

Elastic Seismic Inversion Workflow for Reservoir Characterization and Fluid Prediction, Case Study from Orange Basin Namibia

Introduction

Seismic elastic inversion has become an increasingly essential technique in the exploration and appraisal of deep-water clastic reservoirs, where direct borehole sampling is expensive and subsurface heterogeneity demands high-resolution quantitative characterization. By transforming seismic amplitude-versus-offset (AVO) data into rock-physics parameters such as P-impedance (I_p), S-impedance (I_s), V_p/V_s ratio, and density, elastic inversion bridges the gap between seismic observations and reservoir properties relevant to well planning and resource estimation.

This paper presents an integrated elastic inversion workflow (*Figure 1*) applied to the Mopane complex, located in the Orange Basin offshore Namibia, one of the most significant deepwater discoveries in southern Africa in recent years. The study covers two distinct stages of the quantitative interpretation (QI) workflow conducted by Galp's team:

- (i) Elastic Inversion performed on a Conditioned Fast-Track of High-Resolution seismic survey;
- (ii) Gassmann-based Fluid Substitution and Modelling on previously identified AVO anomalies. Comparison of synthetic gathers with the real seismic data.

Together, these workflows demonstrate how these methodologies can be integrated into an active exploration subsurface workflow to discriminate lithologies, rank AVO anomalies, and predict in-situ fluid type prior to drilling.

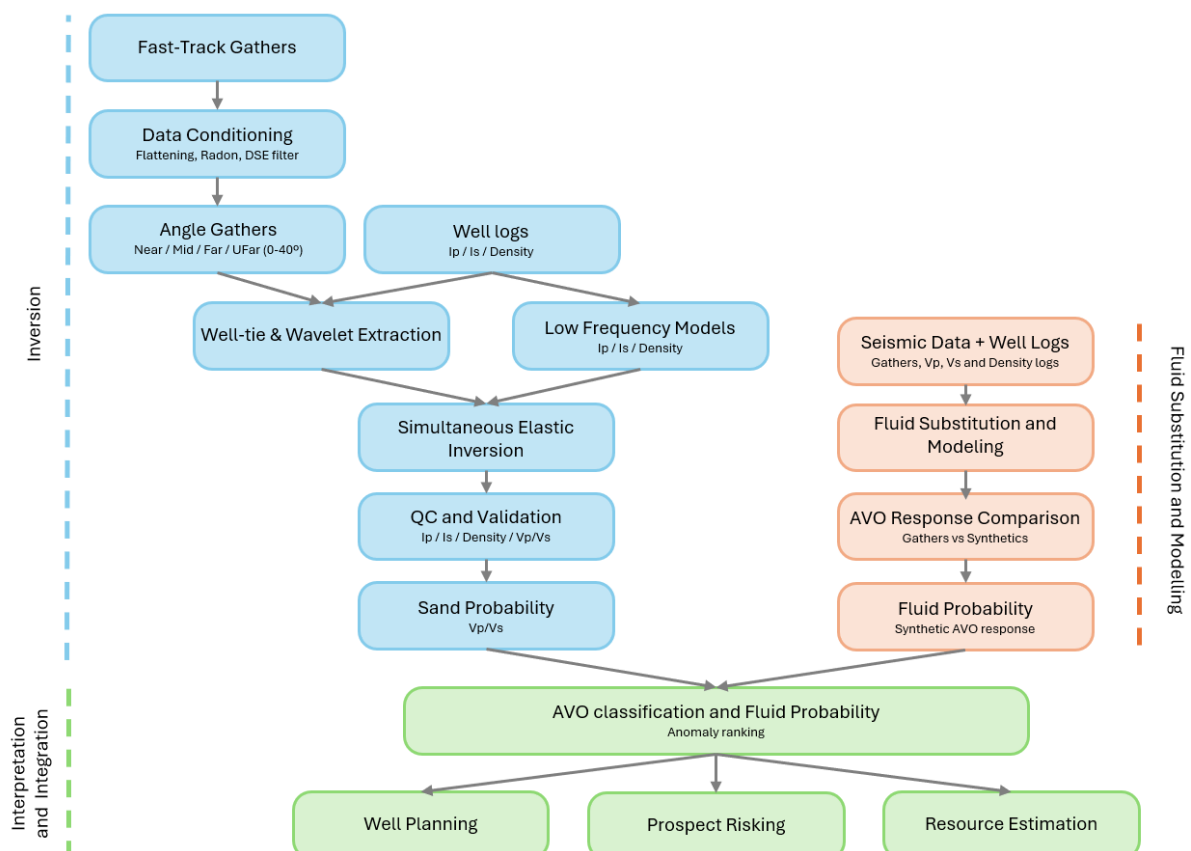


Figure 1 - End-to-end schematic workflow integrating seismic inversion, well-log data, and fluid substitution modeling to derive AVO classification, fluid probability, and support prospect risking and exploration drilling decisions

Geological and Geophysical Challenges

The Mopane field geological characteristics presents several technical challenges that make it an instructive case study for the seismic inversion community. These include a complex stratigraphic setting with turbidite sand packages encased within Mass Transport Complexes, of varying thickness, above or below seismic resolution, and different reservoir quality with a range of fluids from light oil to oil-rich gas condensate. A comprehensive description of the methodology, quality control (QC) strategy, and integration into the subsurface workflow is provided.

Methodology and Data Base

The elastic inversion workflow comprised a sequence of established steps: (1) seismic data conditioning and quality control, (2) well-to-seismic tie and wavelet extraction, (3) construction of the low-frequency model (LFM), (4) simultaneous pre-stack elastic inversion, and (5) QC and interpretation of the inversion results. This workflow used fast-track 3D seismic survey of high resolution, seismic migration velocities and data from five wells drilled in the area.

For the Gassmann-based fluid substitution and forward modelling, reservoir and shale properties, namely compressional and shear velocities, density, temperature, porosity, and pore pressure, were derived using nearby wells as calibration references. Fluid scenarios for brine, oil, and gas condensate were modelled and subsequently compared with angle gathers from a 3D Least-Squares Kirchhoff Pre-Stack Depth Migration (LS-KPSDM) dataset. This dataset is independent from the one used for the elastic inversion, providing an external validation of the modelling results.

Deterministic Simultaneous Pre-Stack Elastic Inversion

The fast-track seismic dataset exhibited elevated noise levels and locally non-flat gathers. To enhance data quality and ensure reliable inversion results, a comprehensive pre-conditioning workflow was applied to the original offset gathers. This included residual moveout correction through gather flattening, multiple attenuation using parabolic Radon demultiple filtering, and random noise suppression via a Dip Steering Enhancement (DSE) filter, designed to preserve AVO amplitude fidelity while improving coherency.

Conditioned gathers were subsequently used to generate new angle stacks, maintaining the same ranges as the original data (Near: 0-10°, Mid: 10-20°, Far: 20-30°, and Ultra-Far: 30-40°). Signal-to-noise variation (SNV) attribute maps were computed at key stratigraphic horizons to quantitatively assess the improvement achieved through conditioning. The resulting dataset demonstrated enhanced continuity and amplitude reliability across all angle stacks.

Broadband statistical wavelets were extracted independently for each angle stack using data from five wells and were validated against well-derived synthetic seismograms. The well-to-seismic ties were generally robust, requiring only minor phase adjustments, primarily for the Ultra-Far angle stack.

LFMs for I_p , I_s , and density were built using co-kriging interpolation of four out of the five wells, constrained by seismic migration velocities and a spherical variogram model. The exclusion of one well from this step is justified by its lower correlation in the well-tie analysis. The resulting differences between the LFMs generated with and without this well were minimal. Consequently, the well is retained as a blind well for subsequent QC validation. The modelling focused on the main interval of interest, the Cretaceous section, ensuring consistent spatial representation across key AVO-sensitive intervals.

A deterministic, model-based simultaneous pre-stack elastic inversion was then performed to estimate I_p , I_s , and V_p/V_s volumes, providing the basis for the reservoir characterization and interpretation.

Fluid Substitution and Modelling

A Gassmann-based fluid substitution and modelling study was conducted across several identified AVO anomalies to evaluate the impact of different fluid types on the seismic response of the reservoirs. The workflow involved the modelling of different scenarios, including brine, oil, light oil, and gas condensate, resulting in corresponding variations in compressional velocity (V_p), shear velocity (V_s), density, and Poisson's ratio logs.

These modified elastic logs were then used to generate synthetic seismograms, which were compared against seismic gathers at the anomaly locations. This comparison enabled the discrimination between hydrocarbon- and brine-bearing scenarios assessment of the most likely fluid response, and the characterization of the expected AVO response associated with each fluid scenario, thereby supporting more informed reservoir interpretation.

Inversion Results, QC, and Integration into the Subsurface Workflow

The elastic inversion results were subjected to a comprehensive QC workflow using multiple complementary approaches. At well locations, inverted elastic logs were compared with low-pass filtered versions of the measured logs (60 Hz, 4 ms), demonstrating that the inversion reliably reproduces both the large-scale trends and inter-well variability within the effective seismic bandwidth. Cross-plot correlation matrices were generated for all five wells and for each inversion-derived property. These analyses indicated that density estimates require cautious interpretation, particularly in thin-bed intervals below the tuning thickness. I_p and I_s were reproduced with high fidelity, exhibiting correlation coefficients of approximately 90%, whereas V_p/V_s and density showed slightly lower correlations of approximately 85% and 70%, respectively.

Within the Mopane dataset, V_p/V_s emerged as the most diagnostic inversion-derived attribute for hydrocarbon-bearing sand identification. Using the interpreted tops of the AVO anomalies, minimum V_p/V_s values were extracted within a defined window extending from the anomaly top over a constant thickness interval. These delineate areas with a higher probability of sand with hydrocarbon occurrence and provide valuable input for well placement optimization in forthcoming drilling campaigns.

Fluid Substitution and Modelling Results

In this workflow, gathers from the 3D LS-KPSDM seismic survey were used to compare the observed AVO response with synthetics generated through fluid substitution. Only one well is present within the survey area, however, three AVO anomalies associated with different fluid scenarios were analyzed. The results indicate a clear distinction in AVO response between brine and hydrocarbon-filled reservoirs. Brine-saturated cases consistently exhibit a Class I AVO response, whereas all hydrocarbon scenarios produce Class II/III anomalies. However, discrimination between oil and gas condensate proved inconclusive based on AVO behavior alone. These findings are nonetheless significant, as they suggest that the observed AVO anomalies are primarily driven by fluid effects rather than lithological variation.

Fluid modelling was subsequently extended to undrilled anomalies, yielding consistent results with those obtained from the fluid substitution analysis. Comparison between observed seismic gathers and modelled synthetics shows a closer match for hydrocarbon scenarios, while brine cases again display a distinct Class I response. Although the modelling process carries inherent uncertainty due to underlying assumptions, the consistency between independent approaches (fluid substitution and forward modelling) enhances confidence in the interpretation.

Conclusions

This study presents an integrated QI workflow combining elastic inversion with fluid substitution and forward modelling, enabling rapid prospect screening, uncertainty reduction, and the delivery of high-value products to support exploration decision-making in a complex deepwater setting.

Seismic pre-conditioning significantly improved data quality by attenuating noise and correcting residual moveout, resulting in flatter gathers while preserving the AVO response of the identified anomalies. The subsequent elastic inversion demonstrates a strong agreement with well log data, enhancing confidence in the reliability of the derived elastic properties. Consistent with observations from previous drilling campaigns, the Vp/Vs ratio emerges as the most robust indicator of bearing hydrocarbon sand presence within the study area. Guided by the seismic interpretation of AVO anomalies, minimum Vp/Vs values were extracted within targeted intervals, providing a practical tool to support well placement optimization.

The Gassmann-based fluid substitution analysis further reveals a clear and consistent distinction in AVO behavior between brine and hydrocarbon-filled reservoirs. In all cases, brine scenarios produce a Class I AVO response, whereas hydrocarbon-bearing cases exhibit Class II/III anomalies. These findings reinforce the interpretation of the observed seismic responses as fluid-driven rather than only lithology-controlled. However, differentiation between oil and gas condensate remains unresolved within the limits of the available data and modelling approach.

The integrated workflow contributed directly to prospect ranking, well placement optimization, and pre-drill fluid risk reduction across the Mopane appraisal portfolio.

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