Workflows for Integrated Seismic Interpretation of Rock Properties and Geomechanical Data: Part 2 – Application and Interpretation

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Introduction

Over the last decade the oil and gas industry has delivered technical and conceptual changes that have entirely changed the fundamentals of natural gas supply in North America. Underpinning the step change in natural gas reserves and market ready supplies has been the change in the perception of fine-grained, organic rich rocks (i.e. shales – although of course not all shales are organic rich). No longer are such rocks viewed only as source and seal candidates, but also as reservoir rocks. These "shale gas" plays, as they are ubiquitously known, can be produced economically through a combination of horizontal drilling and hydraulic-fracture stimulation. Shale gas is often referred to as a "resource play" due to the perceived (and actual) reduction in geologic risk associated with development. Geological variations, complexities and heterogeneities within shale gas plays are exaggerated and downplayed in almost equal measure. One matter that is not in question is the extent to which basins within North America are currently being exploited for shale gas and/or shale oil (Figure 1).

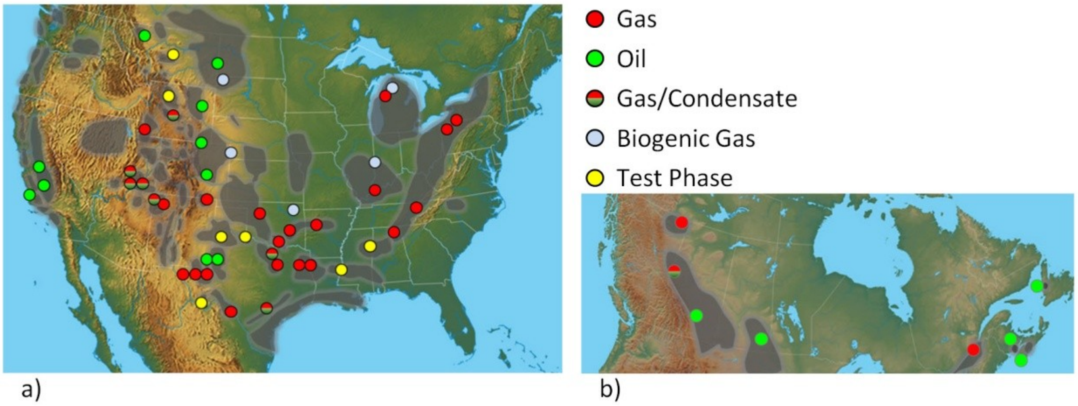

Figure 1: Map of shale gas and shale oil production and potential in a) The USA, and b) Canada (after Jarvie, 2010).

Role of Technology

Although the geological continuity and consistency (in relative terms at least) of shale gas has in part led to the production-line style operations seen across North America today, the low price of natural gas for an extended period has focused operators on cost reduction as a means of maintaining profits. However, it is not only efficiency improvements that allow the economic exploitation of shale gas – it is also the plethora of fit-for-purpose technologies (or at least 'adapted-for-purpose') introduced by shale gas operators and their service company partners. Technological advances are unlikely to contribute materially to the discovery of shale gas resources in mature basins, however, those that assist in maximizing recovery with less impact and effort will continue to be of fundamental importance in unconventional gas development.

The intense focus on induced fracture networks has lead to increased scrutiny on rock physics and geomechanics within the reservoir. Whereas in conventional plays geomechanics studies were typically focused on wellbore stability or sand production, in shale gas plays it is the moduli of the rock and how the rock responds to fracture treatments that is of greatest interest. For this purpose extensive full core and core plug studies are often incorporated into the initial development stages of a shale gas play, as any small increment in efficiency extracted from the core analysis data can have substantial economic impact over the life of the play. Finding the common ground and links between engineering data measured in the laboratory and surface seismic data is one area where substantial advances are being made.

Role of Seismic

The integration of seismic data with engineering and rock physics data is providing new avenues of data exploitation. Seismic data are used to predict closure stress and stress anisotropy, which are calibrated with data and analysis from hydraulic fracturing. Additionally, the integration of surface seismic data with microseismic provides a means of fine-tuning the estimation of stimulated rock volume.

The traditional role of seismic continues to play an important role in mapping horizons of interest and mapping major faults and more subtle structural trends that impact drilling, completion and production. However, advanced seismic studies are shaping to become of greater importance than these traditional uses. Results of advanced seismic studies, utilizing pre-stack AVO inversion in addition to the azimuthal variance in seismic amplitude, are correlated with engineering data for calibration. The combination of AVO analysis with amplitude versus azimuth (AVAZ) and velocity versus azimuth (VVAZ) analyses is providing new means of using existing and newly acquired data.

AVAZ and VVAZ techniques rely on amplitude and velocity variation with offset and azimuth, respectively. Horizontal transverse isotropy (HTI) is assumed when amplitude and velocity variations are observed. HTI is a reasonable equivalent for vertically aligned fractures. Many advances have been made to characterize the azimuthally dependent signature and ascribe physical significance to distinct seismic responses. These include fracture density, fracture fill (gas vs. water), normal and tangential compliances of the fractures and Thomsen's anisotropy parameters (Thomsen, 1986, 1988) which relate compressional and shear velocities in vertical and horizontal directions. Advanced techniques also attempt to characterize potential dispersion effects (fluid flow within fracture at seismic frequencies). These methods are all heavily dependent on the model used and although they are simplistic in comparison to subsurface reality, they can provide useful information. In conjunction with models which account for randomly oriented cracks, AVAZ and VVAZ analysis provides bounds on seismic fracture responses. Figure 2 illustrates an example of closure stress estimates, based on the method of Downton and Roure (2010) visualized with lateral wells and frac ports.

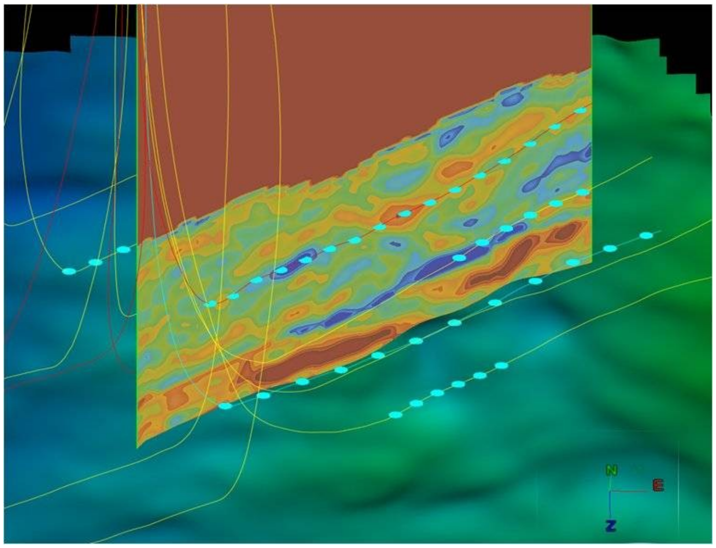

Figure 2: Arbitrary line through an isotropic closure stress volume, derived from seismic data, and horizontal wells from a single pad in 3D space. In simplistic terms the cool colours are relatively easier to fracture than the hot colours. (From Monk et al., 2011).

Integrating Data and Interpretation Workflows

We illustrate the robustness of the results of advanced seismic studies and isotropic and azimuthal AVO inversions by using measurements and metrics from completion and production data. The templates we use for this analysis build on the theory of Perez et al. (2011). The calibration of the seismic interpretation in this manner provides a means of predicting well and pad performance in advance of expensive drilling and completion operations.

To facilitate the comparison of the disparate geophysics, petrophysical, geological, completion and production data sets, the data are loaded to a common platform (Petrel in this case – but many programs could equally be used). Having the data integrated within a common platform where the scalar data is located in real-world space allows for data mining and analysis far beyond what is possible in simple database and spreadsheet applications. The workflow for interpreting and extracting seismic properties and attributes and quantifying these data with engineering data is illustrated.

Conclusions

Advanced seismic studies, utilizing isotropic and azimuthal AVO inversions, provide quantitative predictions of rock properties, in-situ stress and fracture intensity and orientation. These parameters are of critical interest to all disciplines as drilling pad locations and hydraulic fracture stimulations are planned. Look back analysis of completions and production data with existing seismic data allow calibration of the seismic data, providing the confidence necessary for actionable recommendations.

References

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