Using LMR for Dual Attribute Lithology Identification

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Summary

Amplitude versus offset (AVO) analysis of pre-stack seismic data has made several advances since Shuey's (1985) approximation to the Knott's-Zoeppritz equation made it practical. By combining AVO attributes and geology, petrophysical properties of the rocks and fluids that make up the reservoirs that interpreters are interested in are better predicted than with AVO analysis alone. Lambda-Mu-Rho (LMR) analysis is one example of how interpreters are using advanced AVO analysis to identify hydrocarbons and reservoir rocks (Goodway et. al., 1997; Gray and Andersen, 2000). LMR analysis, even in the most classic of circumstances, requires cross plotting or the interpretation of multiple volumes of data to correctly interpret lithology and fluids. By using petrophysics to scale the Lambda-Rho ($\lambda\rho$) and Mu-Rho ($\mu\rho$) volumes, lithology volumes can be based upon rock properties and AVO. Typically this is done through interactive cross-plot analysis of the LMR volumes which are often difficult to reproduce and save for future work.

Theory

Goodway demonstrated how LMR analysis can be used to identify gas sands. This comes from the separation in responses of both the $\lambda\rho$ and $\mu\rho$ sections to gas sands versus shales. In some reservoirs, it is possible to separate lithologies at an even finer scale so as to identify wet sands from shales and carbonates. This can become particularly important in steam flood and injector planning in order to identify the optimum zones to inject fluids. By using petrophysical parameters to scale the results of LMR analysis, 3D seismic volumes can be converted into lithology cubes.

Many different lithologies can be identified by cross-plots of $\lambda\rho$ versus $\mu\rho$. Each lithology has a different rock properties response subject to fluid content and mineral properties (including grain shape). The combination of the fluid compressibility along with the mineral properties and grain shapes yielding different LMR results. For example in a gas sand, the high compressibility (or low *incompressibility*) of gas combined with the high rigidity of the spherical sand grains, result in a low $\lambda\rho$ value (~ < 20 GPa.) and a high $\mu\rho$ response (~ > 20 GPa.). With an understanding of these properties for the lithologies and fluids present, typically from petrophysics, a relatively high degree of precision in lithologies and fluids can be obtained.

Gray and Andersen (2000) demonstrate how LMR cross plot analysis can be used for lithology discrimination (Fig. 1). They conclude that neither $\lambda\rho$ nor $\mu\rho$ are powerful lithologic indicators by themselves, but used in combination can reveal a great deal about lithology. By properly scaling the LMR volumes, it is possible to create a lithology volume. This scaling can be based upon petrophysical analysis.

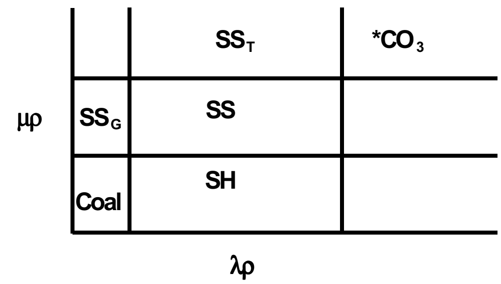

Figure 1: From Gray & Andersen (2000). Cross plot of $\lambda\rho$ versus $\mu\rho$ depicting the orthogonal separation of lithologies. Terms listed above are defined as: SH – Shale, SS – Sandstone, SS_G – Gas saturated Sandstone, SS_T – Cemented Sandstones, $*CO_3$ – Carbonates.

Method

There are a variety of ways to derive lithology sections from LMR results, of which two are discussed here. The first method is best suited for simple lithologies (clastics *or* carbonates) and is a simple procedure of scaling the LMR volumes. First, the amplitude limits of the $\lambda\rho$ and $\mu\rho$ volumes are derived from the data. Then each volume is subdivided into sections based upon amplitudes. For example the $\lambda\rho$ volume could have amplitudes that span the range of 5 GPa to 55 GPa, which is then divided into 10 groups, each 5 GPa. wide. Each group is assigned an integer value between 0 and 9. After a similar procedure is done with the $\mu\rho$ volume, the two scaled volumes can then be combined into a single volume by multiplying the scaled $\lambda\rho$ by 10 and adding the scaled $\mu\rho$, resulting in integer values between 0 and 99 (Fig. 2). These values represent 100 different cross-plot regions and can take advantage of the orthogonal separation of lithologies in a LMR cross-plot to represent different lithologies.

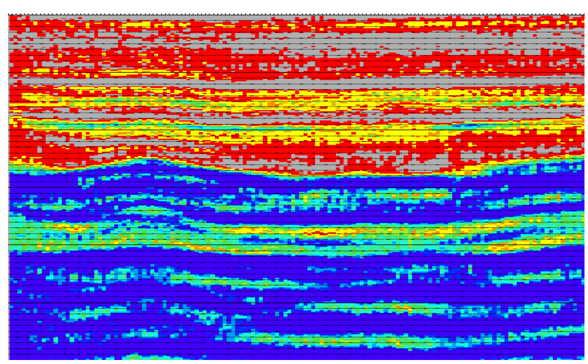

Figure 2: Example of combined scaling of dual attributes to produce a cross-plot zone identification section.

The second method can easily take advantage of petrophysical analysis of well log data to determine exactly where within the cross-plot different lithologies will appear, including complex lithologies (e.g. limey shales). By this procedure, each lithology is defined from well log data in terms of its LMR response. From petrophysical analysis, polygons are derived to classify each lithology within the cross-plot. A batch process is then used to assign a value to each lithology (one value for each polygon). This is then output as a single volume with integer values that represent the different lithologies present. This method has several advantages over the previous one discussed.

First, it can be directly calibrated to well control to accurately represent the various lithologies present. In addition, it can describe polygons of any shape, not only simple rectangles in LMR space, as was discussed with the previous method. As a result it can provide more accurate detail of porosity and fluid saturation, should sufficient calibration be possible. This method can also be applied to various other attributes, including P- and S-wave reflectivities, fracture orientation and fracture density, and even well log data such as water saturation versus resistivity.

Conclusions

Given suitable petrophysical conditions, The method described here can be applied to LMR results to produce volumes that provide a direct indication of both lithology and fluid content. Should the data warrant, this procedure can be expanded to three or more volumes so as to better classify lithologies and fluids. Additionally, this procedure may also be applied to reflectivity data as a means to classify AVO anomalies from almost any group of attributes.

Acknowledgements

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