Imaging Angola's Challenges and Evolving 4D Frontiers

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To unlock the resource potential of Angola requires a combination of innovative geoscience both in acquisition and imaging and a commitment to the use of cutting-edge time-lapse seismic technology across the lifetime of production. In this paper we give an overview of the application of new acquisition and imaging technologies now being applied to data from offshore Angola. These technologies include extended frequency sources, elastic dynamic matching full waveform inversion (E-DMFWI), and 4D DM FWI.

In the world of acquisition, recent surveys have utilized extended frequency sources to help improve low-frequency penetration into the deep subsurface. These innovative sources use a simple design with a single large chamber - this gives a spectrum with more low frequency energy (which contains useful kinematic information for building velocity models), less ultra-high frequency energy (which is generally non-useful for deep seismic imaging) while maintaining good signal in the main imaging frequency band. The source is also essentially a point source – which has strong advantages when imaging structures with strong angular and azimuthal variations. In addition, during the survey acquisition, LEO satellite networks are revolutionizing offshore operations by enabling near real-time, uncompressed data streaming from seismic vessels to cloud environments. This helps accelerate access for imaging teams and clients, streamlining decision-making.

Innovations like elastic FWI (E-DMFWI) and elastic multi-parameter FWI (E-MPFWI) significantly improve seismic imaging, especially in geologically complex areas offshore Angola which include carbonates, volcanics, and salt. These methods can leverage scalable cloud computing to incorporate more accurate elastic physics, enabling better subsurface characterization (Figure 1). E-MPFWI simultaneously inverts for velocity and reflectivity, allowing direct estimation of key rock properties or attributes such as impedance and relative density—moving beyond structural imaging to true reservoir property prediction. However, the non-linear nature of E-DMFWI means that a good starting model is always required. It is now common to use AI in the form of Fourier Neural Operators (FNOs) - a deep learning architecture designed to learn mappings between infinite-dimensional function spaces, which is particularly well-suited for solving partial differential equations (PDEs).

Finally, as shown in the conjugate margins of Brazil, applying 4D DM FWI allows this high-quality imaging method to be applied during reservoir management. The next key step for 4D is to quantify uncertainties associated with these measurements. Assessing uncertainty in 4D seismic will help drilling related decision making such as cost, risk management and accuracy of reserve estimates. While lots of factors affect uncertainty in 4D FWI (e.g., limited survey geometry, noise in data, non-linearity, different acquisition types and conditions like tidal heights, water temperatures amongst other things), we are now adopting approaches such as Bayesian inference based on Stein Variational Gradient Descent (SVGD) to quantify uncertainty in these results (Gao *et al*., 2025)

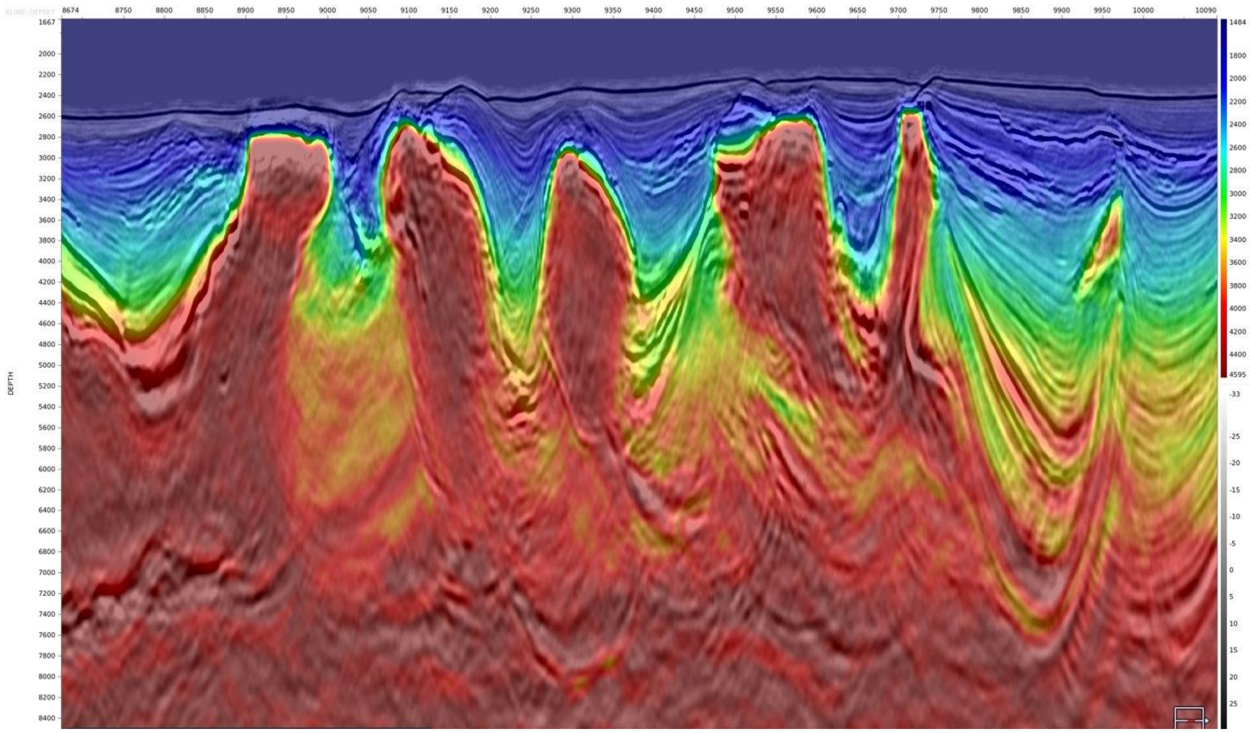

Figure 1. Elastic DM-FWI velocity model from offshore Angola showing the ability to resolve deep reflectors (at around 7.5km depth) below complex salt bodies.

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References

Gao, F., Calderon, C., Liu, F., Huang Y., Gao, S., 2025. Toward reliable 4D full waveform inversion: a study on uncertainty quantification. Presented at IMAGE Workshop on Uncertainty.