Integrated Reservoir Characterisation
- a successful interdisciplinary working model

Satinder Chopra, Scott Singleton*, Craig Hall**, Randy Nickerson[+] and David Carlson[+],*

**Core Laboratories Reservoir Technologies*, ***Core Laboratories Integrated Reservoir Solutions*
+ Dominion Exploration & Production, Inc.

2004 CSEG National Convention

Introduction

Comprehensive reservoir descriptions require multi-disciplinary teams working closely to combine geological, geophysical, pertrophysical and engineering data together. For the success of any such endeavour, the team members need to have the experience of working closely together where integration skills take priority over specialist skills. While the need for such an approach has been echoed loudly over the last decade at different forums, successful integrated case studies are still elusive.

Also, the engineering flow data is not being used to the extent that they could be used in reservoir characterization and model building. It is expected that an integration of these disparate datasets can generate images of reservoir properties that are geologically more meaningful than seismic data alone and can provide better descriptions of inter-well variability than can be had from a purely geological perspective. This has been the inspiration for the case study at hand, where the geological and petrophysical information is integrated with 3D seismic attributes and well information to identify potential hydrocarbon accumulations within a data set from Wilcox Trend in South Texas. It is believed that this quantification of variation in reservoir characterization was done with a greater level of certainty.

Geology of the area

The Wilcox and Midway Groups comprise the oldest thick sandstone/shale sequence of the Tertiary of the Gulf Coast. The Wilcox crops out in a band 10 to 20 mi. wide located 100 to 200 mi. inland from the present-day coastline. The Wilcox sandstones and shales in the outcrop and in the up dip shallow subsurface were deposited primarily in fluvial environments; down dip in the deep subsurface, on the other hand, the Wilcox sediments were deposited in large deltaic and turbidite systems, some of which were reworked into barrier-bar and strand plain systems. Growth faults developed within the depositional systems where they prograded basinward beyond the older, stable Lower Cretaceous shelf margin onto the less stable basinal muds. Continued displacement along these faults during burial resulted in (1) entrapment of pore fluids within isolated sandstone and shale sequences and (2) buildup of pore pressure greater than hydrostatic pressure and development of geopressure (Bebout, et. al, 1982).

Geological analysis

Geological analysis began with examination of drill cuttings to estimate rock properties. Although sidewall coring is a common practice in the Gulf Coast cores were unavailable for the study well. Instead, drill cuttings, spanning the depth of interval 13860 ft to 14220 feet, were utilized for analysis.

In summary, the sandstones analyzed in thin section are very fine to fine grained, poorly to well sorted, and cemented by pervasive interstitial clay and authigenic quartz. Porosity estimates range typically from 5% to 10% with most of the pore volume being microporosity within the clay. Petrographic analysis of the drill cuttings between 13860 to 13880 feet showed sandstone to be moderately compacted and lithified by patchy interstitial clay and minor quartz cement. Over the next 20 foot depth range, the rock exhibited the lowest vshale content but pervasive quartz cement reduces reservoir quality. Figure 1 is a thin section photomicrograph of the rock from this interval. Similarly, in the depth range 13920 to 13940 feet, the sandstone is well compacted and contains common interstitial clay. Water saturation, which was found to be high between 13860 to 13880 feet, was even higher in this zone due to the greater volume of irreducible water associated with the clay. The sandstone between 14210 and 14220 feet has the lowest reservoir quality due to high compaction, high Vshale content and high water saturation. At this stage, Core Laboratories' extensive Wilcox rock petrophysical database was searched for analogous rock types using methods developed for the Core Laboratories' *Worldwide Rock Catalog™.* These rock types were used as proxies for the sandstones in the study well. Data from the analog rock types including porosity, permeability, and electrical properties, i.e., FF, RI, Swi, and Archie "m" and "n" exponents, were subsequently carried forward to enhance the petrophysical evaluation.

Petrophysical evaluation

Petrophysical evaluation involved the analysis of the available log curves, computation of missing portions on some curves and correction to shear logs for stick-and-pull on original log, etc. Vshale, porosity, and water saturation curves were calculated for use in the rock property estimation. P-velocity, S-velocity, and density logs were checked for self-consistency or constructed if missing. This included removal of cycle-skips on sonic data and wash-out zones on density data. Figure 2 shows the stick-and-pull correction effected on the original log.

The velocity and density logs were then modeled using effective media theory and the appropriate fluid mixing relationship. The results of the modeling were moduli, velocity, and density of the reservoir rock and fluids. Once these were determined, property substitution (shale, saturation, porosity) was used to determine the behavior of the rocks and fluids with varying reservoir conditions.

Well log data analysis

Next, the analysis of well logs was carried out as a feasibility tool to determine the fluid and lithology discrimination capabilities of AVO and inversion techniques. To begin with, cross-plotting was used to determine what combination of attributes depict characteristics that can be used as an identifiers of a specific lithology and pore fluid. This could then provide a preliminary assessment of what attributes could be diagnostic, and also to ascertain a link to relate elastic properties relevant to seismic expression (velocity and density) to petrophysical properties of interest, such as lithology, porosity and pore fluid. As seen in Figure 3 a plot of Lambda-Rho against Mu-Rho indicates a cluster of points indicating prospective zones.

Thus, the elastic parameters Lambda*Rho and Mu*Rho could be discriminators of porosity in the reservoir. This result encouraged pursuing seismic AVO analysis and extending to Lambda-Mu-Rho calculations.

Seismic Modeling

The property-substituted results from the well modeling step are convolved with a wavelet representing the seismic data. The resulting gathers represent a theoretical, noise-free simulation of what the actual seismic data should be imaging. These synthetic gathers can then be compared with the real seismic gathers to determine if the gathers contain the appropriate fidelity and imaging accuracy to continue with rock property work. Another significant observation was that the synthetic gathers generated with a wavelet of 60 hz and above with different water saturation values exhibit amplitude variation that could be useful. No amplitude variation is seen at 35 hz or so (Figure 4). This suggests enhancing the frequency of the prestack data above 60 hz.

Processing of seismic gathers

Before the seismic gathers are put through AVO analysis, they should have a low noise component, so that the anomalous amplitude variation can be picked up for analysis. To ensure this, a proprietary technique called LIFT was run on the data. This technique first models the signal and noise using the available techniques and then removes the noise component in an adaptive non-linear fashion. The methodology is important as it preserves the amplitude character, which is crucial for AVO analysis. Figure 5 shows a comparison of the gathers as they are put through different noise removal and frequency enhancement processes. Notice how the amplitude variation can be seen clearly at different levels without the background or linear noise.

Frequency enhancement

One shortcoming of the seismic reflection method is that it is usually not able to distinguish the characteristics of a thin reservoir. An important goal in reservoir description is to resolve thin bed geometries. Techniques to enhance seismic frequencies are critical for optimum thin bed resolution. Different from post-stack spectral whitening, which is usually employed and does not distinguish noise from signal and does not preserve amplitudes, High Frequency Restoration (HFR) uses VSP downgoing wavefield to determine the frequency decay with depth and then restore those losses on surface seismic (Chopra et al, 2003). Application of HFR to pre-stack seismic data is very effective and useful for AVO analysis. A zero offset VSP is used to determine the attenuation in terms of a set of time-variant HFR filters, and applied to the seismic gathers. This enhances the frequency content of the data going into AVO/LMR analysis and useful for thin bed analysis.

Lambda-Mu-Rho analysis

To extract more information for the reservoir, elastic property inversion (Goodway et al. 1997) was used. After preserved amplitude processing the P and S reflectivities from gathers were extracted using Fatti's approximation. These reflectivities were then inverted into P and S impedances and then modulus attributes Lambda*Rho and Mu*Rho were calculated. The effectiveness of this technique is based on the fact that Lambda*Rho is sensitive to fluids while Mu*Rho values have little variation within the reservoir zone. Figure 6 shows these sections for a line pulled out of the 3D volume. The cluster of points corresponding to low lambda-Rho values and high Mu-Rho values lights up a multilevel pay system on the two sections and looks prospective.

Conclusions

The integrated approach to rock property analysis brings together several disciplines that historically have tended to work in isolation from one another. Core analysis from analogous rocks provided baseline calibration of permeability, porosity, density, velocity, and mineral content to carry into the petrophysical evaluation of wireline data. Using property substitution techniques, modeled wireline data was used to determine the potential characteristics of reservoir properties away from the wellbore. Synthetic seismic gathers were then created from the substituted rock properties, showing the seismic response to varying reservoir conditions. Finally, the seismic data was inverted to rock properties and calibrated with the core, wireline, and synthetic gather data.

A well drilled after this analysis encountered multi-level porosity zones as interpreted from the Lambda-Rho and Mu-Rho sections. This successful drilling result prompts us to recommend such an integrated workflow should form a part of the analysis for exploration projects. The workflow gives a logical insight into the analysis and so provides more accurate results.

Acknowledgements

We wish to thank Vasudhaven Sudhakar for encouraging the integrated approach to this work. We thank Core Laboratories and Dominion E & P for permission to present this paper. We also thank WesternGeco for permission to use their data in this presentation.

References

Bebout, D.G., Weise, B.R., Gregory, A.R. and Edwards 1982: *Wilcox Sandstone Reservoirs in the Deep Subsurface along the Texas Gulf Coast, Their Potential for Production of Geopressured Geothermal Energy.* Texas Bureau of Economic Geology Rept. Invest. 117

Chopra,S., Alexeev,V., and Sudhakar,V., 2003, *High frequency restoration of surface seismic data*, The Leading Edge, V22,no.8,2003.

Goodway,W., Chen,T. and Downton,J. 1997, *Improved AVO fluid detection and lithology discrimination using Lame petrophysical parameters, '$\lambda\rho$', '$\mu\rho$' and 'λ/μ' fluid stack from P and S inversion*, CSEG abstract, p148-151.

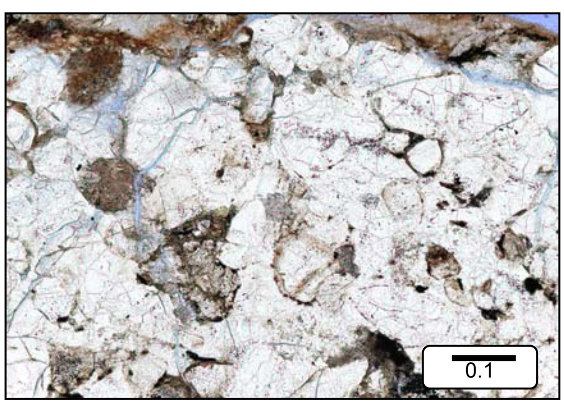

Figure 1: This section of a formation between 13880 and 13900 feet indicates that the rock type exhibited the lowest shale content but the pervasive quartz cement affects reservoir quality.

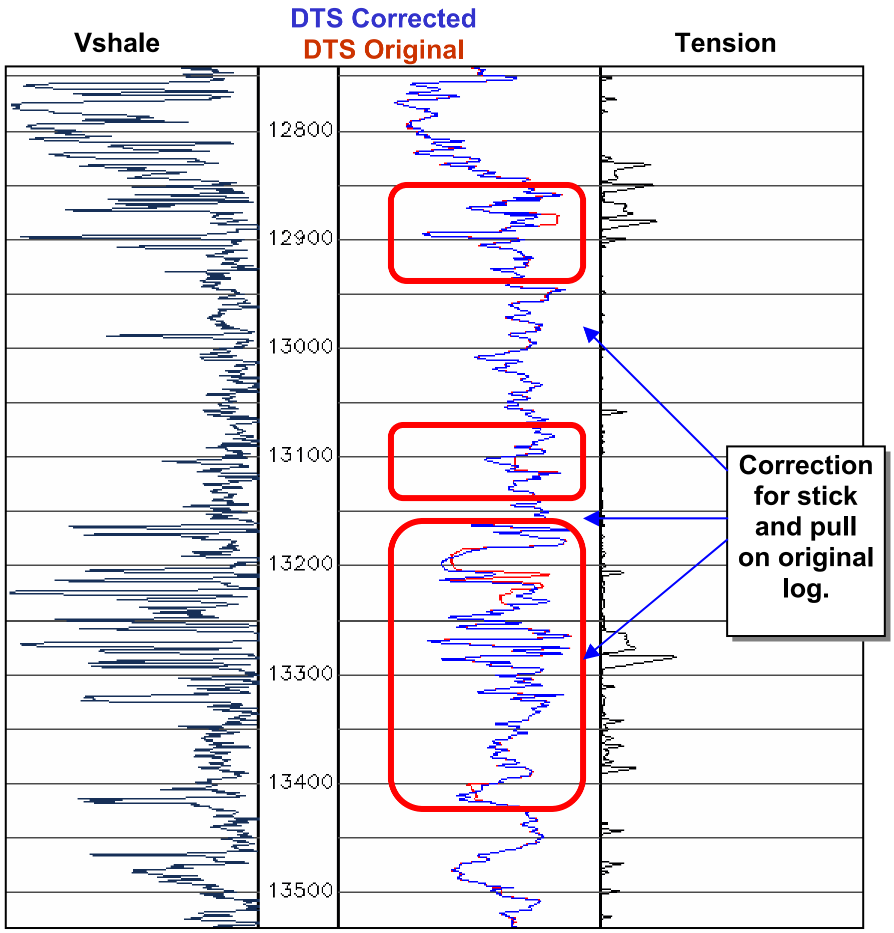

Figure 2: Stick-and-pull correction effected on the original log.

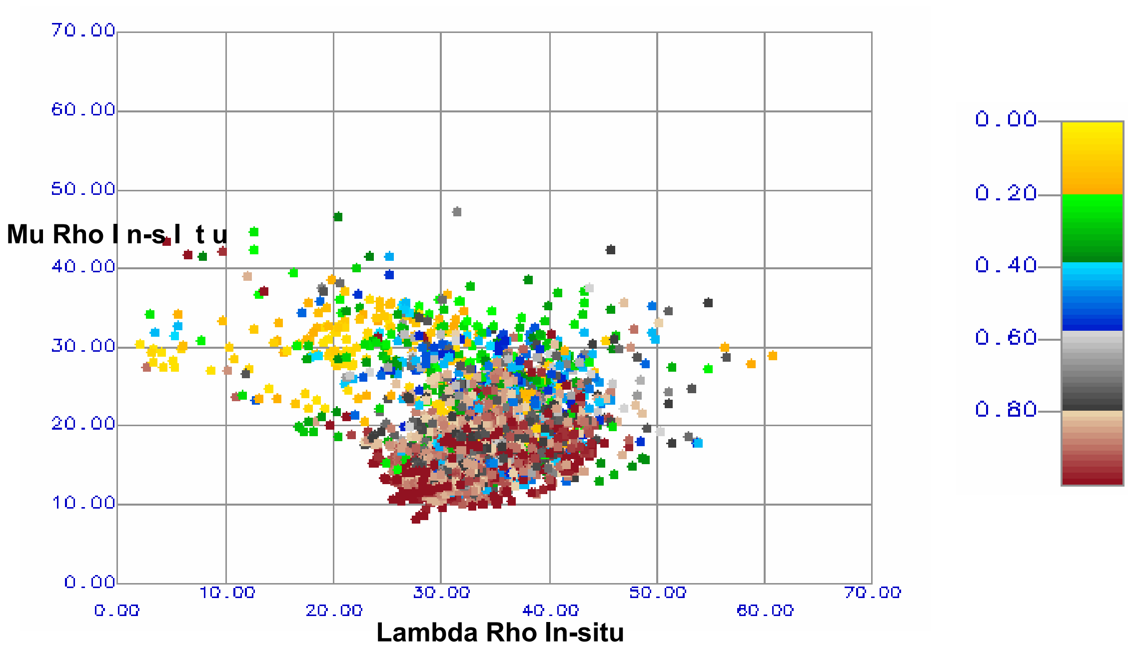

Figure 3: Lambda-Rho in-situ plotted against Mu-Rho in-situ

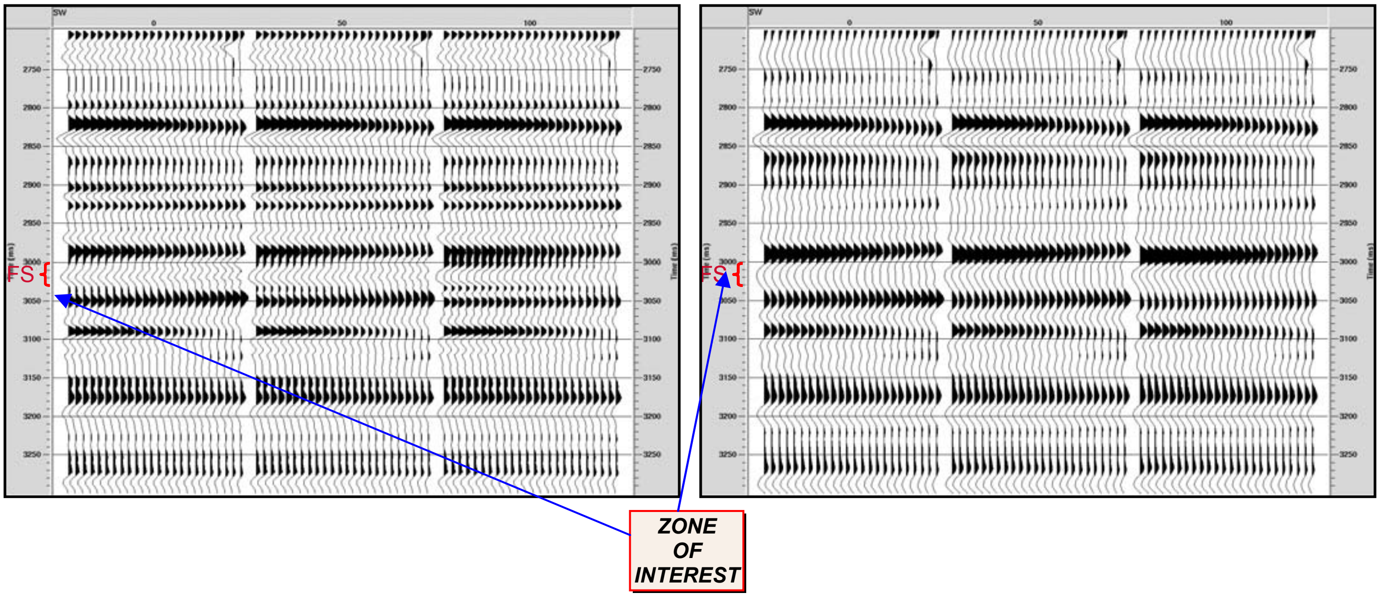

Figure 4: Synthetic gathers generated with a (a) 60 hz wavelet and (b) 35 hz wavelet and indicated values of water saturation. Evidently, gathers with 60 hz exhibit amplitude variation with offset.

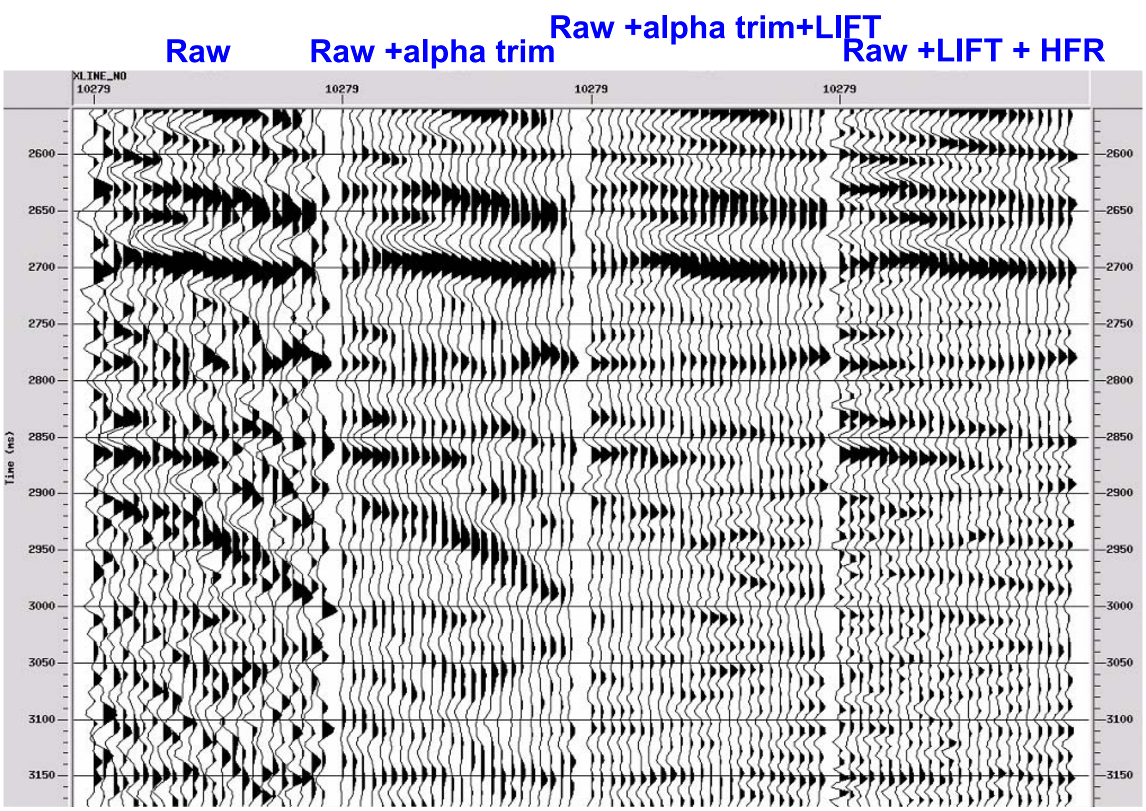

Figure 5: Comparison of the same gather through different indicated processes. Evidently, after LIFT and HFR events are seen much better than before.

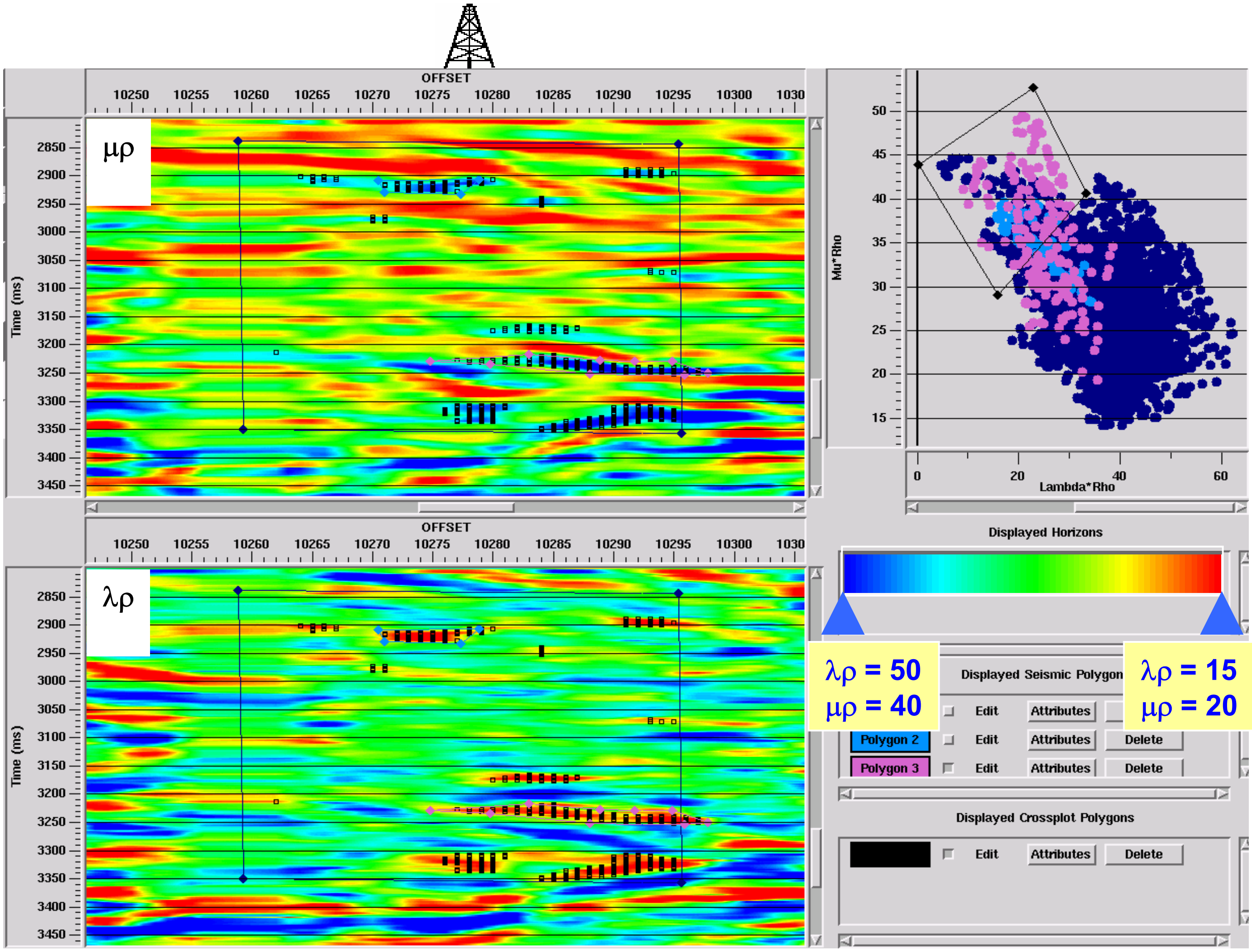

Figure 6: Lambda-Rho and Mu-Rho sections alongwith the associated cross-plot. A polygon on the crossplot loghts up the prospective zones on the two sections.