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Workflows for Integrated Seismic Interpretation of Rock Properties and Geomechanical Data: Part 1 – Principles and Theory

Perez, M. A.*[1], Close, D.I.[1], Goodway, B. [1], and Monk, D. [2]
[1]Apache Canada Ltd., Calgary, AB, Canada
[2]Apache Exploration and Production Technology, Houston, TX, USA

Summary

Unconventional resource plays have required geophysics to redefine the additional value seismic brings for economic development of such assets. It is no longer adequate to integrate geological and geophysical data alone, as much of what contributes to the success of unconventional plays is the optimization of engineering practices. Understanding that seismic data contains information regarding rock properties, in-situ stress, reservoir pressure and fracture intensity/orientation allows for educated and optimized large scale development plans. The heuristic interpretation templates provided herein outline the three parameters affecting minimum closure stress and how each manifest through seismic data.

Introduction

The ability to map minimum closure stress is of fundamental interest to operators in shale gas plays. This interest arises from the importance of optimizing completion efforts in shale gas and tight gas plays. These resource plays are capital intensive and combined with a challenged gas market; the ability to effectively maximize stimulated rock volume (SRV) provides a competitive advantage. Inconsistent productivity in horizontal wells through "homogeneous" media suggests variable SRV and has directed geophysics to mapping "sweet spots" or areas of larger potential SRV and thus increased productivity. Here, we investigate the factors influencing sweet spots and propose that they are primarily attributed to variations in minimum closure stress. Minimum closure stress is a measure of the hydraulic pressure required to fracture reservoir rock. Minimum closure stress is a vector quantity; accordingly, magnitude and direction are both essential measurements. Methods have been presented to estimate the minimum closure stress from seismic data (Downton and Roure, 2010). This has been correlated to the brittleness of a rock as shown by Goodway et al. (2010), and although this has the largest impact on closure stress there are other important parameters. We show that by including these other parameters, namely pore pressure and fractures/stress, the correlation between breakdown pressures and seismic derived rock properties is improved.

Theory

The minimum closure stress equation is given by (Sayers, 2010)

$$\sigma_{xx} - p = \frac{\nu}{1-\nu}\left[\sigma_{zz} - p\right] + + \frac{E}{1-\nu^2}\left(\varepsilon_{xx} - \nu\varepsilon_{yy}\right) \tag{1}$$

and recast (Goodway, 2010) as

$$\sigma_{xx} - p = \frac{\lambda}{\lambda + 2\mu}\left[\sigma_{zz} - p\right] + \frac{\lambda}{\lambda + 2\mu}\left[2\mu\left(\frac{\varepsilon_{yy}^2 - \varepsilon_{xx}^2}{\varepsilon_{yy}}\right)\right] \tag{2}$$

The parameters of interest consist of rock properties, ν, Poisson's ratio, and $\lambda/(\lambda+2\mu)$ where λ and μ are the Lamé constants, pore pressure (p) and the tectonic stress term ($2\mu[\varepsilon_{yy}^2 - \varepsilon_{xx}^2/\varepsilon_{yy}]$). Crossplotting the effective minimum horizontal stress against the effective overburden stress shows basic relationship between the three parameters that affect the minimum horizontal stress.

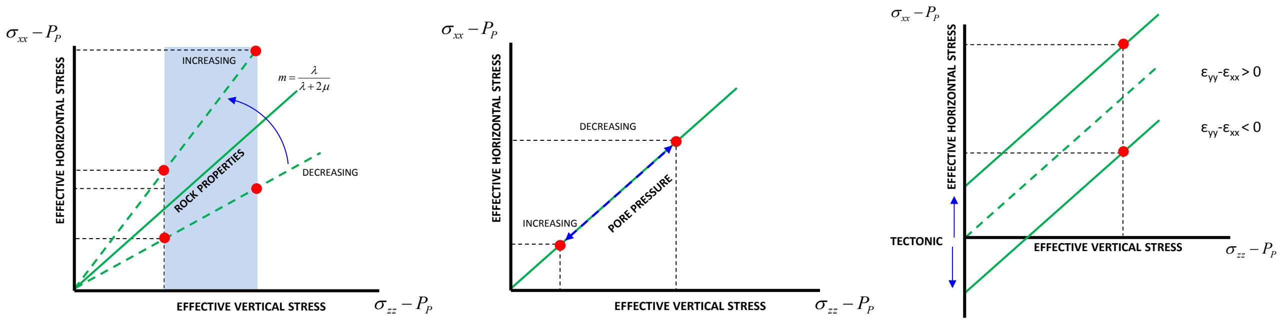

Figure 1: Effective vertical stress vs. effective horizontal stress and impact of a) rock properties, b) pore pressure, and c) tectonic stress

Transferring these trends into a geophysical space such as Lambda-Mu-Rho (Goodway, 2001) allows for interpretation and mapping of minimum closure stress in a regional context for distinct stratigraphic intervals. With sufficient well control it is possible to outline lithologic and mineralogic variations and assess crossplot scatter as perturbations in pore pressure and horizontal stresses or fractures. The LMR crossplots assume inverted seismic data under an isotropic assumption. The fracture interpretation template follows the analysis outlined in Perez, 2010.

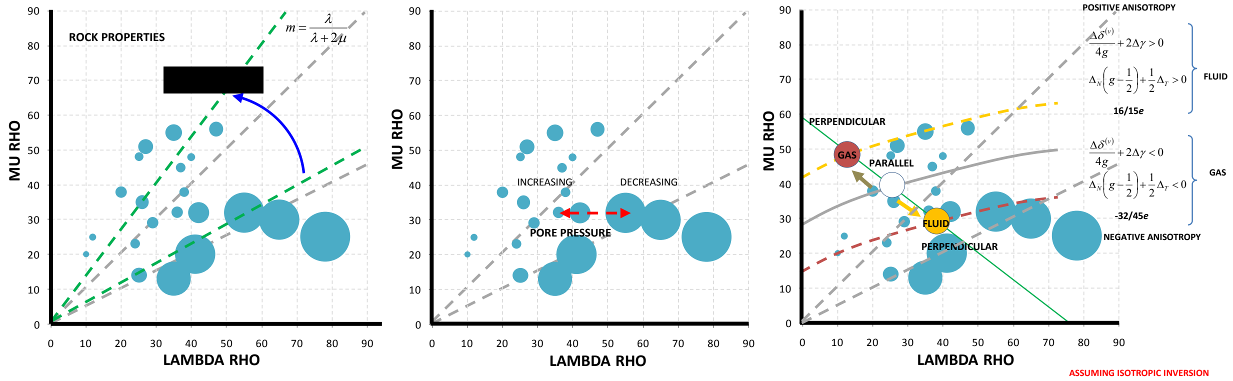

Figure 2: LMR representation of geomechanically relevant parameters a) rock properties b) pore pressure, and c) fractures/tectonic stress. Larger circles indicate larger ISIP. Templates shown are conceptual.

It is more suitable to plot the ratio of $\lambda/(\lambda+2\mu)$ against Lambda-Rho and Mu-Rho individually. This allows for differentiation of rock property effects, $\lambda/(\lambda+2\mu)$, from the effects of pore pressure and horizontal stress or fractures.

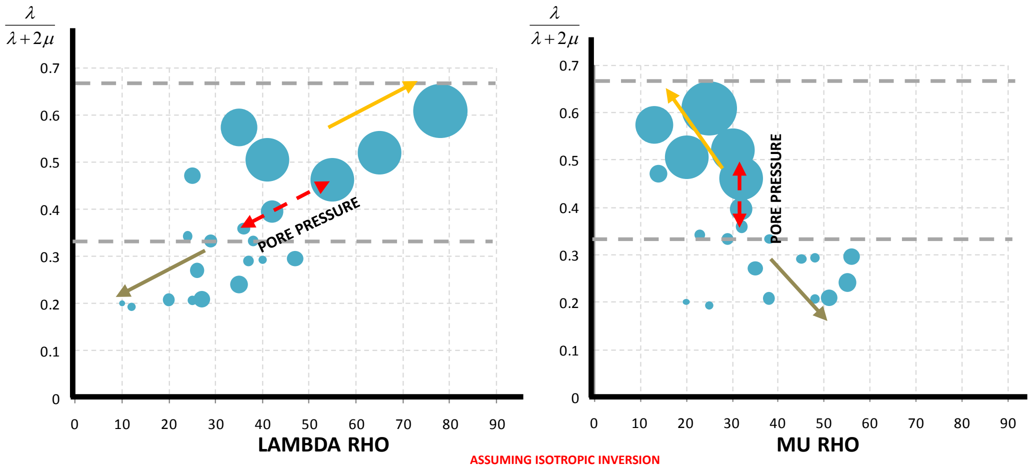

Figure 3: Closure stress scalar plots with rock properties, pore pressure and fracture/tectonic stress trends.

With the additional data contained in azimuthal and velocity variations with offset and azimuth, stress or fracture information can be included to corroborate the isotropic inversion results and distinguish between lithologic variations and the presence of fractures or non-zero differential stress in the horizontal plane. Methods, such as the one described by Downton and Roure (2010), simultaneously invert for isotropic mechanical properties as well as normal and tangential compliances used to characterize fractures in a rock.

The combination of these plots will high-grade development plans and facilitate appropriate capital expenditure based on reservoir quality, pore pressure and lateral stress variations. Understanding that completing a zone will have parameters out of an engineers control will allow for appropriate production expectations and minimize over capitalization of the project.

Conclusions

Enhancing the ability for seismic data to provide more than a subsurface image allows for optimized capital expenditure in large scale unconventional plays. Understanding the in-situ parameters controlling the SRV and ultimate gas recovery is vital for a successful program. Seismic data can help in high-grading reservoir quality using advanced seismic techinques with the appropriate interpretation templates.

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