Cross-plotting shows anomalies

Cross-plotting attributes in three dimensions makes it possible to look through more data quickly and conveniently.

AUTHORS

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Cross-plotting has evolved to be a widely used technique in attribute vs. offset (AVO) analysis as it enables the simultaneous and meaningful evaluation of two attributes with ease. Generally, common lithology units and fluid types tend to form separate clusters in AVO cross-plot space, and this helps in making a straightforward interpretation.

We explore here the advantages of using 3-D cross-plot visualization in the derived elastic parameter cross-plot space. We first begin by visualizing the different combinations of the measured well log parameters — P-velocity (V_P), S-velocity (V_S), density (r), porosity (f), and gamma ray — in two and three dimensions. Next, we compare the visualization of these observed patterns with the patterns seen in the derived elastic parameter cross-plot space. We then extend this analysis to three dimensions for both well log and 3-D seismic data. Clusters hanging in 3-D space are more readily recognizable and diagnostic, resulting in accurate, reliable and hence useful interpretation.

Example for well log data

This example is for the Barnett Shale gas play. The lithology is indicated with the conventional legends for shale and limestone (Figure 1a). The shale unit is essentially Barnett Shale producing gas. There are two limestone units — one is tight, as seen at the bottom of the sonic log, and the other one is a composite unit consisting of dolomite and limestone, but is wet. The upper unit we have named "regional lithology," as no information for this was available. The goal here is to understand well log attribute combinations distinguishing different lithologies, reservoir rocks and fluids. A traditional well log evaluation would involve comparing the different available log curves, which usually proves to be an impractical method of making predictions about production, for example, from Barnett Shale. The available suite of log curves was loaded into the GeoCore software developed for the purpose. It has 2-D /3-D cross-plotting features for both well log and seismic data and their derived attributes.

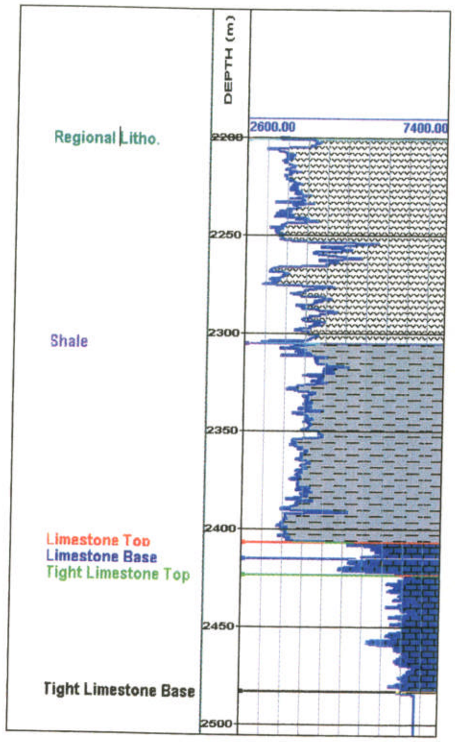

Figure 1a: This velocity log shows stratigraphy and formation tops from the Barnett Shale gas play.

The different formation tops are seen marked on the log curve (Figure 1a), and the color assigned to each formation top activates the range of points seen on the cross-plot from that formation top to the next one. Gas is being produced from the shale unit (purple) and overlain by impermeable unit (regional lithology) that serves as a "frac" barrier.

The cross-plot of V_P-V_S shows all these units as clusters and enclosed within ellipses. The wet limestone actually comprises two units. One is the dolomite and the other limestone. The dolomite unit has a high concentration of pyrite and calcium phosphate nodules. Four best-fit lines can be drawn on the V_P-V_S crossplot, if desired — one for regional lithology, one for shale, one for wet lithology (limestones) and one for dolomite.

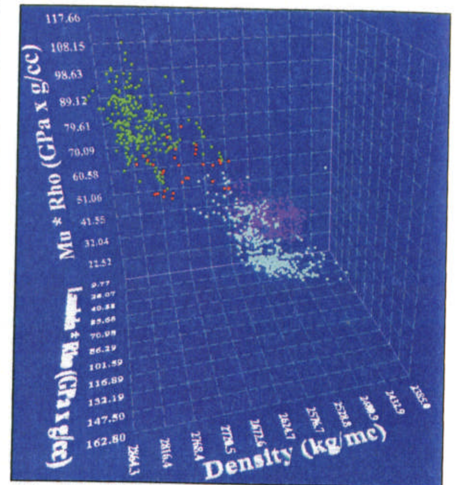

Figure 1b: This 3-D cross-plot shows Lambda-Rho – Lambda/Mu ratio – Density.

The Lambda-Rho vs. Mu-Rho cross-plot shows the different units as distinct clusters that are better separated. All such cross-plots can be generated on the fly. Lambda-Rho is a sensitive indicator of water vs. gas saturation, and Mu-Rho is used to help define pure rock fabric or lithology. The carbonates show a large variation range on the Lambda-Rho vs.

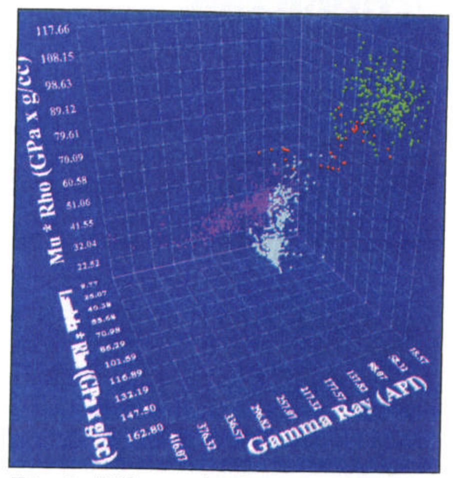

Figure 1c: A 3-D cross-plot of Vp – Vs – Gamma Ray. Such a cross-plot allows the interpretation of three attributes together, and the individual clusters can be studied by simply turning the cube from one side to the other.

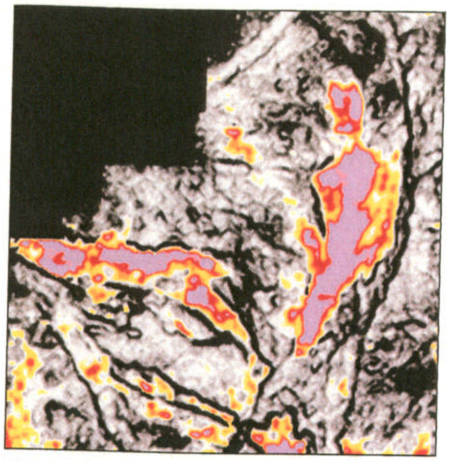

Figure 2a: This composite display of reservoir channel sands shows that while the boundaries of the channels are seen distinctly on the coherence slice, the high amplitude envelope values indicate sandstone deposition. This is independently confirmed by Lambda-Mu-Rho analysis.

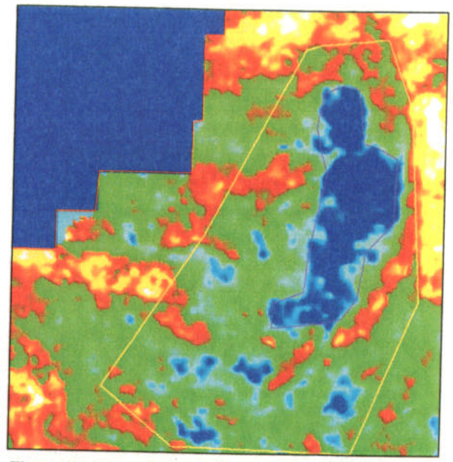

Figure 2b: Polygons selected on a time slice from the Lambda-Rho volume. The red polygon encompasses the entire are being analyzed.

Mu-Rho cross-plot. Lambda-Rho changes from 50-150, and Mu-Rho changes from 50 to 120. Porosity is the major factor causing this change. LMR (Lambda-Mu-Rho) attributes thus show the advantage to map porosity changes. Similarly, the cross-plot of Lambda-Rho vs. Mu-Rho indicates the gas shale cluster depicting low values of both Lambda-Rho and Lambda/Mu ratio as expected.

We may add a third axis to each of these plots by bringing in density or gamma-ray curves. Figures 1b and 1c show the 3-D cross-plots one with density and the other with gamma-ray. As expected, looking at the 3-D cross-plot in Figure 1b, tight limestone shows the highest density followed by the wet limestone and shale. Similarly, in Figure 1c, the gamma ray values are very low for the tight and wet limestone, while the Barnett Shale shows a cariation. All this information is retrieved simply by turning the 3-D plot about the vertical axis. The 3-D cross-plot shown is for Lambda-Rho-Mu-Rho-Density and gamma ray. Alternatively, Vp, Vs or any of the other attributes could be meaningfully used.

Interactive AVO cross-plotting

Interactive 3-D cross-plotting is computationally intensive. To get a feel for this computation, a 40 sq mile (100 sq km) area with a 500 millisecond (ms) time window at 2 ms sample rate and a square bin of 82 ft (25 m) will generate 40 million pairs.

With the fast processing speeds of the computers available today, it is possible to load this bulk of data, but the quantity of data coming in could be overwhelming in that the high density of individual points, due to their opacity, may mask the extraction of meaningful information from the clusters that the anomalies entail.

Example from seismic data

Figure 2 shows an example from a producing Cretaceous-aged gas field in southern Alberta, Canada. A Coherence Cube was generated for the reprocessed 3-D seismic volume. The data were datumed on an easily mapped Upper Cretaceous marker to remove distortions of regional dip from time slices at the zone of interest. Figure 2a shows a datumed time slice through a composite coherence volume where the high amplitude envelope attribute values (seen in color) have been merged with the coherence (seen in black, white and grey).

Figure 2b shows a time slice from a Lambda-Rho volume where the gas anomaly is indicated by the blue patch. We would expect a gas sand to exhibit low values of Lambda-Rho, high values of Mu-Rho and negative values of fluid stack. Fluid stack highlights zones where the P-reflectivity is different from S-reflectivity. While these two will be pretty much the same, for gas-bearing zones the P-reflectivity will be different (lower) than the S-reflectivity, and an indicator that displays these differences is interesting. Figure 2c shows these three indicators cross-plotted for a gas anomaly, (Lambda-Rho on the x-axis, Mu-Rho on the y-axis and fluid stack on the z-axis).

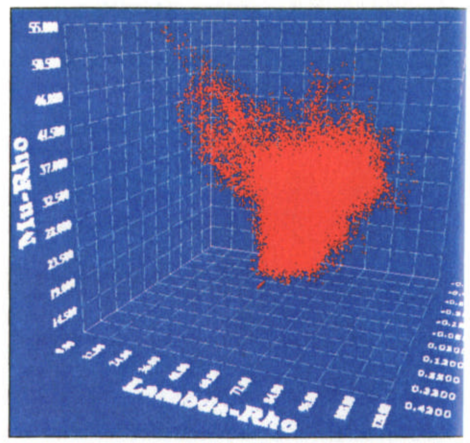

Figure 2c: Points within the red polygon only are seen in the 3-D cross plot.

A polygon (red) is drawn to select the live data points on the time slice that can be brought into the cross-plot. The red cluster of points seen in Figure 2c comes from five time slices (2 above and 2 below the one shown in Figure 2b) that have been selected for the purpose. It is possible to narrow down on a given anomalous region by drawing different colored polygons and looking at the clusters they light up in 3-D cross plot in that color. As the cross-plot is turned towards the left on the vertical axis, the fluid stack shows the expected negative values for the gas sand. It is possible that the clusters of points coming from outside the anomaly clutter the cross-plot and may mask the points coming from the anomaly. A selection of points coming from any polygon can be incorporated into the software to allow the desired set of points to be displayed in the cross plot. E&P