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Effect of overpressure and diagenesis on seismic attributes and AVO analysis of stiff reservoirs

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Introduction

Pore pressure build-up in sedimentary formations shifts part of the overburden stress from the rock skeleton to the pore fluids. This load transfer alters elastic wave velocities and tends to preserve porosity under burial. Although overpressure mechanisms are widely studied for drilling hazard mitigation, their impact on amplitude variation with offset (AVO) responses remains underexplored. In this work, we implement a pressure-sensitive rock physics framework to quantify the elastic behaviour of shales and sandstones under varying stress regimes. Using data from core plugs, well logs, and 3D seismic volumes, we analyse how compositional and diagenetic differences influence the pressure dependence of seismic attributes in the offshore French Guiana and Amapá basins. Our modelling demonstrates that elevated pore pressures lead to reductions in both intercept and gradient reflectivity amplitudes, occasionally shifting AVO responses from class I to class II. However, through interpretation of the field seismic dataset, we attribute some observed amplitude dimming not to pressure alone but to inhibited quartz cementation—linked to differential diagenesis—which preserves porosity and moderates the increase in bulk density.

Method

To account for the contrasting mechanical behaviour of shales and sands under pore pressure influence, we adopt a hybrid rock physics modelling approach. The dry rock moduli are made pressure-dependent through the following formulations:

$$K_{dry} = K_{\infty}/\left(1 + Ek \times e^{-P/Pk}\right); \qquad (1)$$

$$\mu_{dry} = \mu_{\infty}/\left(1 + E\mu \times e^{-P/P\mu}\right). \qquad (2)$$

Where P is the confining pressure, K and μ refer to the bulk and shear moduli, respectively. The are calibrated using laboratory and log data methodology incorporates concepts from Gassmann fluid substitution, MacBeth's (2004) semi-empirical pressure sensitivity model, and the DEM theory proposed by Berryman (2002). We simulate fluid effects (brine, oil, and gas) through Gassmann's relations. Overpressure leads to decreased velocities and acoustic impedance, and higher Poisson's ratio in both lithologies. These velocity and density variations were used to compute reflectivity curves at different incidence angles. Synthetic seismograms were generated using a 25 Hz Ricker wavelet to replicate field seismic conditions.

Results and Conclusions

Our findings underscore the complex interaction between geological history, mineral composition, diagenetic pathways, and pressure evolution in shaping seismic responses. Elevated pore pressures can enhance the visibility of fluid effects by increasing contrasts in elastic properties—particularly acoustic impedance and Poisson's ratio—between sands and shales. Properly constraining dry frame moduli and incorporating geological controls improves interpretation of amplitude anomalies, helping to distinguish pressure effects from genuine hydrocarbon indicators. These insights are particularly relevant for frontier exploration settings where well control is limited. Nevertheless, interpreters are advised to combine rock physics modelling with regional geological context to minimise the risk of false positives in amplitude-based prospecting.