Seismic Inversion in a Tight Gas Sand: An Illuminating Case Study

David Close*
David Cho
Frederik Horn
Reservoir Seismic Services (Calgary), Schlumberger, Canada
DClose@slb.com*
and
Charles Wagner
Shantanu Singh
Reservoir Seismic Services (Houston), Schlumberger, USA

Summary

Prestack seismic AVO inversion results, from a field comprising vertically stacked, non-continuous tight gas sand reservoirs, illuminate prospective areas that have previously been bypassed. The undrilled sweet-spots are most effectively illuminated in a pre-stack inversion volume of Poisson's ratio, in contrast the acoustic impedance interpretability is limited by variations in geopressure that are not independently constrained. The well-log calibrated seismic inversion results are relatively robust qualitative predictors of well productivity, both for blind wells and wells included in the inversion process.

Integration of independent data from enhanced seismic discontinuity mapping ("Ant Tracking"), borehole imaging, petrophysical analysis, and stress anisotropy profiling allows a more detailed understanding and improved reservoir characterization. A 3D reservoir model based on all available well data, structural interpretations, and seismic inversion results provides both direct and intangible interpretation and visualization benefits.

Introduction

The exploitation of unconventional gas reservoirs has exploded in recent years in North America, primarily from shale gas, coal-bed methane, and tight gas reservoirs. A number of factors have contributed to the substantial increase in production from unconventional reservoirs, primary amongst these factors has been an increased utilization of new technologies or previously 'high-tier' technologies not commonly applied in the North American land environment. However, this new paradigm of 'profit maximization over cost minimization' is ultimately necessary for successful operations.

Uptake of technological advances in geophysics has tended to be slower in unconventional plays due to the strong focus on engineering, while advances in logging, stimulation and core analysis have been rapidly adopted. This is partly a function of the change in focus required from conventional structural, play and reservoir mapping in seismic data to the need to predict, amongst other things, fracture density and orientation, and sweet spot location. For example, traditional seismic mapping and interpretation is less directly applicable to exploration for sub-seismic stratigraphic traps in tight gas reservoirs and lack relevance in very low permeabilty (nano-darcy) clastics such as shale gas reservoirs where four-way closure is not required to prevent gas migration.

Prestack seismic AVO inversion data are increasingly being recognized as a means to improve the interpretability of seismic data. Zero-centric stacked amplitude data is of limited utility in identifying hydrocarbon prospective drilling targets in unconventional reservoirs, however, acoustic impedance and Poisson's ratio are directly representative of rock properties, often show a strong correlation to well log measurements, and can illuminate potential drilling targets.

Method

Initial rock physics analyses suggested that an acoustic impedance inversion alone was insufficient in the discrimination of gas sands from wet sands. In contrast, fluid substitution experiments in the target interval indicate that Poisson's ratio is sensitive to gas saturation. Figure 1 illustrates the separation in an acoustic impedance versus Poisson's ratio crossplot of gas and water saturated intervals.

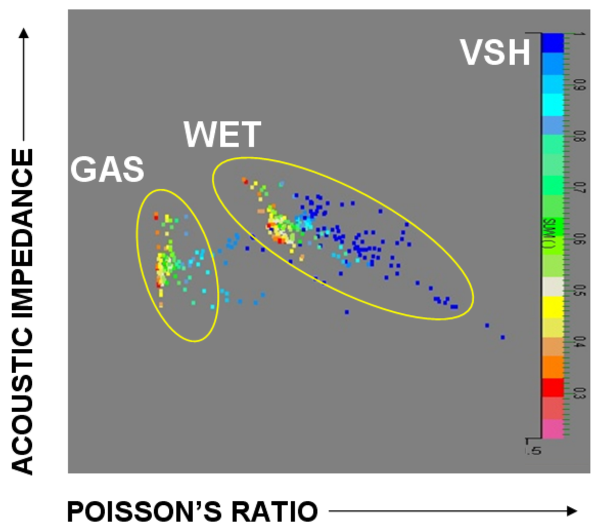


Figure 1: Fluid substitution analysis for gas and wet sands in target interval.

To obtain the Poisson's ratio, a simultaneous seismic AVO inversion was performed on the prestack seismic data. The inversion algorithm inverts for the acoustic impedance, Poisson's ratio and density simultaneously using a linearized form of the plane wave Zoeppritz equations as presented by Aki and Richards (1980). These inversion data are ideally suited to provide the necessary constraints for a 3D reservoir model based on available well log data.

Major faults (with >100s metres of offset) increase the risk of fault compartmentalization in this field. An enhanced structural mapping workflow (referred to as Ant Tracking) delineates major faults and discontinuities, objectively and efficiently, within the field. The Ant Tracking workflow consists of four independent steps:

1. Enhance the spatial discontinuities in the seismic amplitude data using an edge detection algorithm (i.e. variance, chaos, edge detection)
2. Generate the Ant Track volume and extract fault patches
3. Validate and edit the fault patches
4. Create final fault interpretation model

A time slice through the Ant Track volume (Figure 2) illustrates major structural features, many of which correspond to manually interpreted faults. However, the Ant Track volume provides far greater detail of smaller scale structural discontinuities. For example, following the Ant Tracking analysis a failed hydraulic fracture job (expected pressure was not reached) was attributed to the proximity of the well to a vertical fracture observed in the Ant Track volume.

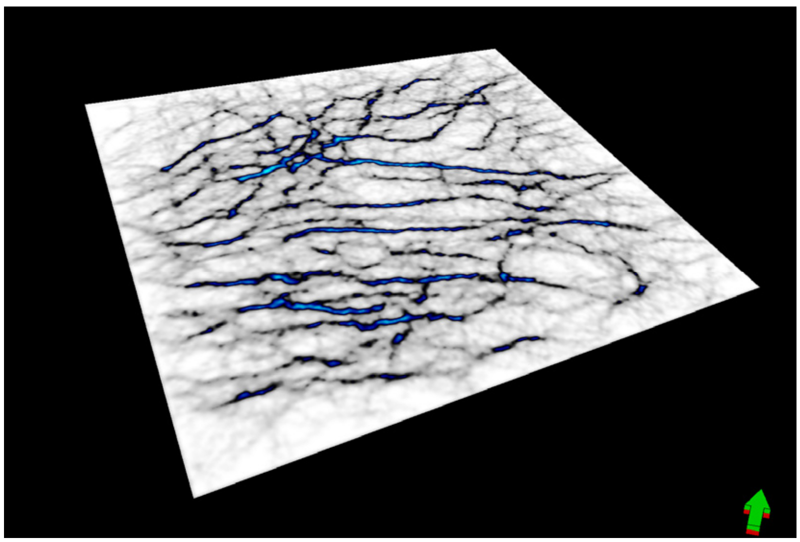
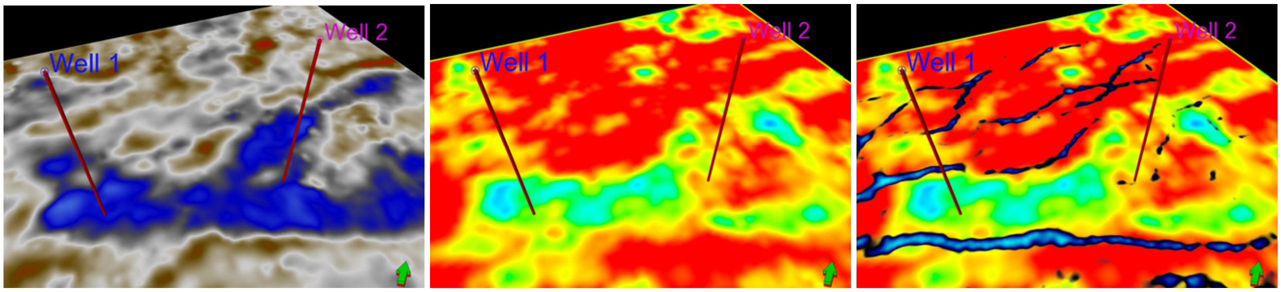


Figure 2: Ant Tracking volume for fault delineation.

Figure 3 illustrates the locations of two wells drilled in the target area along with the corresponding data derived in this study. Well 2 production has been substantially lower than the offset Well 1. Seismic amplitude data (Figure 3a) do not provide a justification for the difference in well productivity. However, the Poisson’s ratio (Figure 3b), which illuminates areas of high gas saturation (low Poisson’s ratio), indicates that Well 2 was drilled at a location with a relatively high Poisson’s ratio, thus providing a reason for the low productivity of Well 2. The Ant Tracking results are overlaid with the Poisson’s ratio results (Figure 3c) and illustrate that major faults provide boundaries to the rock-properties (due to offset of stratigraphic intervals) and do not adversely segment the reservoir in the central fault block.



a) b) c)

Figure 3: Well locations with a) seismic amplitude, b) Poisson's ratio, c) Poisson's ratio with Ant Tracking

Borehole imaging data and azimuthal shear wave data from a number of wells within the field also provide insight into the depositional environment and the local stress regime. Interpretation of dip patterns and borehole images indicate a dynamic near-shore environment with strong tidal influences. The geometry of a tidal inlet interpreted in borehole image data correlates to the strike of a Poisson's ratio sweetspot within the core of the reservoir, providing a geological context for the geophysical data. Similarly, results of shear wave anisotropy studies at the wellbore scale can be correlated to the mapped regional scale structures and faults.

Conclusions

Prestack AVO seismic inversion data provide a means of illuminating potential reservoir targets within this field comprising tight-gas sand reservoirs. The data also illustrate low prospectivity areas where uneconomical production is considered likely based on backward looking analysis of production data and seismic inversion results.

Calibrated seismic inversion, in concert with all other available geological and geophysical data, can provide improved interpretation results at both the exploration and production stage of development. The application of inversion technology to unconventional reservoirs will continue to provide advantages for operators prepared to apply differentiating technologies.

Acknowledgements

The authors thank an anonymous co-operative client for releasing these data for display and publication.

References

Aki, K., and Richards, P.G., 1980, Quantitative seismology. W.H. Freeman & Co.