AVO Interpretation in LMR Space: A Primer

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Summary

In this paper we present how the more frequently used AVO attributes such as P-impedance, S-impedance, V_p/V_s and Poisson's Ratio petrophysically relate to $\lambda \cdot \rho$ and $\mu \cdot \rho$ as well as to each other in the LMR crossplot space. We also present how the magnitude and direction of anomalous movement away from a given non-reservoir reference point in LMR crossplot space can be related to fluid content and AVO class respectively, of the reservoir under scrutiny. Finally we point to possible LMR interpretation pitfalls due to the fact that multiple combinations of mineralogy, fluid and porosity can produce ambiguities in the LMR crossplot space.

Introduction

The use of $\lambda \cdot \rho$ and $\mu \cdot \rho$ (LMR) parameters have been proven to be key lithology and fluid indicators in quantitative AVO interpretation (Goodway et al. 1997, Goodway 2001). This ability to discriminate between lithology and fluid effects can be better understood if the LMR crossplot space is related to the other well known and more commonly used AVO attributes such as P-impedance, S-impedance, V_p/V_s and Poisson's Ratio.

Petrophysically relating these more commonly used AVO attributes both to $\lambda \cdot \rho$ and $\mu \cdot \rho$ and to each other in LMR crossplot space can be be very instructive for the quantitative AVO interpreter in helping to understand the AVO class (see Rutherford and Williams, 1989 and Castagna and Swan, 1997) of the reservoir in question, first from a log modeling perspective and then, how this may be impacted by incorporating band-limited seismic data.

Finally, interpretation of AVO classes and LMR crossplot space is not without inherent ambiguity common to all seismic petrophysical analysis and the interpreter needs to take care in understanding how this ambiguity may arise. However, this ambiguity is worse in the case of AVO as only relative anomalies due to changes in V_p/V_S or Poisson's Ratio are detected. By contrast, log-calibrated LMR inversion can provide a quantitative extraction of rock properties to clearly discriminate lithology, porosity and fluids thereby overcoming the ambiguity caused by the coincidence of these properties in AVO interpretation.

Still, various unusual combinations of mineralogy, fluid and porosity can cause confusion in the LMR interpretation with respect to their discrimination. The use of porosity trend lines, along with a solid understanding of the depositional environment in which the reservoir was formed, can aid the interpreter to discount much of this ambiguity and better constrain the AVO interpretation.

Method

The relationship $\lambda \cdot \rho = I_p^2 - 2\mu \cdot \rho$ follows from the laterally constrained axial modulus that determines seismic P-wave propagation. In LMR crossplot space, $\mu \cdot \rho$ is coventionally plotted on the y-axis and $\lambda \cdot \rho$ on the x-axis. As such, lines of constant P-impedance can be plotted using the following expression:

$$x = I_p^2 - 2y \tag{1}$$

where the user simply substitutes a number of I_p values spanning the range of the data (see constant P-impedance lines in Figure 1). Similarly, $\mu \cdot \rho = I_s^2$ so that lines of constant S-impedance can be plotted in LMR crossplot space using the following expression:

$$y = I_s^2 \tag{2}$$

and substituting a number of I_s values spanning the range of the data (see constant S-impedance lines in Figure 1). Also, it can be shown that $\lambda/\mu = \left(V_p/V_s\right)^2 - 2 = 2\nu/1 - 2\nu$ where ν is Poisson's Ratio. This demonstrates how λ/μ, V_p/V_s and ν are all inter-related. Lines of constant V_p/V_s can be plotted in LMR crossplot space using the following expression:

$$x = \left[\left(\frac{V_p}{V_s}\right)^2 - 2\right] \cdot y \tag{3}$$

and, again, substituting a number of V_p/V_s values spanning the range of the data (see constant V_p/V_S lines in Figure 1). Therefore, for a given range of λ/μ, equivalent values of V_p/V_s and ν values can be computed.

Examples

Figure 1 presents a schematic outline of how to begin the AVO interpretation using LMR data. It is generally agreed, to first order, that the presence of fluid contained within the pore space of a rock volume has little impact on the rock's shear strength. As such, anomalous movement due to a fluid effect in LMR crossplot space must be in a direction horizontal or sub-horizontal to the lines of constant S-impedance (i.e. no change in S-impedance; see lines of constant S-impedance in Figure 1). Similarly, porosity and P-impedance have a strong negative correlation. That is to say, significant porosity increase in a reservoir rock produces a significant decrease in its P-impedance. As such, anomalous movement due to a porosity effect in LMR crossplot space must be in a direction normal or sub-normal to the lines of constant P-impedance which generally is in the direction of the origin (i.e. greatest change in P-impedance; see lines of constant P-impedance in Figure 1)

Rutherford and Williams (1989) along with Castagna and Swan (1997) defined four distinct AVO classes based on the relative P-impedance and AVO gradient change between non-reservoir and reservoir units (i.e. top of reservoir; see inset in the bottom right hand corner of Figure 1). It is important to note that all these AVO classes exhibit a decrease in both V_p / V_s and ν. This manifests itself in LMR crossplot space as a counterclockwise rotation from a reference point. Class I consists of high P-impedance contrast reservoirs (i.e. low to high P-impedance change) and, as illustrated in Figure 1, this is expressed in LMR crossplot space as points with larger values of P-impedance, relative to the reference point (see cyan colored area on Figure 1). Class II are near-zero impedance reservoirs (i.e. very little change in P-impedance). Referring to Figure 1, these are points located parallel or sub-parallel to lines of constant P-impedance, relative to the reference point (i.e. no change in P-impedance; see blue colored area on Figure 1). Finally, Class III and IV are low impedance constrast reservoirs (i.e. high to low P-impedance change) which correspond to points with smaller values of P-imedpance, relative to the reference point (see orange and green colored areas in Figure 1).

AVO/LMR interpretation is not, however, without ambiguity and it is important to understand where this uncertainty lies. Referring to Figure 1, consider a group of points in LMR space that lie directly to the left of the 10% limestone porosity point. What do these points indicate? Is it a hydrocarbon saturated limestone reservoir or is it wet dolomite with a significant amount (~15%) of clay content? Numerous different combinations of mineralogy, fluid and porosity can exist in a LMR crossplot which can lead to ambiguity. Understanding the depositional environment allows for an interpreter to discount a large number of these possibilities and constrain the solution.

Conclusions

An LMR dataset can be a powerful tool in helping to interpret AVO for any seismic play. Common AVO attributes can be superimposed to help better understand the anomaly. The main key in understanding the crossplot is the depositional context that the data is attempting to represent. By limiting the range of porosities and mineral types that are expected, LMR anomalies can be interpreted accurately.

Acknowledgements

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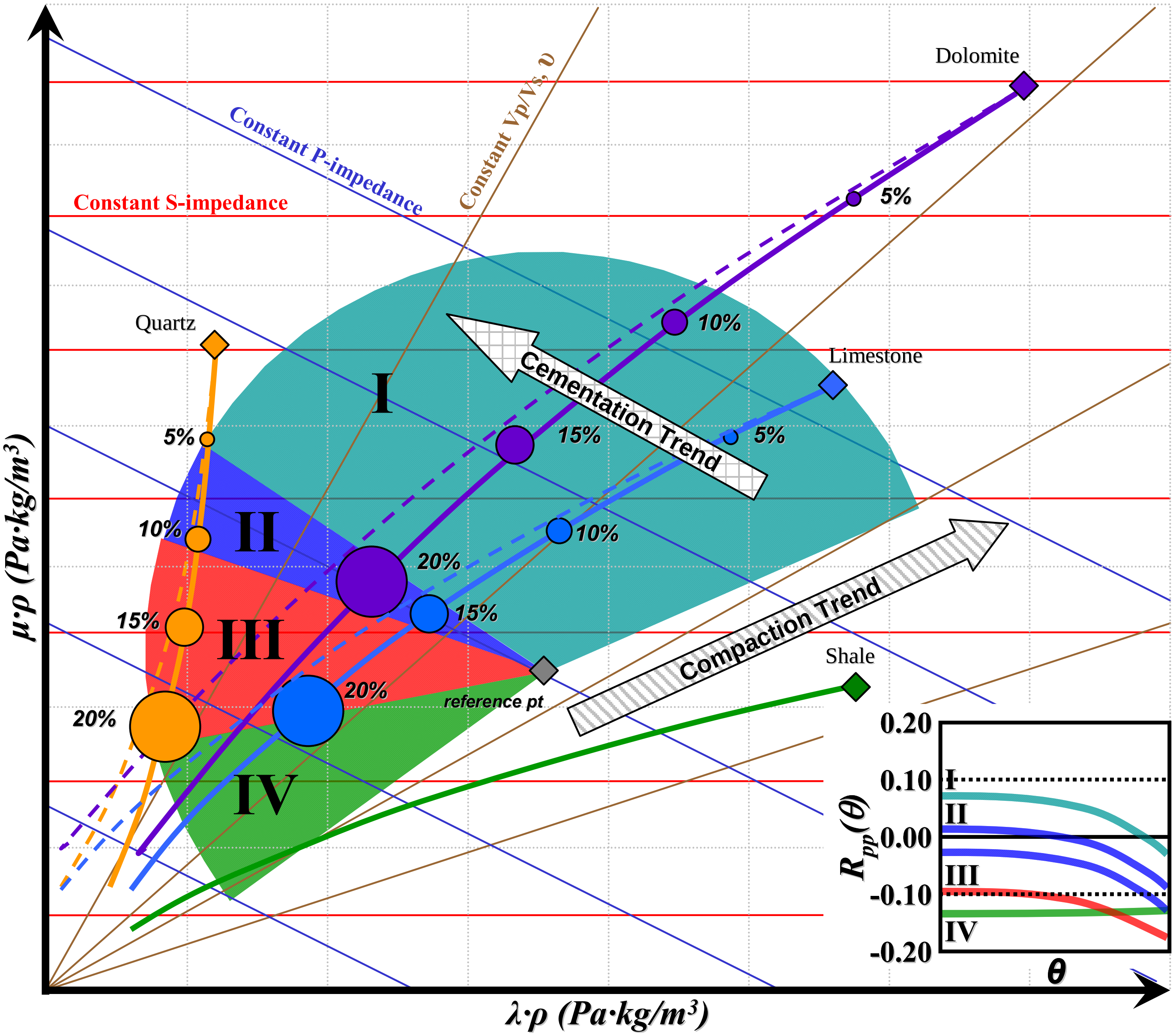

Figure 1: Schematic LMR crossplot indicating differences in mineralogy, porosity and fluids effect. Lines of constant Ip, Is, Vp/Vs and Poisson's Ratio have been mapped in LMR space. The solid curved lines represent the direction of porosity increase and the dashed curved lines represent the same porosity increase but shifted due to hydrocarbon presence. Superimposed is a general AVO indicator displaying where different AVO classes would appear on the crossplot for a given reference point. Inset in bottom right corner are AVO classes as originally defined by Rutherford and Williams (1989) and Castagna and Swan (1997).