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Pore Pressure Prediction from Model-Based Seismic Inversion Integrated with Geotechnical and Well Data — Búzios Field, Santos Basin

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Abstract Summary

This study presents a methodology for predicting pore pressure in shallow sediments of the Búzios Field using model-based seismic inversion, aiming to support subsurface characterization and ensure greater safety in well drilling operations. Accurate pore pressure estimation is critical for planning drilling activities and evaluating the geomechanical stability of subsea slopes, especially in salt tectonic environments. The workflow began with the establishment of a quantitative relationship between acoustic impedance (AI) and pore pressure, derived from geotechnical data. Subsequently, a model-based inversion with Tikhonov regularization was then performed to obtain a high-resolution volume of acoustic impedance. This AI volume was converted into a pore pressure volume through polynomial regression calibrated with the previously established geotechnical relationship. The results demonstrated a strong correlation between Vp and AI from well data (R = 0.9766), and a good fit in the regression between AI and pore pressure (R = 0.6950). The spatial distribution of predicted pore pressure highlighted anomalous zones coinciding with fault structures, suggesting the influence of salt tectonics on fluid migration and pressure buildup. This approach proved effective for generating reliable pore pressure models in shallow subsurface settings, contributing significantly to risk mitigation in drilling operations and enhancing the assessment of slope stability in deepwater environments.

Introduction

Pore pressure prediction plays a key role in offshore operations, especially in overpressurized shallow environments, where unexpected pressure conditions may compromise drilling safety and slope stability (Osborne and Swarbrick, 1997). Accurate estimation of pore pressure is essential for minimizing geomechanical risks and guiding safe drilling and construction practices in deepwater fields.

Seismic methods, particularly model-based inversion, enable the estimation of acoustic impedance and the indirect derivation of petrophysical and geotechnical properties using empirical relationships (Russell and Hampson, 1991). This type of inversion is well suited for shallow sections where reflectors may present lateral discontinuity, offering better local control and lower computational cost (Ravasi and Vasconcelos, 2019). In this study, a model-based inversion workflow is proposed to predict pore pressure in the Búzios Field by integrating seismic, well, and geotechnical data.

Method

This study was carried out with the aim of estimating acoustic impedance and predicting pore pressure in shallow marine sediments in the Búzios Field. It was necessary to integrate seismic, well and geotechnical data. The corresponding flowchart is shown in Figure 1. Initially, two horizons were interpreted: the seabed and an underlying shallow horizon, delimiting the region of interest of approximately 80m. In order to improve the signal-to-noise ratio and temporal resolution, the seismic data was preconditioned. Sparse-spike deconvolution was used to recover the reflectivity and compress the wavelet (Yilmaz, 2001). Subsequently, the band-pass filter was applied to attenuate the low frequencies. Subsequently, the dip-steering filter was applied to reinforce the lateral continuity of the reflectors (Francelino et al., 2011) and a recursive Gaussian filter for smoothing of the volume. A statistical wavelet was estimated from the preconditioned data and used in the seismic inversion.

Initially, the conversion from inverted acoustic impedance to poropressure followed the approach proposed by Esmaeilpour and Ispas (2021), based on linear regression between measured AI and pore pressure. However, due to the non-linear behavior observed in the local geotechnical data, especially at low values of acoustic impedance (AI), a second-degree polynomial regression was tested, which showed better statistical performance. Thus, the pore pressure prediction for the acoustic impedance volume obtained by the model-based inversion was carried out using the polynomial regression adjusted to the AI and pore pressure of the geotechnical data.

To perform the model-based inversion, an initial acoustic impedance model was constructed from the velocity model and well data. The seismic velocity values were converted into acoustic impedance using a linear regression derived from the relationship between Vp and AI obtained from the well data. The model-based seismic inversion was performed using the Pylops library (Ravasi and Vasconcelos, 2019), considering the seismic response as the result of the convolution between the estimated wavelet and the reflectivity derived from the acoustic impedance. The trace-by-trace approach was adopted, in which each trace was inverted individually using the LSQR iterative solver, with Tikhonov regularization, minimizing:

$$\min_{r_i} ||d_i - Wr_i||_2^2 + \epsilon^2 ||r_i||_2^2, \quad (1)$$

where d_i is the seismic data for trace i, W is the convolution operator that applies the estimated wavelet to the reflectivity to generate the synthetic seismic corresponding to the trace, r_i is the estimated reflectivity and ϵ is the Tikhonov regularization parameter.

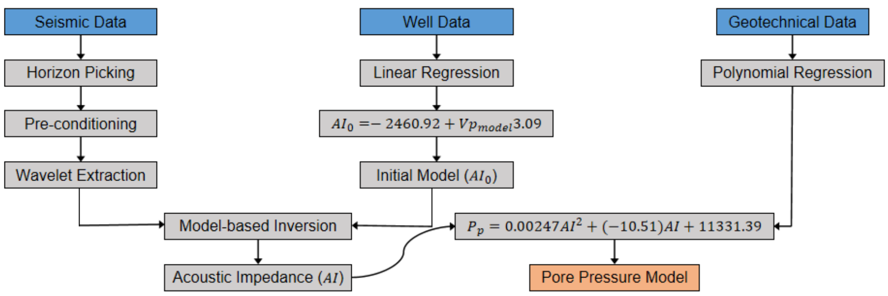

Figure 1: Flowchart of the methodology applied in the work.

Results

Figure 2 shows two crossplots that are fundamental to the methodology adopted. Figure 2 - a) presents the relationship between Vp and AI from the well data, used to construct the initial acoustic impedance model. The linear regression resulted in the equation:

$$AI_0 = -2460.92 + VP_{model}3.09 \quad (2)$$

with a high coefficient of determination ($R^2 = 0.9766$), confirming the strong linear correlation and validating its use for generating the initial impedance model based on the seismic velocity cube.

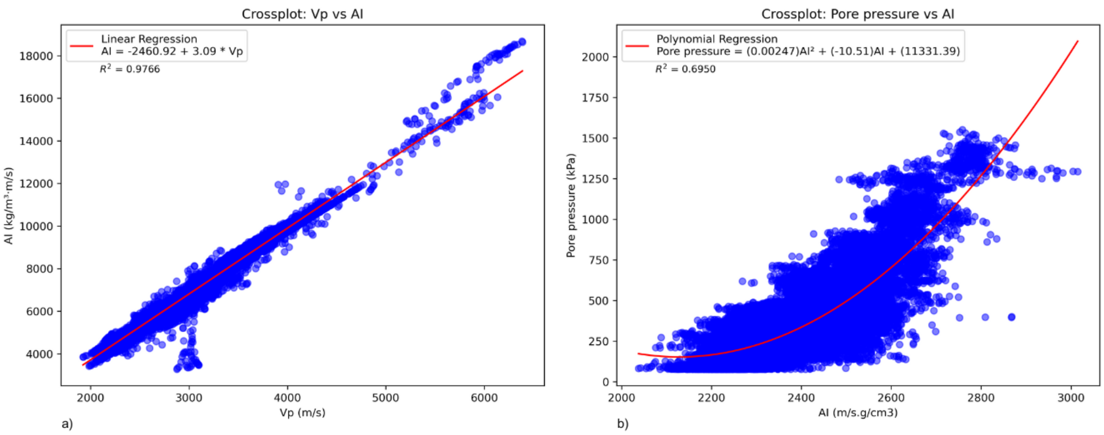

Figure 2: a) Crossplot of Vp and AI of the wells used in the initial model. b) Crossplot of pore pressure and AI of the geotechnical data for the empirical AI to pore pressure conversion relationship.

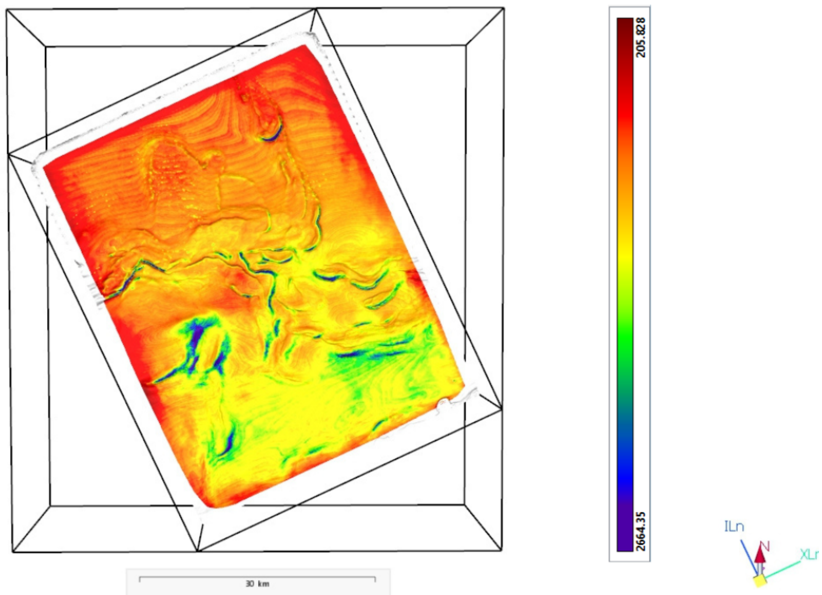

Figure 3: Average amplitude map of the pore pressure model for the interval between the two shallow seismic horizons interpreted in the Búzios Field.

Figure 2 - b) shows the relationship between pore pressure and AI from geotechnical data. Although a linear regression was initially tested, a second-degree polynomial regression provided a better fit, resulting in:

$$P_p = 0.00247AI^2 + (-10.31)AI + 11331.39 \quad (3)$$

with a coefficient of determination ($R^2 = 0.6950$). Despite moderate dispersion, typical of the natural variability in poorly consolidated marine sediments, the correlation was considered satisfactory for converting the inverted AI volume into pore pressure.

Figure 3 shows the average amplitude map of the pore pressure model estimated for the interval between the two seismic horizons interpreted in the shallow portion of the Búzios Field. Well-defined spatial variations can be observed, with higher amplitude zones concentrated in the central and lower portions of the area. When correlating this map with the seismic data, these high-amplitude anomalies were found to coincide with relatively shallow faulted regions, which are possibly related to salt tectonic activity, a characteristic feature of the Búzios Field. These results indicate that the proposed methodology, based on model-based inversion and subsequent conversion through polynomial regression, was effective in generating a reliable pore pressure volume consistent with the empirical data relationships.

Conclusions

The model-based inversion and pore pressure prediction workflow proposed for the shallow sediments of the Búzios Field showed consistent results in estimating acoustic impedance and pore pressure. The relationship tested showed strong correlation between Vp and AI in well data, and the tested polynomial regression showed a good fit between AI and pore pressure values from geotechnical data. The average amplitude map of pore pressure showed areas of high amplitudes, when analyzed together with seismic sections, can be associated with the salt tectonics of the region. The results indicate that the methodology addressed in this work can be applied to the analysis of submarine slope stability and the assessment of operational risk.

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