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Density Estimates from Pre-Stack Seismic Inversion

Fred M Peterson, Consultant, Brian H. Russell and Daniel P. Hampson, Hampson-Russell, a CGG Company

Summary

An interpreter's perspective on the reservoir can be enhanced by the use and understanding of density volumes estimated through the simultaneous inversion of pre-stack P- wave seismic data, as described by Hampson et al, 2005. Although it has been stated that density estimates for low far angles of incidence are difficult to obtain, we present a rationale and an example of where it is possible to obtain useful density estimates from low angles.

Introduction

Density is a key measure of reservoir quality in both clastic and carbonate rocks and is used extensively by geologists and reservoir engineers to quantify and model reservoirs. Quantified density estimates from seismic can be a valuable addition to an exploration and development decision-making process. The simultaneous inversion process can be viewed as combining low angle pre-stack, P-wave reflection seismic data with Gardner's equation which relates P-wave velocity and density (Gardner et al, 1974), and the Greenberg- Castagna equation (Greenberg et al, 1992), which relates P-wave and S-wave velocity. The addition of these two empirical equations to the AVO intercept and gradient information from low angle seismic data enables density estimates to be reliably calculated. These density estimates can be a very useful interpretive tool in the understanding of the geology of the reservoir and the quantification of reservoir properties.

Theory and/or Method

The simultaneous inversion approach utilized here incorporates the Fatti equation (Fatti et al, 1994), and imposes a linear relationship between the natural logarithm of P-impedance and density and a second linear relationship between ln(Zp) and ln(Zs).

Gardner's equation was derived from lab measurements from a sample of rocks and is given by

$$\rho = \alpha V_p^{\beta} \qquad 1$$

where ρ is bulk density, V_p is p-wave velocity, and α and β are emperically derived constants. This can be shown to be mathematically equivalent to relationship:

$$\ln(\rho) = [\beta/(\beta+1)]\ln(Zp) + \ln(\alpha)/(\beta+1) \qquad 2$$

This is the linear constraint equation of the Hampson et al. (2005) approach to simultaneous inversion. Crossplotting the logarithm of P-wave velocity of the sonic log against the logarithm of bulk density for the rocks of interest allows the necessary constants to be estimated. Similarly the linear relationship between $\ln(Z_p)$ and $\ln(Z_s)$ can be shown to be an approximation to the Greenberg-Castagna equation and similarly estimated.

For offset angles of less than 35 degrees it has been pointed out by several authors that the third term of the Fatti equation is so small that it is generally neglible for seismic data. The Fatti equations then reduce to two equations that essentially relate estimated seismic intercept and gradient information to changes in P-impedance and S-impedance. Assuming that the seismic data data wavelet is stable and can be estimated and the reflectivity data inverted, then we are left with four equations relating the three elastic parameters, Z_p, Z_s, and ρ. Solving the overconstrained system of four equations using the least-squares error technique yields the P-impedance, S-impedance and bulk density estimates. The quality of the density estimates is determined by a number of factors varying from seismic data quality, elimination of multiples and other imaging issues combined with the validity of the imposed local knowledge empirical equations. Variance variables in the inversion process allow the weighting between the Gardner equation and Z_p - Z_s equation to be controlled by the interpreter to reflect local knowledge of the rock properties.

Density estimate volumes enable a different perspective on the rock properties and geology than seismic impedance volumes and can yield important additional quantified information about the reservoirs. The low gas saturation or fizz gas problem creates a seismic impedance anomaly but doesn't impact the bulk density significantly, so density volumes can potentially solve that problem. Density logs in clastics are often far more useful for reservoir evaluation than sonic logs or impedance logs. Sonic logs in carbonates have a bit more functionality but are still in second place behind density logs, so reliable density volumes can be quite informative.

Examples

An example from offshore Tunisia Tertiary clastic rocks illustrates how the well log data and rock properties are changed by the presence of hydrocarbon fluids. Density is a clear discriminant for the hydrocarbon fluids. Marine sand trends on strata slices with defined sharp boundaries and definition from the density estimates are clearer when compared to the impedance data. The trends conform very well with the geological knowledge of the area. This improved definition of geology is what is expected from regional observations of the density and sonic logs. Rock bulk density is distinct and definitive of clean sand presence and reservoir character. Velocity is variable, sometimes informative, but generally poorly correlated to sand presence and reservoir quality.

Conclusions

Density is a key rock property and can be estimated from low angle pre-stack seismic inversion of P-wave reflectivity data. Understanding the rock property environments and uncertainties embedded within the inverted density estimates is a critical area for analysis by sub-surface geoscientists.

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References

Fatti, J., Smith, G., Vail, P., Strauss, P., and Levitt, P. 1994, Detection of gas in sandstone reservoirs using AVO analysis: a 3D Seismic Case History Using the Geostack Technique: Geophysics, **59**, 1362-1376

Greenberg, M. L., and J. P. Castagna, 1992, Shear-wave velocity estimation in porous rocks: Theoretical formulation, preliminary verification and applications: Geophysical Prospecting, 40, 195–209.

Gardner, G.H.F., Gardner, L.W. and Gregory, A.R. 1974, Formation velocity and density - The diagnostic basics for stratigraphic traps: Geophysics, **50,** 2085-2095.

Hampson, D.P , Russell, B.H and Bankhead,B, Simultaneous inversion of pre-stack seismic data; SEG/Houston 2005 Annual Meeting.