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Correlating 3-D Seismic and Micro-Seismic Data for Shale Gas Reservoir Characterization

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Abstract

Quantitative seismic interpretation workflows are still immature for shale gas reservoirs compared to QI applications for conventional carbonate and clastic reservoirs. Nevertheless, elastic and geomechanical attributes derived from 3-D seismic reflection data are potentially very useful for shale gas reservoir management, in particular for delineating reservoir sweet spots where formation properties make the rock matrix more fracture-prone under hydraulic stimulation and for predicting reservoir stress anisotropy which may affect the orientation of hydraulic fractures. Studying the relationship between hydraulically-induced micros-seismic activity and 3-D seismic attributes is therefore important to understand the impact of rock properties and stress spatial distribution on the success of hydraulic fracturing treatments. We have performed 3-D pre-stack seismic inversion over a pilot area of the Haynesville Formation in the U.S.A and have attempted to correlate spatially the inverted seismic attributes with the locations of micro-seismic events. We have used both isotropic and anisotropic seismic inversion techniques to derive 3-D attribute volumes for P-wave impedance, S-wave impedance and density, and for geomechanical properties such as Young’s modulus and horizontal stress anisotropy. The $5km^2$ inverted pilot area contains 7 horizontal wells which have been hydraulically stimulated. Micro-seismic data have been recorded to monitor the fracture treatments. Initially, we performed a statistical correlation analysis between the 3-D spatial density of micro-seismic events and the inverted seismic attributes. Due to the large uncertainty in the estimated depth locations of the micro-seismic events, we were not able to derive meaningful 3-D correlations. Instead of a full 3-D analysis, we have therefore performed a 2-D areal correlation analysis using seismic attributes vertically averaged across the stimulated reservoir zone and the corresponding areal density of micro-seismic events. The areal study reveals physically meaningful statistical correlation between micro-seismic event density and seismic-derived estimates of Young’s Modulus and differential horizontal stress ratio. Using mathematical morphology and non-parametric statistical techniques, we have also calculated the Stimulated Reservoir Volume (SRV) and the Stimulated Reservoir Area (SRA) associated with each hydraulic fracturing stage. Furthermore, we can calculate and display in 3-D the time-evolution of the SRV to gain insight into the fracture growth process and better understand the spatio-temporal correlation between the micro-seismic activity and the spatial distribution of seismic-derived rock properties. We were able to enhance the seismic-to-micro-seismic correlation by relating the calculated size of the stimulated reservoir zone with seismic attributes spatially averaged over the computed SRA for each stage. Although promising, we conclude that the significance of the observed correlations is hard to fully evaluate in view of the small variability of the seismic-derived rock properties over the pilot area and the relatively low correlation levels.