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Rock-physics-based seismic modeling

NOGUEIRA PETERSON (UfBA), João Pedro Silva Gomes (Federal University of Bahia - GAIA)

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Introduction

Accurate modeling of seismic wavefields is fundamental to seismic imaging and reservoir characterization. Conventional approaches typically express the wave equation in terms of elastic parameters such as P-wave velocity (Vp), S-wave velocity (Vs), and density (ρ), which are not always directly related to reservoir properties. To bridge this gap, it is essential to incorporate petrophysical variables—such as porosity (ϕ), clay content (CC), and water saturation (Sw)—into seismic modeling frameworks.

In this study, we propose a reparameterization of the elastic wave equation in terms of key petrophysical properties. This formulation enables seismic simulations to be directly informed by lithological- and fluid-related subsurface characteristics. By grounding the wave propagation model in rock physics theory, our goal is to enhance the integration of seismic modeling with reservoir and petrophysical analysis, ultimately facilitating the direct inversion of high-resolution petrophysical parameters through Full Waveform Inversion (FWI).

Method

To more directly link seismic wave propagation to rock and fluid properties, we reparameterized the elastic wave equation using petrophysical variables. This was accomplished by applying empirical relationships, inspired by Han's rock physics model, to express Vp, Vs, and ρ as linear functions of ϕ, CC, and Sw. Treating this as a linear regression problem allowed for the wave equation to be reformulated in terms of rock-physics inputs.

By substituting these relationships into the elastic wave equation, we derived a modified formulation in which the wavefields are governed by the spatial distribution of petrophysical parameters. As a result, the forward model becomes inherently sensitive to reservoir properties, forming a basis for petrophysically-constrained inversion schemes.

To evaluate the robustness of this petroelastic modeling approach, we employed a realistic 2D elastic model and its corresponding rock-physics attributes. For this purpose, we used modified versions of the 2D rock-physics Marmousi models presented by Mardan et al. (2023).

Results and Conclusions

The results demonstrate that the Finite Difference (FD) method could successfully simulate realistic wavefields using only rock-physics parameters, with negligible differences when compared to conventional elastic modeling. These findings are significant, as they establish a foundation for future applications of full-waveform inversion aimed at high-resolution recovery of petrophysical properties directly from seismic data.