Z-99 Seismic Data Mining

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Summary

Data mining is a process that seeks to establish patterns and relationships in data that provide information leading to a more rapid uptake of knowledge and understanding of the essential parameters controlling the data being mined.

The process often uses progressive steps such that the results from an earlier step are passed to a subsequent step, gradually reducing the volume of data samples being mined. In this way, it is postulated that each step focuses the elements leading to the final objective of the mining.

In seismic data mining for oil and gas, one such process is proposed as follows. Firstly, the process finds the samples that express a high probability of reservoir mineral, in this case, high quartz content (sand). This objective can equally be a high probability of carbonate, but we example sand here.

Secondly, the total porosity is estimated just for the samples expressing reservoir rock mineral property. This can be accomplished in a qualitative way, by high, medium or low porosity, or more quantitatively by calibrating with well data.

Thirdly, the predominant pore fluid type is estimated, as one of gas, oil or water. Of course, we normally expect to be able to discriminate gas from water pore fluids, while oil pore fluid success invariably depends of the oil PVT properties.

Although well data is not required for each phase of the workflow, it makes sense to calibrate when possible. This makes this form of seismic data mining very attractive for pure exploration activity. Well data permits the use of local rock physics transforms used in the various stages.

Other seismic data mining processes have been developed that target different objectives. Because oil and gas explorers are often more comfortable with the seismic AVO response designed to discriminate AVO Classes. These Classes, as defined by Rutherford & Williams, fall into different sections of the AVO intercept & gradient space. The information is realized by visualizing the AVO classes using different colors. The base reservoir response as well as the top reservoir response may be optionally selected, and the strength of the AVO response may also be optionally color-coded.

While both methods start with what is essentially an AVO inversion, each has its own objectives. The first process works in the layer domain, the second in the interface domain. The explorer can select the most appropriate method to rapidly and robustly focus on regions of the subsurface that warrant further study as required.

Theory

The Castagna mud rock line is well known for its linear relationship *(Equations 1, 2)* of shear velocity (Vs) to compressional velocity (Vp), as well as the variations on the linear relationship, one of which is the Greenberg-Castagna relationship used to estimate Vs over quite a large range of Vp for Gulf of Mexico type rocks.

$$Vs = 0.8042Vp - 0.8559 \quad \text{for sandstone} \quad (1)$$

$$Vs = 0.7700Vp - 0.8674 \quad \text{for shale} \quad (2)$$

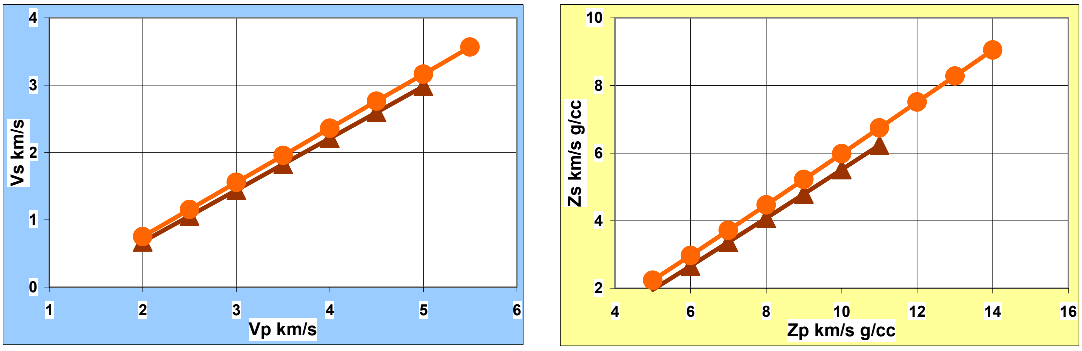

Figure 1: Vs versus Vp based on Greenberg/Castagna & density versus Vp based on Gardner power law for shale (triangles) and sandstone (circles).

It is intuitive, that the shear impedance (Zs) and the acoustic impedance (Zp) are similarly related in a linear fashion, since the velocity axes of the velocity relationship are simply multiplied by the same property, density. It follows that a linear relationship of Zs to Zp is independent of any relationship of density to Vp, therefore it may be possible to analytically derive the Zs to Zp transform using the simplest Density to Vp transform.

A common relationship for density related to Vp is the Gardner relationship *(Equations 3,4)*, which supports parameters for polynomial or power relationships for both shale and sandstone.

$$\rho = 1.75\ Vp^{0.265} \quad \text{for shale} \quad (3)$$

$$\rho = 1.66\ Vp^{0.261} \quad \text{for sandstone} \quad (4)$$

Introducing these density relationships into the Vs to Vp relationship results in a linear relationship between Zs and Zp.

$$Zs = 0.7100Zp - 1.592 \quad \text{for shale} \quad (5)$$

$$Zs = 0.7579Zp - 1.582 \quad \text{for sandstone} \quad (6)$$

Equations 5 and 6 are similar to those for velocity, and the addition of rock physics analysis for local trends between velocity and density can optionally be used. In the absence of local trends, the Greenberg-Castagna and Gardner trends are thought to be quite robust.

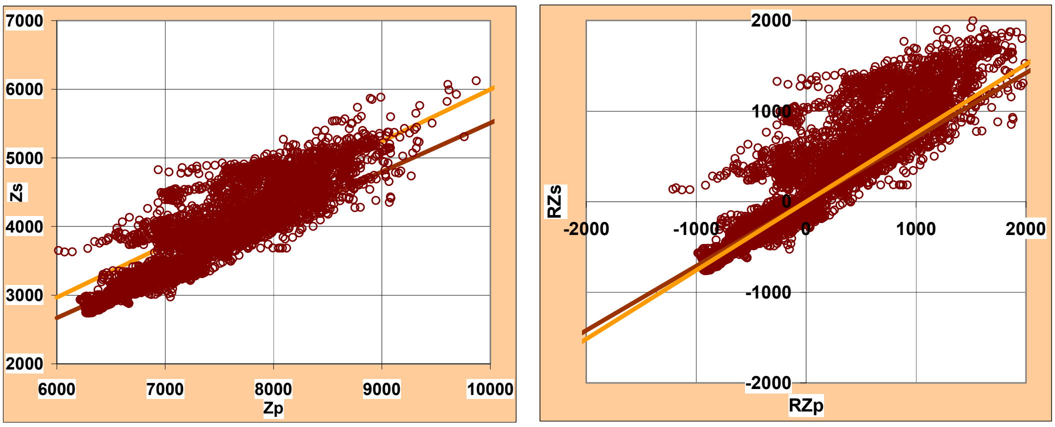

Figure 2: Absolute & Relative Acoustic, Shear Impedances

Descriptions afforded by the absolute Zs to Zp relationship transcribe into the relative domain, such that the low frequency components are removed to simulate seismic equivalent attributes.

In the relative domain, the constant is lost leaving just the slope of the relationship. However, many of the elements of the descriptions seen in absolute domain are carried through to the relative domain.

Generally, in a clastic environment, most of the rock is shale with different sandstones embedded in the sediment column. This tends to cause the mass of data samples to be grouped near a line intersecting the origin of the relative space. However, some separation is still evident between sandstone and shale, which is quite pronounced for gas charged low impedance sandstone for example.

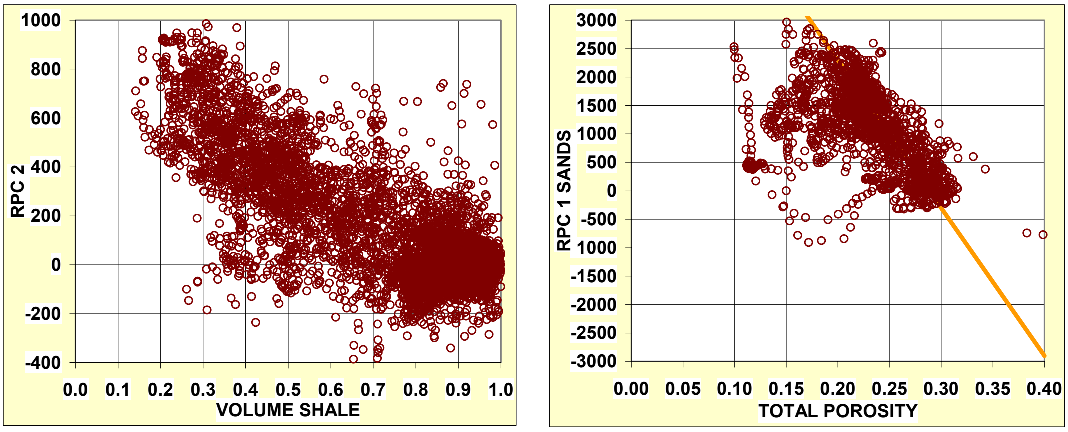

Figure 3: Principal Component of relative Zp and relative Zs RPC2 on the left and defined sand samples for RPC1 on the right

We take advantage of this by applying linear principal component analysis (PCA) to the relative Zs, Zp data. Applying PCA to just two attributes amounts to an axis rotation, the parameters for which are computed from the slope of the shale line in the relative impedance domain. Since the Zs to Zp relationship is linear it is well suited to analysis by linear PCA or axis rotation.

Our interpretation of the Zs, Zp domain tells us that the PC1 (the major axis of the analysis along the shale line) responds mostly to porosity, while the PC2 direction (normal to the shale line) responds mostly to lithology.

Application to Seismic Data

Using an appropriate AVO inversion method, estimates of RZp and RZs provide equivalent attributes to those discussed in theory. The seismic derived attributes require some calibration to determine the PC2 sand cut-off. The porosity estimate is made from the PC1 attribute, while the fluid type attribute is estimated from the Lambda-rho equation.

This paper introduces lithology, porosity and fluid type data mining process that rapidly and robustly bring the oil and gas explorer those zones in the subsurface that demand more detailed study. This procedure circumvents the requirement to manually or visually inspects large volumes of 3D seismic data when looking for prospective leads.

References

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