

From Rock Physics to Well Location: Integrated Seismic Inversion and QI Workflow for Deepwater Stratigraphic Reservoir Characterisation

Introduction

Quantitative interpretation (QI) in frontier deepwater settings is inherently challenging due to limited well data control. These challenges are amplified by complex overburden geology and the occurrence of stratigraphic traps. In such cases, robust subsurface characterization relies on the integration of inversion, rock physics, seismic attributes, and AVO analysis, supported by workflows that maximize the utility of available data and provide explicit quantification of uncertainty.

This study presents an integrated QI workflow (*Figure 1*) for an Early Campanian stratigraphic prospect in the Gulf of Guinea. A single offset well, with thin oil pay provided rock physics constraints for inversion. The workflow integrates deterministic pre-stack inversion, seismic attributes, geobody detection, AVO, I_p - V_p/V_s classification, and depth uncertainty analysis to support well placement decisions, with clear QA/QC and uncertainty assessment.

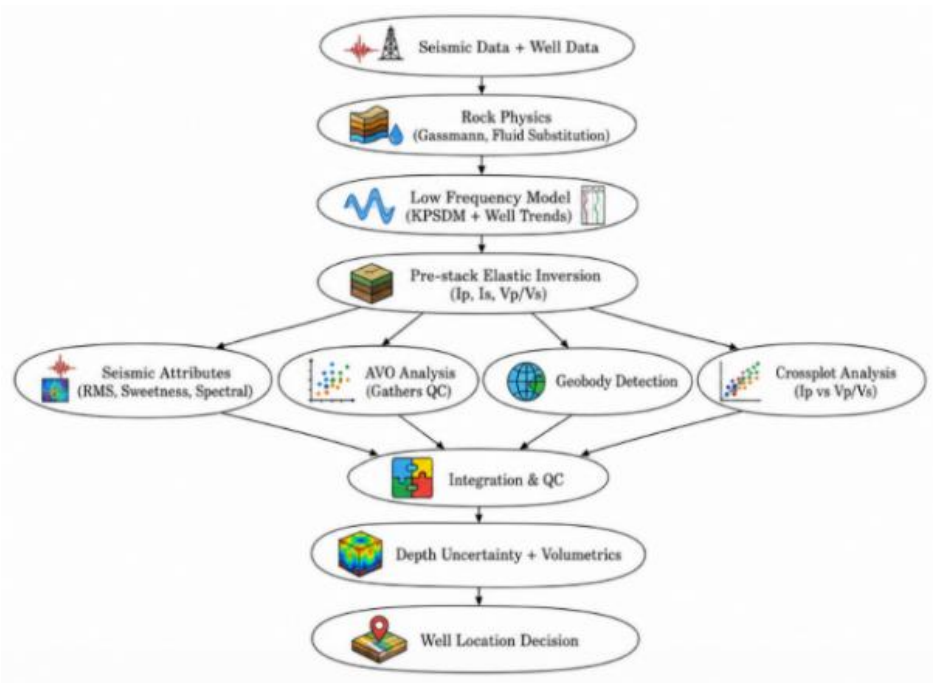


Figure 1 Schematic illustration of the proposed workflow for the reservoir characterization and QC for well location decision

Geological and Seismic Context

The target is an Early Campanian clastic frontal splay comprising a main fan and two up-dip lobes. Trapping is primarily stratigraphic, driven by lateral facies changes and channel-related amplitude disruption associated with sediment bypass, reinforcing the possibility of disconnection within the feeder channels. Hydrocarbons charge is sourced from Early Campanian-Santonian source rock linked to OAE-3 event, sitting immediately underlying the reservoir unit. The prospect lies in ~2500 m water depth, with the reservoir just below 5000 m TVDSS.

Seismic data was reprocessed using KPSDM with 12 Hz FWI integrated into the velocity model. Inclusion of the calibration well improved imaging beneath the Paleocene and captured a variable fast overburden layer. However, residual multiples and moveout still persist, while critical-angle effects

further limit the usable angle range. Three angle stacks (0-10°, 10°-20°, 20°-30°) were generated and converted to depth, with these limitations guiding the QI QA/QC strategy.

Rock Physics Foundation: Elastic Modelling

The rock physics study underpins the workflow. Three Campanian intervals were modelled using Gassmann substitution (Smith, *et al.*), spanning brine-HC saturations.

A critical and non-intuitive finding from the rock physics study is a depth-dependent inversion of the sand-shale elastic contrast. In the upper Campanian interval, shales are harder than the encasing sands, producing a class I AVO response regardless of fluid content. In the mid-Campanian, shales and sands have similar impedances at brine saturation, yielding a class II/III AVO response for hydrocarbon-bearing sands. This behaviour is fundamentally non-standard: P-impedance alone cannot distinguish lithology across depth zones, and the AVO class itself changes with depth.

Sands are related with high P-impedance and low Vp/Vs signatures irrespective of fluid content, a direct ambiguity between tight cemented sands and HC-bearing sands. The model with total porosity around 25% best matches the observed seismic response at the calibration well, providing the most probable reservoir condition to be extrapolated to the target.

Deterministic Simultaneous Pre-Stack Elastic Inversion

Deterministic simultaneous pre-stack inversion (model-based) of three angle stacks generated Ip (acoustic impedance), Is (shear impedance), and Vp/Vs volumes. The low frequency model was generated combining the seismic processing velocities and the well data trends prioritising geological consistency rather than long-distance well-log extrapolation. Wavelets were statistically extracted and validated with well synthetics. QC included residual analysis, well ties, and LFM consistency, with inversion results at the calibration well reproducing key elastic trends.

At the reservoir, high Ip (8800-12000 (g/cc*m/s)) and low Vp/Vs (1.4-1.75) align with mapped sand bodies and rock physics predictions for stiff sands. Density is less reliable and used qualitatively.

Seismic Attribute Analysis and QC of Inversion Products

Seismic attributes supported both reservoir characterisation and inversion QC. Spectral decomposition, sweetness, and RMS amplitude were extracted and compared with inversion outputs. Attributes delineate channel-fan architecture and highlight a thicker, sand-prone northern sector, consistent with inversion anomalies. High Ip (~11000-11200 (g/cc*m/s)) and low Vp/Vs (1.43-1.46), support the interpretation as probable good reservoir-quality sands.

Geobody extraction from Ip and Vp/Vs volumes shows strong lateral connectivity for each expected sandy reservoir, with single-seed detection under base-case thresholds and persistent connectivity under conservative scenarios.

AVO Analysis and Gather QC

Pre-stack gather analysis was performed across candidate well locations, reference locations, and non-reservoir settings. The critical angle (~30-35°), derived from Vp/Vs, confirms that the Far stack ($\leq 30^\circ$) is within the pre-critical regime and suitable for AVO analysis.

All candidate locations show a consistent Class I AVO response at the Top Reservoir, matching rock physics predictions for stiff sands (~25% porosity). Feeder channel and distal areas exhibit weaker, thinner responses, consistent with the expected non-reservoir conditions.

Integration of Inversion Products into the Well Location Workflow

Inversion results were integrated with structural mapping, volumetrics, depth uncertainty, and hazard screening to support well placement. The workflow aimed to maximise reservoir thickness and presence and secondary targets while minimising uncertainty and drilling risk, with QI informing the former and structural/uncertainty analyses the latter.

At the target level (*Figure 2*), a reference uncertainty of $\pm 3.5\%$ (equivalent to $\pm 5\%$ at TD) results in Top Reservoir uncertainty ranging from ± 195 to ± 200 m across candidates, increasing to ± 275 - 280 m at $\pm 5\%$. These ranges were incorporated into the prognosis and casing design (P90/Mean/P10 scenarios).

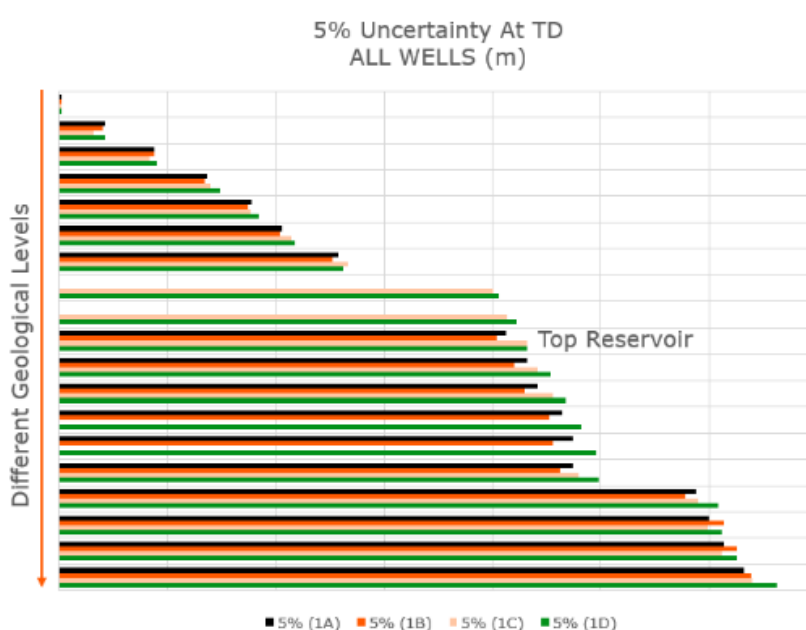


Figure 2 Depth uncertainty comparison for different geological levels. Horizontal bars show $\pm$ uncertainty (m) at each stratigraphic top from seafloor to basement. The Top Reservoir (highlighted) shows ± 196 - 201 m.

All inputs were combined into a comparative scoring framework, integrating structural position, secondary target access, QI indicators (sand thickness, AVO response, amplitudes), and depth uncertainty to provide a transparent and technically robust basis for well location selection.

Residual Uncertainties and Limitations

The integrated QI workflow highlights four key uncertainties:

- Fluid vs. cementation ambiguity: Relatively high I_p , low V_p/V_s , and Class I AVO responses are consistent with both HC-bearing and cemented sands, particularly below $\sim 15\%$ porosity, where fluid discrimination is not possible with the current well control.
- LFM extrapolation bias: Reliance on a single offset well introduces uncertainty in absolute I_p values ($\sim \pm 500$ (g/cc·m/s)), though anomaly geometry remains robust.
- Seismic data quality: Residual multiples and imperfect gather flatness reduce AVO reliability and may bias inversion results. Further gather conditioning is recommended.

- Rock physics non-stationarity: Depth-dependent elastic behavior between sand and shale may be local rather than regional, limiting the reliability of I_p -based lithology discrimination, only partially mitigated by I_p - V_p/V_s integration.

Conclusions

This study presents an end-to-end QI workflow for stratigraphic reservoir characterisation and well placement in a frontier deepwater setting. The approach integrates elastic inversion, seismic attributes, AVO analysis, geobody extraction, I_p - V_p/V_s classification, rock physics modelling, volumetrics, and depth uncertainty to deliver a traceable, QC-driven, and risk-aware well-location decision.

Rock physics modelling shows that elastic behaviour is controlled primarily by porosity and lithology rather than fluid, with a depth-dependent reversal of sand-shale impedance contrast. As a result, the observed high- I_p , low- V_p/V_s signature and Class I AVO response are consistent with both HC-bearing and cemented sands. Cross-validation across inversion outputs, seismic attributes, and gathers ensures internal consistency but cannot resolve this fundamental ambiguity without drilling.

Integration of QI results within a multi-criteria framework enables balancing reservoir indicators (thickness, amplitude, AVO response) against structural position and depth uncertainty.

The selected location combined the thickest geobody expression, strongest Class I AVO response, lowest depth uncertainty and access to secondary objectives.

Explicit treatment of uncertainties, including fluid ambiguity, LFM bias, data quality, and rock physics variability, ensures appropriate use of inversion outputs in decision-making. This case demonstrates that in data-limited frontier settings, seismic inversion reduced reservoir presence uncertainty rather than fluid uncertainty while providing a consistent, QC-validated spatial framework that constrains risk, supports well placement, and guides future data acquisition.

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References

- Aki, K. and Richards, P.G. [1980] Quantitative Seismology: Theory and Methods. W.H. Freeman, San Francisco.
- Batzle, M. and Wang, Z. [1992] Seismic properties of pore fluids. *Geophysics*, 57(11), 1396–1408.
- Smith, T. M., Sondergeld, C. H., and Rai, C. S., 2003, Gassmann fluid substitutions: A tutorial: *Geophysics*, 68, 430–440.
- Mavko, G., Mukerji, T. and Dvorkin, J. [2009] *The Rock Physics Handbook: Tools for Seismic Analysis of Porous Media* (2nd ed.). Cambridge University Press.
- Rutherford, S.R. and Williams, R.H. [1989] Amplitude-versus-offset variations in gas sands. *Geophysics*, 54(6), 680–688.
- Shuey, R.T. [1985] A simplification of the Zoeppritz equations. *Geophysics*, 50(4), 609–614.
- Simm, R. and Bacon, M. [2014] *Seismic Amplitude: An Interpreter's Handbook*. Cambridge University Press.
- Veeken, P.C.H. and Da Silva, M. [2004] Seismic inversion methods and some of their constraints. *First Break*, 22(6), 47–70.