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Extracting high fidelity geological information from 3D seismic and well data.

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Abstract

Digital well log and 3D pre-stack seismic data are combined to improve reservoir characterization. 3D seismic pre-stack gathers contain significant information about lithology, rock properties and fluid content. The biggest challenge is to integrate log scale geologic information with seismic scale measurement of the same geological unit. Gulf Coast geoscientists have actively been using integrated seismic gathers and well logs in AVO and inversion analysis for decades. Rocks of the mid-continent have often led us to discount, or even dismiss completely, the analytical capabilities of onshore seismic gathers. Traditionally, rock properties are estimated from elastic inversion results using neural networks. This article discusses a method that utilizes the power of digital log analysis, LambdaRho/MuRho innovative cross plots and integration with seismic pre-stack gathers to predict rock properties in the unconventional reservoirs.

Introduction

Drilling and producing of unconventional reservoirs have been considered a “mining” operation for many years. The general thinking was that is more important to secure land leases over areas that seem to produce higher yielding wells than spending money and time on science projects. After all, the shale deposits are widespread and no large variation in production was expected. However, this was proven to be unrealistic and the value of seismic data are now recognized. Seismic data, especially attributes derived from pre-stack data are now extensively used to design and execute lateral drilling programs as the reservoirs have a much larger heterogeneity than expected. Higher producing wells characteristically are drilled into shales with higher Total Organic Content (TOC) and more favorable rock properties like porosity and elasticity which is a measurement of how easy the rock cracks during fracking and opens space for the hydrocarbons to flow towards the pipe. Carbonate units can be embedded within the producing shale units and the pre-drill knowledge of their locations is very useful when designing the lateral drilling path.

P-sonic and density are key measurements to estimate rock properties/geological information from well data and subsequently from pre-stack seismic data. The usage of neural network produces results faster and often more reliable. Aki et al derived an estimation of the Zoeppritz equation that allows for a reasonably good estimation of the p and s velocities but falls short for density. The density information is in the third term of the equation and requires long usable offsets which on land data are rarely available (Aki, K., 1980). We developed an innovative approach and are using the LambdaRho – MuRho cross plot to convert seismic information to rock properties. The seismic LambdaRho and MuRho values are derived from pre-stack inversions and are correlated to existing well data. The results indicate that this method yields more accurate results and can separate shale and carbonate units more precisely, Rauch, M. 2022.

Geology

The Permian Basin consists of 3 main sub-basins, the Delaware Basin, Midland Basin and Central Basin Platform, figure 1 sourced from the Encyclopedia Britannica, 2007. In the Delaware Basin, the most productive reservoir units are the Bone Spring and various members of the Wolfcamp. The highest producing shales in the Midland Basin are the Sparberry and the Wolfcamp. This article will focus on the Wolfcamp and Bone Spring shale groups.

Figure 1: Sub-basins of the Permian Basin.

The Wolfcamp Shale that includes Wolfcamp A, Wolfcamp B, Wolfcamp C and Wolfcamp D are present in all three sub-basins. The whole section is between 200 ft and 7,050 ft thick and can be found as outcrop with a maximum burial depth of 10,000 ft (Gaswirth, 2017).

The Bone Spring Formation is up to 4,000 ft thick and is split into 4 different intervals. From top to bottom: The First, Second, Third Bone Spring and the Avalon shale. Both shale units exhibit low porosity and permeability but can be excellent producers when fracked. Figure 2 illustrates the stratigraphic section of the Permian Basin, modified from Rowe, H., 2018

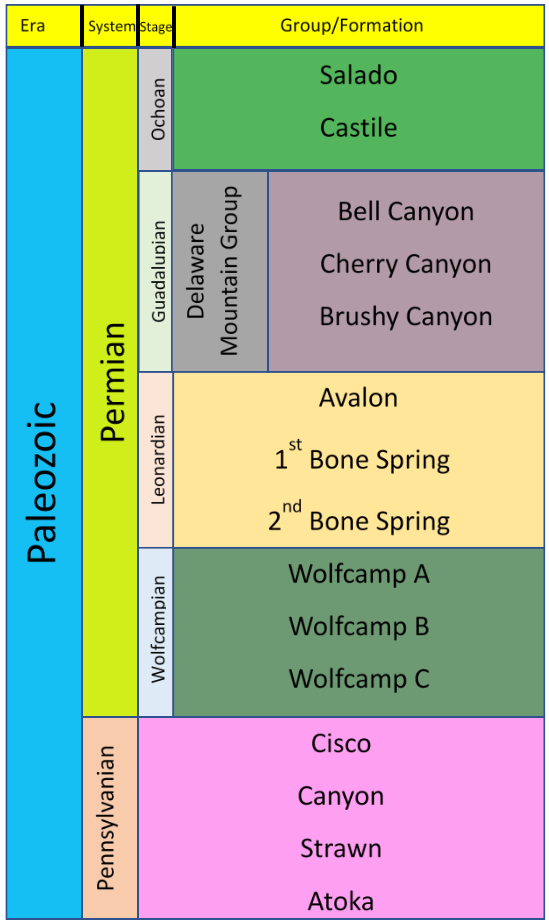

Figure 2: Stratigraphic section of the Permian Basin

Method

Seismic amplitudes and attributes derived from 3D seismic data have been successfully applied to assist in designing lateral well paths. The data allows for a more successful in-zone drilling, highlights sweet spots within the shale units and aids in recognizing geological features like embedded carbonate blocks. Depending on resolution, seismic data contain most of the geological information such as reservoir structure, hardness of the shale, lithology and more. Previous research indicates that the preferred input data for any geological studies is pre-stack depth migrated, Rauch-Davies, M., 2019.

In some instances, the seismic doesn't supply the needed resolution but is very useful for detection. Resolution and detection are defined as two different parameters. The main definition of resolution is the ability to resolve rock boundaries. On the other hand, detection determines the rock type, which can be beyond resolution. To convert the seismic data to rock properties, pre-stack inversions are performed. Besides the actual migrated pre-stack seismic data those also require geological interfaces (horizons) and well data, mainly P and S sonic and density logs. The integration of those data types provides an understanding of the rock properties and lithologies derived from the pre-stack seismic data.

Interpreters use cross-plots from well data to establish and define different rock types. Figure 3 illustrates a rock property classification using the LambdaRho/MuRho cross-plot. Shales clearly separate from other lithologies.

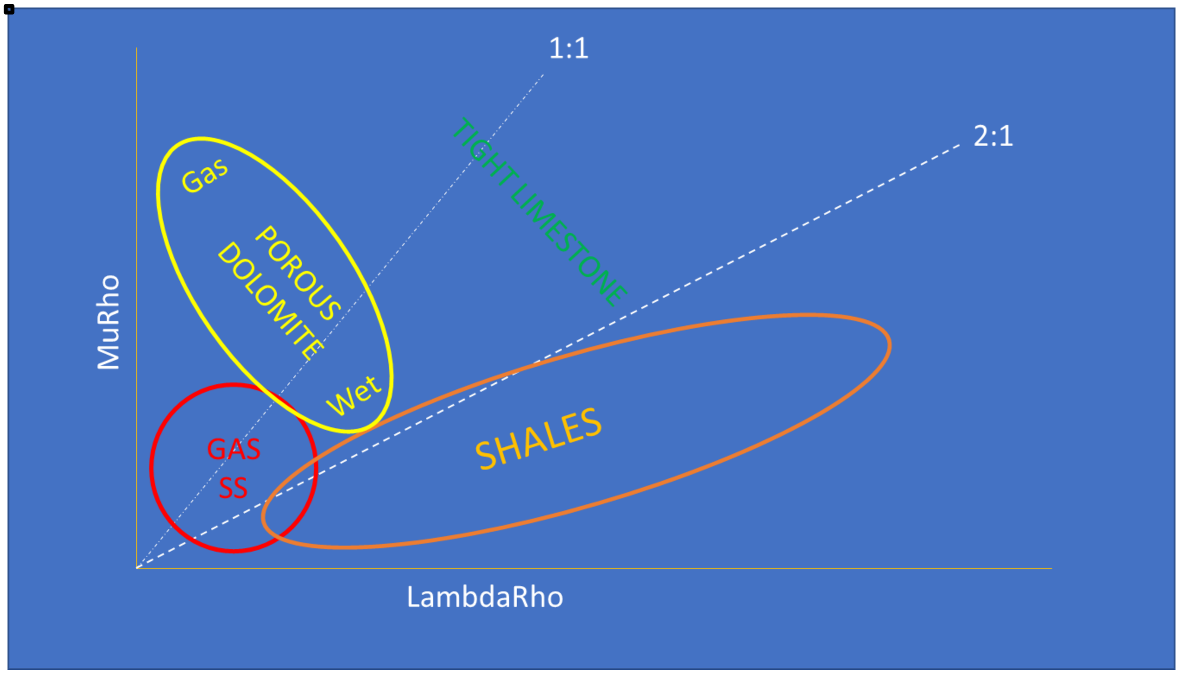

Figure 3: LambdaRho/MuRho cross-plot

Traditionally, a full electrofacies volume from seismically derived sonic and density is generated using neural network predictions. On land data, it is challenging to estimate density values as this information resides in the higher offsets that are mostly contaminated with noise (various wave modes) and not useable. Figure 4a displays the rock property results of this approach and figure 4b shows the rock properties using the more elegant LambdaRho/MuRho cross-plot method along an arbitrary seismic line as shown on image 5. These images clearly show the superiority of the later technique. The rock layers exhibit a better continuity and lesser artifacts are visible.

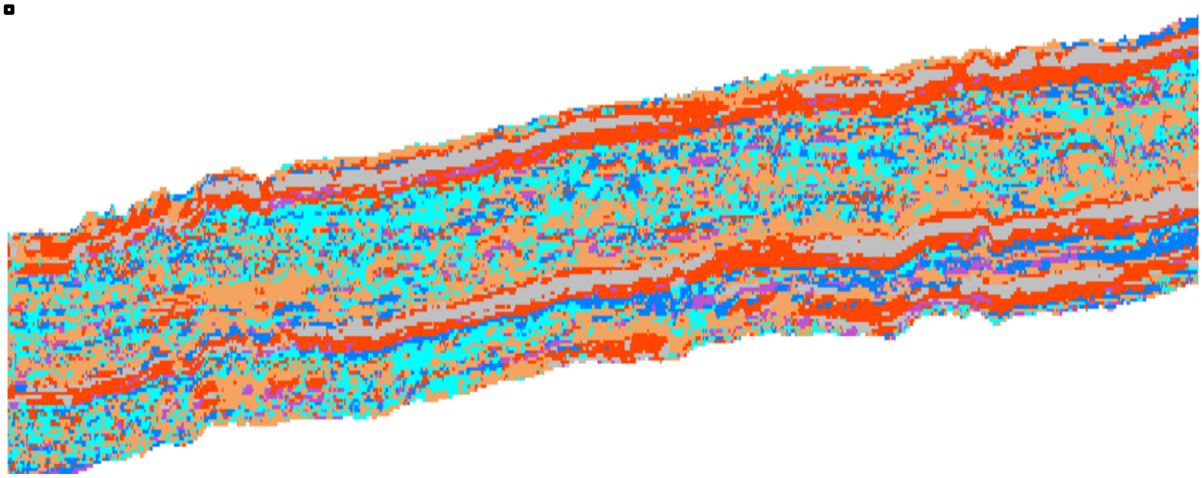

Figure 4a: Rock properties derived using the traditional electrofacies neural network method.

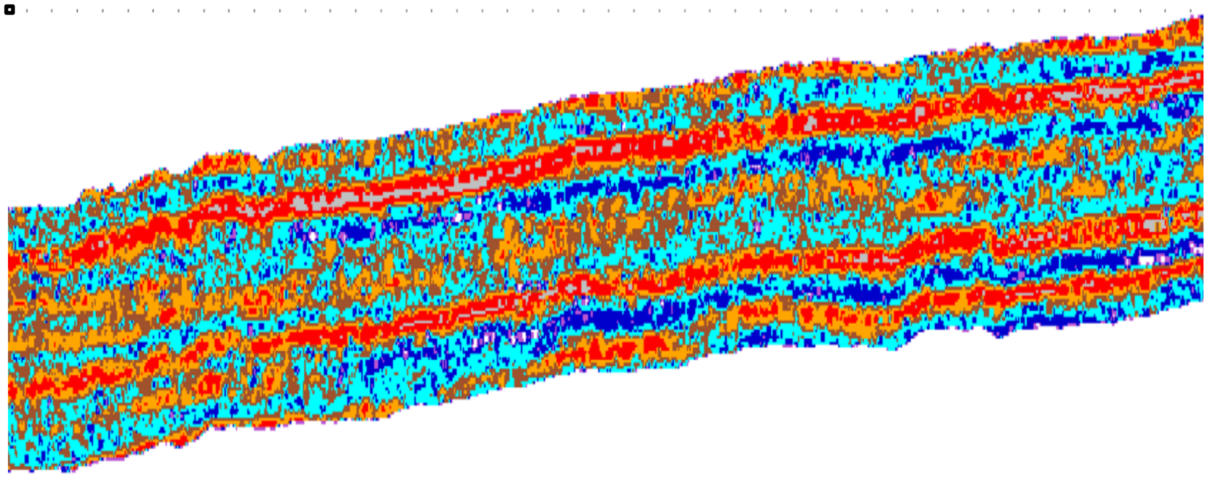

Figure 4b: Rock properties derived using the LambdaRho/MuRho method.

Figure 5 displays TOC map around one of the key producing intervals. Yellow/red colors indicate high TOC, blue colors predict low TOC. This product provides a superior and very detailed tool to design landing zones and plan the location and direction of the lateral wellbore.

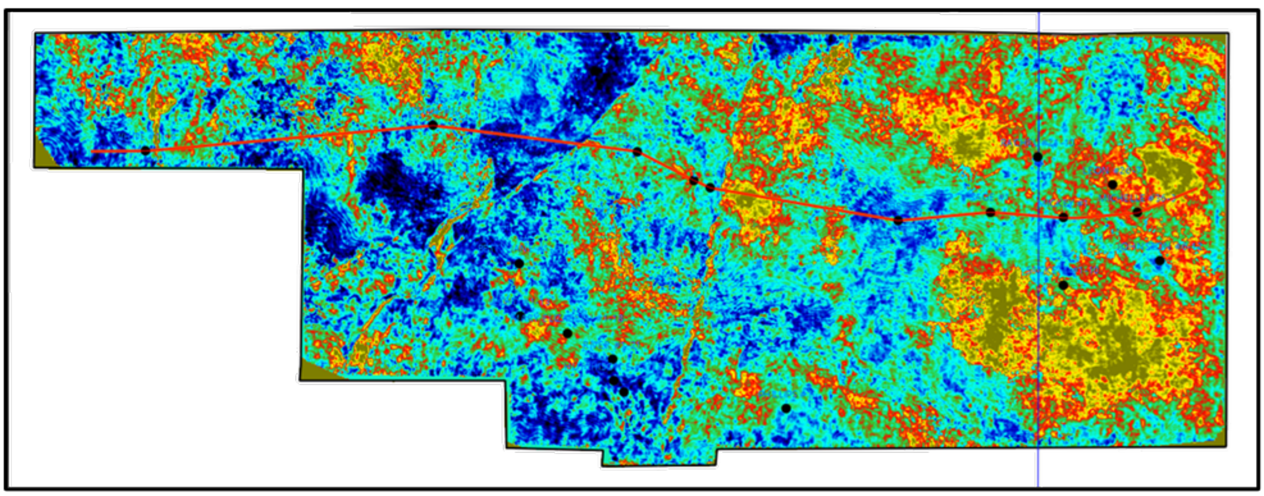

Figure 5: TOC horizon map generated from the LambdaRho/MuRho volume.

Conclusions

Reflection data indicates rock boundaries and are mainly based on velocity variations. Those don't necessarily indicate the rock type of properties. Seismic pre-stack data are very useful to predict rock properties and lithologies. Elastic pre-stack migrations produce relative high-resolution P and S velocities that can then be used to calculate parameters like LambdaRho (incompressibility) and MuRho (rigidity). Traditionally this is done using a neural network approach. The input to this process is pre-stack migrated seismic data, well information, especially P and S sonic and density and seismic horizons. Traditionally, the velocity and density were input into neural network applications to estimate rock properties from seismic directly based on wave propagation relations. It is challenging to estimate density from seismic, and the approximations are highly uncertain as extracting rock density requires long good quality offsets that are normally not available in land data. The LambdaRho/MuRho relationship generated from elastic inversion provides a high-resolution volume of rock property values. Once calibrated with well data, those results can directly be tied to lithologies and are an excellent dataset to assist the engineering (drilling, producing) part of the operations.

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