Shale Rock Physics, Geomechanics and Petrophysics: a discussion about nothing

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Abstract:

The first part of the talk will explore nothing and its measurement. We will then discuss the common links to nothing as observed in studying physics and mechanics of unconventional reservoir rocks. The discussion will include recent findings on elastic and petrophysical properties. Static and dynamic measures of rock stiffnesses will be compared and used to calculate horizontal stresses. We will also explore permanence and the indications of CO2 storage effects in reservoir and in seal rocks.

Dynamic elastic mechanical properties and transverse anisotropy in shales are used to estimate in-situ stresses and evaluate petrophysical and geophysical data. Typically, these mechanical properties are calculated from measured ultrasonic velocities under simulated in-situ conditions in a laboratory environment. Specifically, compressional and shear velocities are measured in 0°, 45°, and 90° orientation to bedding plane of the particular shale sample. In previous studies, these measurements were made using three-plug-method, which would require coring three independent samples oriented parallel, at 45°, and perpendicular to any alignments in the core. We present here data acquired with a core holder that allowed simultaneous multidirectional ultrasonic compressional and shear velocity measurements on the single 1.5 in. cylindrical core plug under simulated in-situ conditions.

Efficient development of shale (properly called mudrock) reservoirs require systematic studies of their mineral compositions and pore structure and their effects on transport and seismic properties. Static and dynamic moduli as well as horizontal stresses are derived using laboratory-measured VTI stiffness tensors. Using the measured moduli, minimum horizontal stresses are calculated for the dynamic isotropic, dynamic anisotropic, static isotropic, and dynamic anisotropic cases. The difference between the static and dynamic isotropic cases is roughly 15 %, while the anisotropic static and dynamic cases differ by only 5 %. First, we find a general correlation between the Hydrogen Index (HI) of various formations and their corresponding P- and S-wave velocities (Figure 1).
Figure 1. P-wave (black circles) and S-wave (red circles) velocities decrease as Hydrogen Index increases. Note the large scatter in data derived from various formations. The scatter might be due to composition of the framework as well as organic maturity.

The correlation greatly improved within each formation. Thus, Figure 2 shows a much higher goodness of fit for HI – velocity relations in the Bakken (Figure 2a) and the Niobrara (Figure 2b) formations. A comparison of both trends (Figure 2c) shows small but distinct differences.
Figure 1. P-wave (black circles) and S-wave (red circles) velocities decrease as Hydrogen Index (HI) increases. Note the significant reduction in data scatter for each formation. a: Bakken; b: Niobrara. A comparison of the two trends (c) shows that at higher HI, velocity in the Bakken formation can be lower than in the Niobrara formation rocks.

Our results provide an insight into the elastic mechanical behavior and the degree of anisotropy that organic shales may experience under in-situ conditions. Specifically, we find and quantify that the Young’s moduli in the direction parallel to the bedding plane is greater than perpendicular to it. The degree of anisotropy in terms of Thomsen anisotropy parameters and horizontal to vertical ratio of Young’s moduli have been estimated under elevated pressures on the up and down pressure cycles. It was observed that anisotropy decreases dramatically with increase in pressure, but does not approach zero. It was concluded that this observed phenomena at high confining pressures may potentially be explained by the existence of some degree of intrinsic anisotropy in organic matter and clay particles.

Our comparison of true and apparent dynamic Young’s moduli in vertical and horizontal directions for the Niobrara shale samples (Figure 3) showed that the true dynamic Young’s moduli is greater on the order of 15% on average in comparison to the apparent dynamic Young’s moduli in appropriate directions. By ignoring this effect, the Eh and Ev stress contrast can be either underestimated or overestimated leading to false assessment of failure potential in a rock formation.
Figure 3: Comparison between VTI model Young’s modulus from stiffness data and Apparent Young’s modulus neglecting the off-angle stiffnesses. The data in perpendicular and parallel to bedding directions show up to 20% deviation from the line of equality. This figure shows that variations in stress estimates are to be expected due to discrepancies in the Young’s modulus estimates.

Conclusions

We have presented measurements of stiffness coefficients in the Niobrara formation and compared them with other organic-rich formations. We find that formation-specific data allow us to create better empirical models of velocity variations with organic maturity. Furthermore, we have shown that variability in stress estimates arises from discrepancy in Young’s moduli due to lack of off-angle stiffness data.