geoconvention
Calgary • Canada • May 7-11 2018

The added value of geophysics in estimating natural fractures and reservoir stresses in 3G integrated workflows

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Summary

Geophysical attributes could contribute significantly to improving the estimation of the distribution of natural fractures and reservoir stresses when used as input in integrated workflows where other disciplines such as structural gelogy and continuum mechanics are used to estimate these key reservoir properties.

Introduction

The North American shale revolution has created many opportunities and operational challenges. While many of these challenges are often laid at the feet of engineers, the data and information which drives effective solutions however, comes from multiple disciplines. Geophysics remains the most affected discipline created by these challenges due to its lack of adaptation to the fast paced, low density and quality of data in unconventional reservoirs. Despite the lower for longer environment, geophysicists continue to have unrealistic expectations in terms of data availability and turn-around time of their deliverables thus missing the great opportunities that quantitative seismic reservoir characterization can bring to solving engineering challenges. These challenges can no longer be solved with the conventional approach where geophysics and other disciplines are disconnected and separated in different silos. The need for a true integrated approach where geophysics, geology and geomechanics (3G) are used simultaneously in new algorithms, workflows and single integrated software is urgent. To better illustrate this urgency, an engineer who spent the last three decades developing and using geophysical algorithms to improve his natural fracture models and reservoir stresses shares his experience with geophysicists tasked with the responsibility to contribute to the estimation of these key reservoir properties.

The two-major facts to remember when dealing with challenges in fractured reservoirs are: 1) lack of data and 2) engineering applications require high resolution validated models. Thus, any process that requires many advanced logs, high quality wide azimuth seismic, and efforts that are counted in weeks to provide a model with a 10-20 m resolution is doomed from the beginning. Given these tough constraints, combined with the false perception that natural fracture models can only be estimated with random statistical distributions, what are the geophysical tools and workflows that could add value to the estimation of these complex reservoir properties?

Seismically Driven Continuous Fracture Modeling

For many years geophysicists tried to use AVO concepts both for imaging natural fractures and more recently reservoir stresses (Gray et al. 2015). The drawbacks of this approach include the drastic and sometimes unrealistic assumptions made to derive the necessary equations, the need for wide azimuth seismic and the resulting poor vertical resolution of the deliverables. For multiple reasons related to costs and resolution, these techniques have contributed to the perception that geophysics does not add value to the estimation of natural fractures and reservoir stresses. To the contrary, geophysics could play a major role in creating value when estimating natural fractures and reservoir stresses if the proper methods are used.

An example of such value creation is the use of geophysical attributes to model the distribution of natural fractures. Since natural fractures measured along the wellbore or estimated from multiple proxies, including using surface drilling data (Jacques et al., 2017), could be available at multiple wells, geophysical attributes could provide the necessary information known in structural geology to influence the presence of natural fractures. For example, the density of natural fractures at a given point in the reservoir does not depend on poorly sampled statistics of various fracture sets measured through limited wireline data, but on the volumetric distribution and interaction of lithology, structural settings and distance to faults, porosity, and many other reservoir properties that compete to create the resulting natural fractures. These reservoir properties commonly called natural fracture drivers could all be estimated directly or indirectly through seismic processes that involve post stack inversion and facies constrained pre-stack inversions (Kiche et al. 2016) along with multiple attributes derived from spectral decomposition and structural attributes such as volumetric curvatures. This seismically driven approach (Jenkins et al. 2009) has been successfully used during the last three decades and has provided engineers the necessary information needed to handle natural fractures including those found in unconventional reservoirs where their impact is significant (Fig. 1). This impact could be positive through the creation of additional surface contact during hydraulic fracturing commonly referred to as frac complexity that can be sometimes imaged with microseismicity (Aimene and Ouenes, 2015). The contribution of the natural fractures could also be negative by creating frac hits through poro-elastic effects (Ouenes et al. 2017) that will often damage the production from child and parent wells. Thus, the need for an accurate and validated natural fracture model and that can only be achieved when geophysics is used.

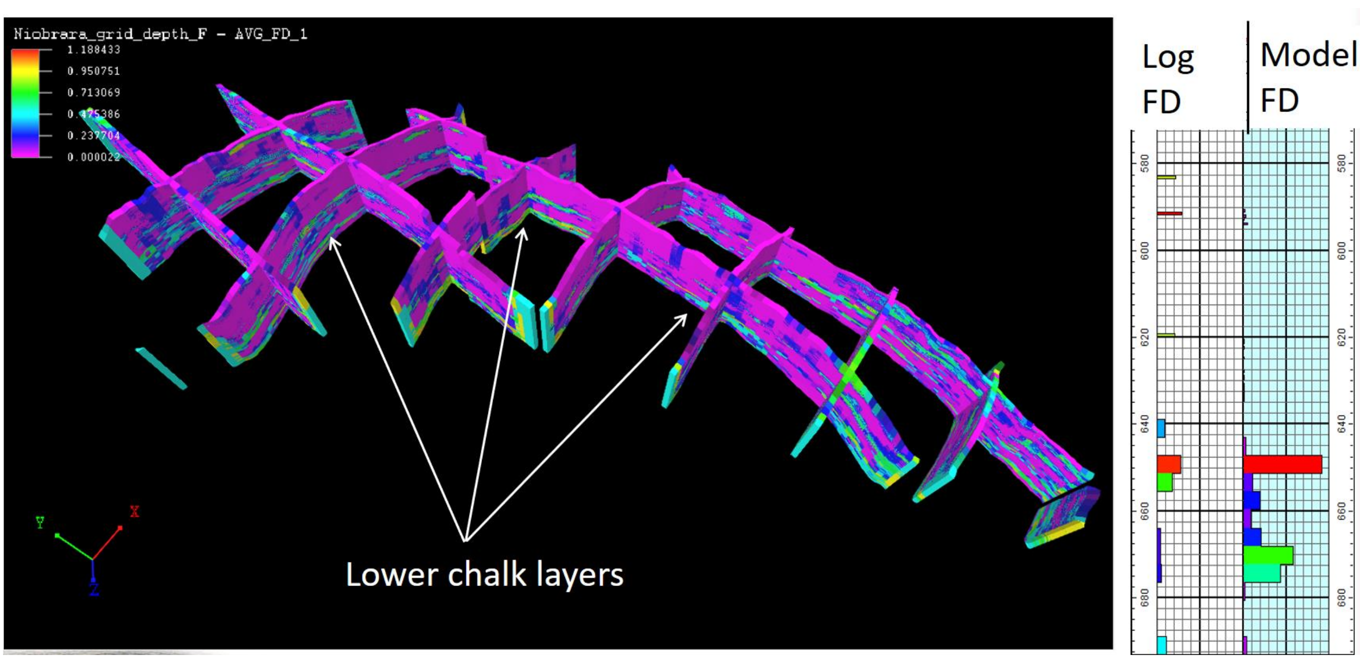
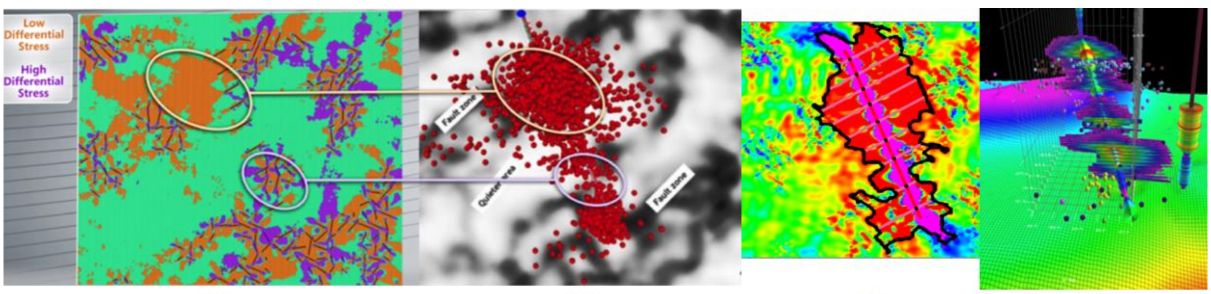


Figure 1: Continuous Fracture Model and its validation at a blind well. The model benefited from the simultaneous use of multiple elastic properties derived using facies constrained pre-stack inversion, structural attributes such as volumetric curvature and spectral decomposition

Seismically Driven Stress Estimation Using Continuum Mechanics

The cumulative effect of natural fractures and stresses will determine the outcome of the hydraulic fracturing. So, it is critical to first constrain the multiple sources of stress gradients in a reservoir, and simulate their interaction with the regional stress to understand local stress heterogeneity. In addition to elastic properties and natural fractures, the last reservoir property that has an impact on the reservoir stresses is the pore pressure which has been computed by geophysicists in multiple ways or estimated by engineers through reservoir simulation when dealing with existing depletion. With the help of geophysics, the three key factors affecting the stress gradients are computed and ready to be used as input in the continuum reservoir geomechanics (Aimene and Ouenes, 2015) workflow that provides the reservoir stresses. The geomechanical model simulates the proper initial stress conditions resulting from the various sources of stress variability followed by the simulation of hydraulic fracturing in this heterogeneous stress medium. Since microseismic data is limited to only a few wells, the geomechanical approach using the seismically derived reservoir inputs, can predict microseismicity rather than use it as calibration, thus validating the geophysical inputs and the geomechanical approach that uses them simultaneously (Fig. 2). The resulting hydraulic fracture geometries and their subsequent use in production forecast provide engineers a more accurate representation of the stimulated volume and the resulting reservoir depletion.



(A) (B) (C) (D)

Figure 2: Differential stress (A) and strain (C) validated with microseismicity (B) and the resulting geomechanically constrained hydraulic fractures (D) that benefited from the geophysical input

Conclusions

Geophysical attributes are more useful when considered as input in other processes used to estimate more accuately natural fracture models and reservoir stresses.

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