$ appearing in Archie’s laws. Water and oil saturations calculated with Archie’s equations are highly sensitive to the value of the cementation exponent, and the new interpretation proposed by the author may help in understanding the physical meaning of this parameter.

Deformational analysis
Hossain et al. (“Elastic and nonelastic deformation of greensand”) discuss the deformation of a greensand sample from the North Sea using geotechnical compression testing, sonic measurements, and image analysis of backscattered electron micrographs. The authors demonstrate that this method allows the resultant elastic and plastic deformation to be determined. Such information is useful to understand how deformation of the reservoir rock affects hydrocarbon production.

In “Stress sensitivity of sandstones and 4D applications,” Vernik and Hamman refine a popular empirical model for relatively clean sands and sandstones with dry clay content less than 12%, in which the velocity varies in an exponential manner with stress. Using the correlations revealed between the fitting parameters, the creation of rock physics based software to iteratively predict the likely change in dry-compressional and shear-wave velocities as a function of the change in stress is possible. The computed rock frame properties can be used in a fluid substitution routine to model the synthetic seismic response of the reservoir under in-situ stress and saturation conditions.

Seismic reservoir characterization
An interesting observation is discussed by Mukerji et al. in “Cross-property rock physics relations for estimating low-frequency seismic impedance trend from electromagnetic resistivity data.” Normally, for impedance inversion of seismic data, the low-frequency trend (2–10 Hz) is obtained from logs or seismic velocities and added to the inverted traces. The authors suggest that trend can be obtained from the CSEM resistivity data which is typically low resolution using cross-property rock physics relations.

Avseth et al. (“Rock physics estimation of cement volume, sorting, and net-to-gross in North Sea sandstones”) demonstrate an integrated methodology as applied to a North Sea turbidite sandstone case study where two adjacent wells have very different seismic signatures due to local differences in diagenetic and depositional characters. The quantification of geologic difference in terms of quartz cementation, sorting, and net-to-gross helped in predicting the correct fluid in the two wells, which was earlier showing up as counter-intuitive AVO anomalies.

In “Scale of experiment and rock physics trends,” Dvorkin and Nur ask how data obtained on a given sample can be used in the context of remote sensing, which samples a formation at a different scale to that used in the laboratory. The authors show that under certain, possibly limited, circumstances, trends formed by pairs of data points obtained on an internally heterogeneous data set form a trend that is valid over a range of scales. Such a trend is stationary with respect to position and scale, and so can be applied to a remotely-sensed quantity (e.g., porosity) to arrive at another desired property (e.g., permeability) at the scale of practical measurement.

Finally, in the last paper in the special section, “Table of elastic constants for isotropic media,” Smidt presents a table that allows the conversion from one set of rock physics parameters to another.

We thank the authors for their valuable contributions to this special section and hope that the readership of TLE finds the articles both informative and interesting.