

## **Give your seismic another chance: Improved stochastic inversion results with minimal seismic data conditioning.**

### **Introduction**

This study focuses on an onshore siliciclastic field and demonstrates how a carefully designed inversion workflow, supported by a detailed analysis of all available input well and seismic data, and a detailed validation of the inversion parameters are crucial to obtaining a geologically plausible results from less than optimal land seismic data without the need of costly seismic data reprocessing project.

The objective of the project was to characterise multiple thin, compartmentalised reservoirs exhibiting variable quality and fluid content across several stratigraphic intervals. The key deliverables included the delineation of thin bed architecture and pinch-out geometries, estimation of net-to-gross, porosity, missed pay sections and fluid fill within the sand bodies. The combination of structural and stratigraphic trapping mechanisms observed in the study area make us heavily rely on AVO responses, hence making seismic data quality a critical factor.

This study builds upon a previous project where probabilistic inversion has already been applied in this area using the same seismic and well data set. Although the earlier results were encouraging, they did not fully address all geological challenges. Broad range near, mid and far angle stacks delivered by the processing contractor were used as seismic inputs and inversion targeted three facies. The legacy study concluded that seismic noise remained a significant limitation despite using an anisotropic PreSDM seismic processing sequence.

A conventional solution would have to undertake a full-scale reprocessing project focused on noise attenuation and improving resolution within the target interval, which would require investing time and cost. The other potential route to success was to use previous inversion project findings and improve inversion parameterisation strengthened with post processing conditioning of the seismic. This study sought to maximise the value of the existing dataset by applying lessons learned from the earlier project. The revised workflow employed finer angle-stack partitioning to provide greater control over residual near-angle noise and far-angle stretch effects while maintaining sufficient fold for robust intercept and gradient estimation. The facies scheme was also expanded to precisely capture the elastic diversity of the reservoir and non-reservoir lithologies.

Estimation of reservoir properties and discrete facies from seismic data is a well-established technique, and numerous methods have been developed by the industry over the years. This study demonstrates that a stochastic inversion process, based on matching a large number of pseudo-well realisations at each trace of the seismic volume to relative Extended Elastic Impedance (EEI) attributes can deliver accurate estimations of facies and reservoir properties even on challenging onshore seismic data.

### **Challenges**

The multidisciplinary team addressed several challenges associated with both the geological complexity of the reservoir system and the quality limitations of the available seismic data.

Onshore seismic data quality is severely compromised by near-surface conditions, ground roll, offset limitations, and near-surface layer velocity complexity (complex statics). These factors often reduce the reliability of quantitative reservoir characterisation workflows that can limit the contribution to the geological understanding and reservoir prediction of the study area.

In addition to the above, the reservoir interval comprises thin, laterally disconnected fine-grained siliciclastic units. Established hydrocarbon accumulations are contained within good quality (low shale

fraction and high porosity) sandstones within structural and stratigraphic combination traps. The reservoirs appear as prograding parasequences, which are often laterally disconnected as sands pinch out. The geological complexity of the siliciclastic system is further increased by carbonate diagenesis. Carbonate material occurs as isolated calcite clasts and nodules, as well as more pervasive calcite cementation that forms complex coatings around detrital quartz grains. These processes introduce significant heterogeneity in reservoir properties and elastic responses. (Benguigui, A. 2026).

### **Method: Stochastic Inversion by Trace Matching**

The study employs a One-Dimensional (1D) Stochastic Inversion by trace matching workflow as described by Connolly and Hughes (2016). The principle of 1D Stochastic Inversion is based on pseudo-wells defined as Time Markov Chain simulations of vertical stratigraphic profiles with associated petrophysical and elastic properties but without lateral constraints (de Groot et al., 1996). The algorithm generates numerous pseudo-wells (model realisations) for each seismic trace, tying them to the local stratigraphy. The pseudo-wells are sampled from a prior distribution that describes the range of possible facies and property combinations before incorporation of the seismic data.

A statistically robust prior model was constructed incorporating the horizons and well interpretations, facies probabilities, transition matrices and facies specific Rock Physics Models (RPMs) derived in this study from eight wells. This framework was used to generate 10,000 pseudo-well realisations for each seismic trace and calculate their associated elastic properties.

The inversion employs the Extended Elastic Impedance (EEI) concept (Whitcombe et al., 2002) to generate synthetics at selected  $\chi$  angles from compressional velocity, shear velocities and density logs derived from each pseudo-well. Synthetic traces are filtered to the seismic bandwidth and then matched simultaneously to multiple EEI angle stacks derived from the colour-inverted input seismic angle stacks (Lancaster and Whitcombe, 2000).

At each trace in the volume, the misfit Root-Mean-Square Error (RMSE) between the synthetic for each pseudo-well and the input seismic trace is calculated to pick realisations demonstrating lowest RMSE. The 100 Best-Match Pseudo-Wells (BMPWs) are then averaged to estimate reservoir properties including lithofacies, net-to-gross, porosity and associated uncertainties.

Drawing on lessons learned from previous studies, the following approach was adopted to achieve the improved inversion results without extensive pre- and post-stack seismic data conditioning. Migrated offset gathers were first converted into eleven angle stacks, each spanning  $10^\circ$  wide and generated at  $5^\circ$  increments from  $0^\circ$  to  $60^\circ$ . This process produced angle stacks with mid angles ranging from  $5^\circ$  to  $55^\circ$ .

Although this level of angle partitioning may appear excessive, it provided the flexibility to selectively retain angle stacks containing the highest signal-to-noise ratio, whilst minimizing the need for aggressive denoising. Testing demonstrated that the optimal results were achieved using angle stacks from  $10^\circ$  to  $40^\circ$ . The very near  $5^\circ$  angle stack was excluded because of elevated noise levels, whilst the ultra-far angles were discarded due to insignificant signal strength. This significantly improved the quality of the seismic Intercept and Gradient products, while reducing the influence of residual moveout present at the ultra-far traces.

Despite of notable amount of noise remaining in the data, seismic pre-conditioning was intentionally limited to angle stacking to preserve the resolution of the data needed to target thin reservoirs. On the other hand, the number of stochastic simulations was increased to overcome the random noise still present in the seismic data.

A second key modification involved the inversion parameterisation as it adopted a more granular approach in which six facies were defined: Brine Sand, Gas Sand, Shaly Sand, Shale, Cemented Silt,

and Clean Limestone, in contrast to the previous study with three defined facies. This granular facies scheme enabled a better representation of individual rock physics trends and allowed the inversion to reconstruct a broader range of elastic properties. Consequently, the inversion achieved a closer match between synthetic and observed input seismic data.

The parameterisation also differs from the original implementation described by Connolly & Hughes (2016). In this study, the gas and brine bearing reservoir sands were explicitly defined instead of performing fluid substitution from a dry rock framework based on a Phi-Sw function and pre-defined fluid contacts.

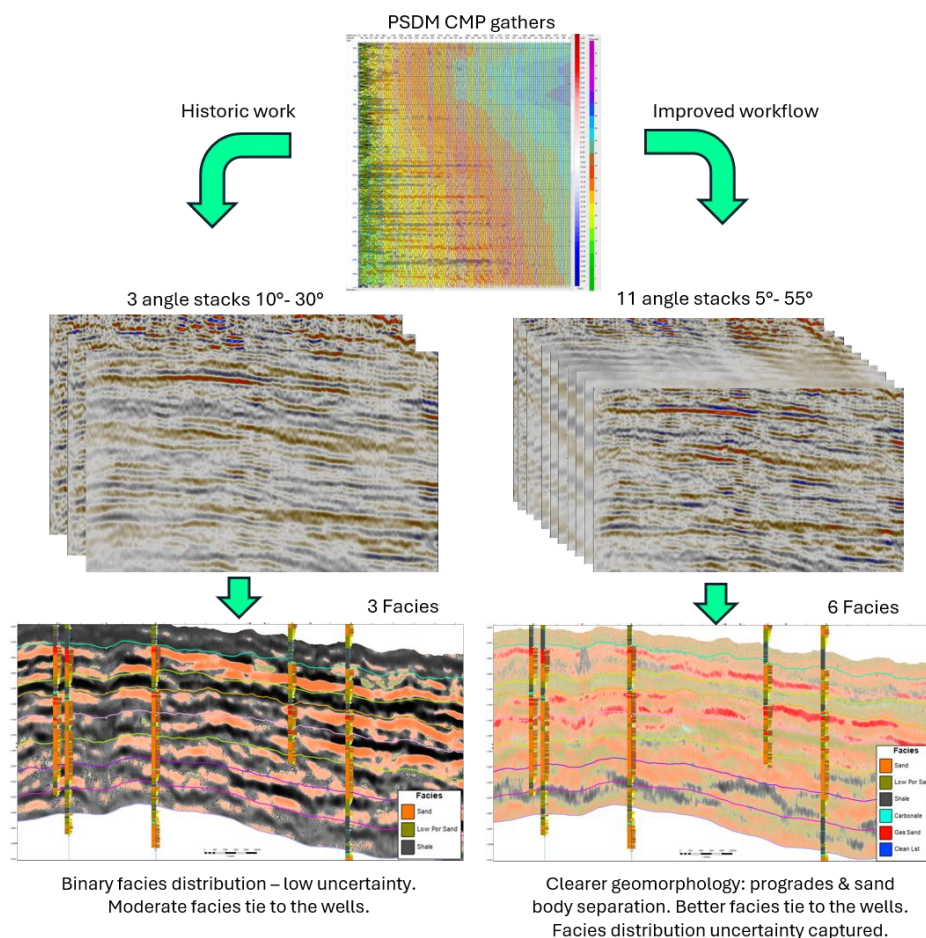


**Figure 1** The diagram illustrates the difference in seismic data preparation, stochastic inversion parameterisation and improved inversion results between the past and current projects.

Given the increased number of facies investigated which led to a considerable expansion of solution space, the number of seismic attributes for trace matching had to be increased from three to five: litho-fluid EEI20, EEI30, and lithology tuned EEI-50 were accompanied by relative acoustic impedance and relative gradient impedance. This multidimensional attribute framework provided stronger constraints during the trace matching exercise, leading to a reduction in prediction error by distinguishing signals from random noise more effectively.

At every stage of testing and parameter optimisation, inversion results were validated against available well data to ensure the selection of optimal statistical models, rock physics relationships, and inversion parameters.

The final inversion results demonstrated a superior facies tie to the wells (control points) and a clearer realisation of the prograding sand body geometries consistent with the established depositional model for these reservoirs (*Figure 1*).

## Conclusions

This study demonstrates that significant improvements in stochastic inversion performance can be achieved through careful parameterisation, rock physics calibration, and attribute selection without extensive seismic data conditioning or costly seismic reprocessing. The workflow successfully identified missed-pay intervals and fluid-fill patterns not evident in conventional seismic data or prior inversion results.

Generating a greater number of narrower angle stacks proved highly effective at improving signal-to-noise ratio without explicit need for aggressive denoising techniques that often compromise seismic resolution. Selective retention of the optimal range of angle stacks enhanced AVO intercept and gradient quality and as a result the fidelity of Extended Elastic Impedance attributes. The use of multiple EEI attributes is a key strength of the 1D Stochastic Inversion by trace matching approach, as each can be independently tuned to highlight lithology or fluid effects, enabling more effective decoupling than algorithms relying solely on seismic reflectivity.

Expanding the facies model from three to six classes; although some facies exhibited only modest elastic separation, gave the inversion significantly greater flexibility to characterise a wider range of rock property combinations which in turn helped to significantly enhance match to the seismic response, improving thin-bed resolution and the fidelity of the resulting geological model.

The study reaffirms the value of an iterative approach to reservoir characterisation: revisiting an existing dataset with refined parameterisation delivered a significantly more detailed and geologically consistent reservoir model cost-effectively, without the need for full-scale seismic reprocessing.

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## References

- Connolly, P. A., and Hughes, M. J. (2016). Stochastic inversion by matching large numbers of pseudo-wells. *Geophysics*, 81, No. 2.
- de Groot, P., A. H. Bril, F. J. Floris, and A. E. Campbell, 1996, Monte Carlo simulation of wells: *Geophysics*, 61, no. 3.
- Whitcombe, D. N., P. A. Connolly, R. L. Reagan, and T. C. Redshaw, 2002, Extended elastic impedance for fluid and lithology prediction: *Geophysics*, 67, no. 1.
- Lancaster, S., and D. Whitcombe, 2000, Fast-track 'coloured' inversion. 70th Annual International Meeting, SEG, Expanded Abstracts.
- Benguigui, A. 2026, Calcite influence on the seismic amplitudes of Mozambique siliciclastic reservoirs: A stochastic inversion by trace-matching study. 87<sup>th</sup> Annual conference & exhibition, EAGE, Expanded Abstracts.