

Unlocking Gharif Channel Sand to Support Drilling using Machine Learning and Conventional approaches, Sultanate of Oman

Introduction

Delineating thin-bed reservoirs using seismic inversion remains a persistent challenge especially in fluvial systems, where sand bodies are often narrow, laterally discontinuous, and thinner than the seismic tuning thickness. The Upper Gharif Formation in northern Oman exemplifies this complexity: its productive sands are typically just a few meters thick and embedded within shale-rich sequences. The UG3 interval is the primary exploration target in this setting. Precisely mapping UG3 sand distribution is essential to reduce drilling risk and guide optimal sidetrack placement.

While recent machine learning (ML)-based seismic inversion methods offer enhanced pattern recognition and non-linear relationships between seismic attributes and elastic properties, their performance in resolving thin beds is still unproven. This study compares multiple ML inversion approaches with a conventional geostatistical AVO inversion to evaluate their effectiveness in delineating thin sands and to directly inform the sidetrack decision for the AS-1 well.

Data and Geological Setting

This study utilizes a wide-azimuth PSDM seismic dataset acquired in North Sultanate of Oman, processed via a Kirchhoff migration workflow. At the Gharif level, the seismic data exhibits a reliable frequency bandwidth of approximately 5 Hz to 70–80 Hz, offering favorable resolution for thin-bed characterization. Eight partially overlapping angle stacks were generated and used as input for AVO-based inversion. The Upper Gharif Formation is interpreted as a fluvial channel system, featuring laterally discontinuous sand bodies interbedded with shale. Inversion and interpretation were constrained using two key regional horizons: the Upper Gharif and Middle Gharif. Calibration and validation were supported by multiple wells with edited, quality-controlled logs including density, P-sonic, and S-sonic ensuring reliable control across the study area.

Rock Physics Feasibility Analysis

Rock physics analysis was conducted to evaluate the potential for distinguishing lithology and to identify the most reliable elastic attributes for predicting sand presence. At the well-log scale, cross-plots of V_p vs. density and acoustic impedance (AI) vs. V_p/V_s were examined. At seismic resolution, V_p/V_s emerged as the most effective attribute for differentiating sand from shale with a threshold of approximately 1.85 providing consistent and robust separation within the Upper Gharif interval, see Figure 1.

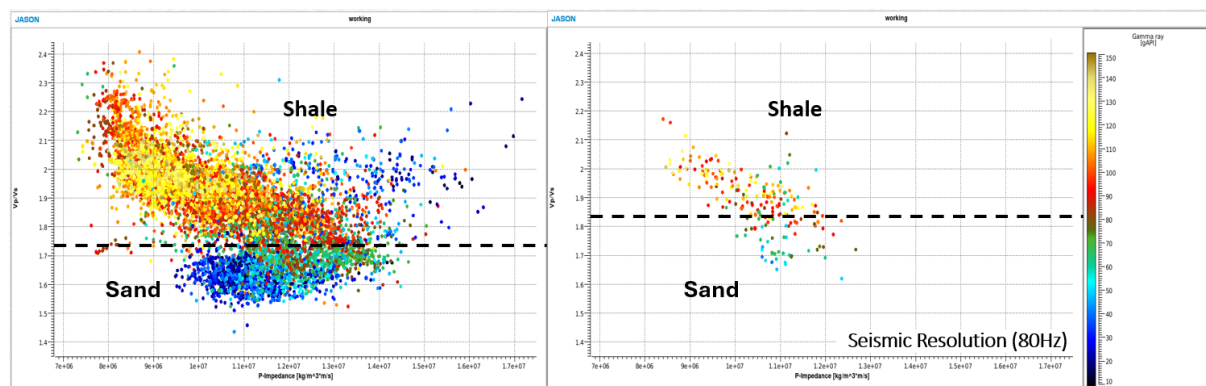


Figure 1 Upper Gharif V_p/V_s vs. P -Impedance cross-plot coloured by GR in wells resolution (left) and seismic resolution (right), showing the sand-shale separation in V_p/V_s domain and the suggested cutoff values around 1.85.

Inversion Evaluation Method

The study evaluates multiple inversion outputs generated using identical data:

- Three ML-based seismic inversion workflows (vendor and in-house)
- A conventional geostatistical AVO inversion

To ensure objective benchmarking, a multi-level evaluation framework was applied for couple of blind wells:

1. Cross-plot correlation with well logs

Inverted elastic properties were compared against well logs within the Upper Gharif interval. While some ML inversions achieved high correlation coefficients, many exhibited significant deviations in absolute magnitudes, as indicated by slopes far from unity.

2. Well-based sand prediction scoring

Inverted V_p/V_s logs were compared against gamma ray logs using the 1.85 cut-off. A quantitative scoring metric was applied to assess each inversion's ability to correctly predict sand units at well locations as illustrated in Figure 2.

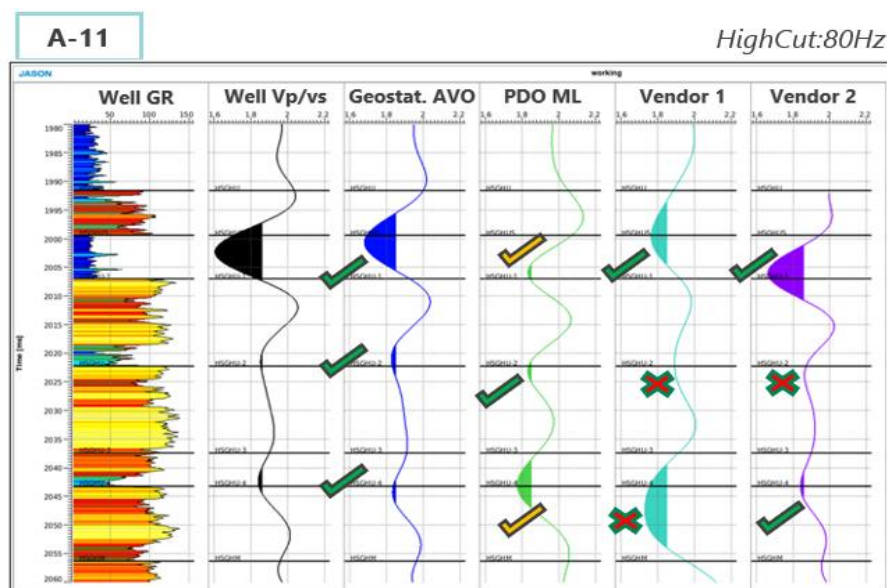


Figure 2 Scoring V_p/V_s in blind well (A-11) of the different inversion products over Upper Gharif against the sand units found in the GR log and V_p/V_s log, with a high cut to seismic resolution (80 Hz).

3. 3D seismic cross-correlation

Inverted P-impedance volumes were forward-modelled and cross-correlated with seismic data to assess consistency in three dimensions and map view over Upper Gharif.

4. Qualitative sand tracking

V_p/V_s sections through key wells were visually inspected to evaluate lateral continuity and geological plausibility of predicted sand bodies across different blind wells.

Results

Across the different evaluation criteria, the conventional geostatistical AVO inversion and the in-house ML inversion consistently rank highest, see Figure 3. Both approaches show reasonable correlation with well data, more realistic recovery of elastic magnitudes, and better lateral continuity of sand bodies.

Vendor	A-26	A-12	A-9	A-13	Score
Vendor 1	50	100	100	66	79
Geostat. AVO	100	100	100	33	83.25
PDO ML	66	100	100	100	91.5
Vendor 2	50	100	66	100	79

Figure 3 V_p/V_s scoring sheet of the different inversion products over Upper Gharif against the sand units found in the GR log and V_p/V_s log.

3D cross-correlation values near AS-1 location are approximately 45–50%, indicating moderate uncertainty and reinforcing the need for integrated interpretation. Despite this uncertainty, both selected inversion methods predict limited sand presence at the AS-1 pilot hole and highlight a more favorable sand development trend toward the southwest.

Sand Body Extraction and Sidetrack Implications

A bodycheck analysis was performed using the V_p/V_s attribute within a window encompassing UG3 and UG4, see Figure 4. A V_p/V_s cut-off of 1.85 was applied to isolate predicted sand bodies. Both the geostatistical AVO and inhouse ML inversions consistently indicate that the pilot hole location is unlikely to encounter significant sand, while thicker and lower V_p/V_s anomalies are observed southwest of the wellhead. Based on these results, a southwest-directed sidetrack was recommended as the most favorable option.

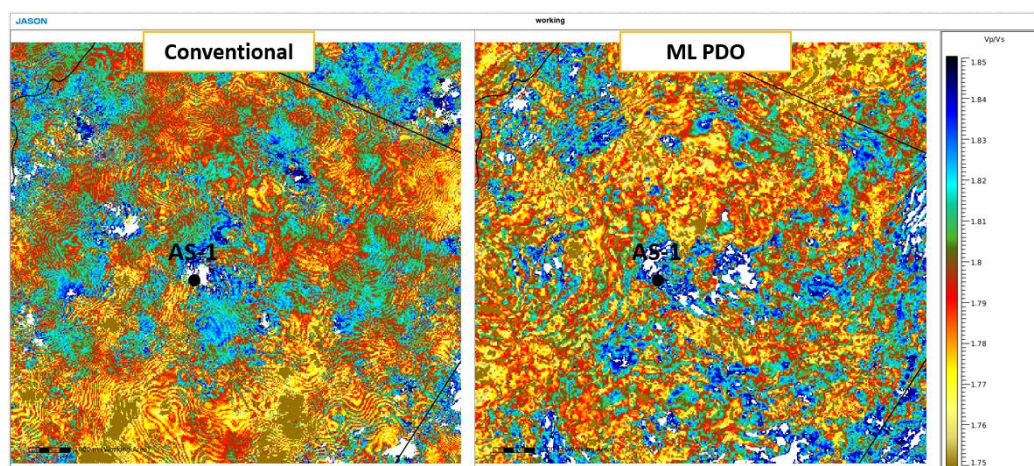


Figure 4 Mean V_p/V_s of extracted sand bodies around UG3 & UG4 of the conventional geostatistical AVO inversion (left) and inhouse ML inversion (right).

Post-Drill Validation

The AS-1 pilot hole was drilled shortly after completion of the study. Well logs confirmed the pre-drill predictions, with no significant sand encountered at UG3 or UG4. The post-drill rock physics analysis supports the adopted V_p/V_s threshold, and comparison of inverted and logged properties shows a closer

match for the geostatistical AVO inversion, see Figure 5. The QI results were taken into consideration to decide on the sidetrack direction. Following the success of sidetrack of AS-1, a new AS-2 pilot hole is currently drilled based on the QI analysis and results should be ready in Q3, 2026.

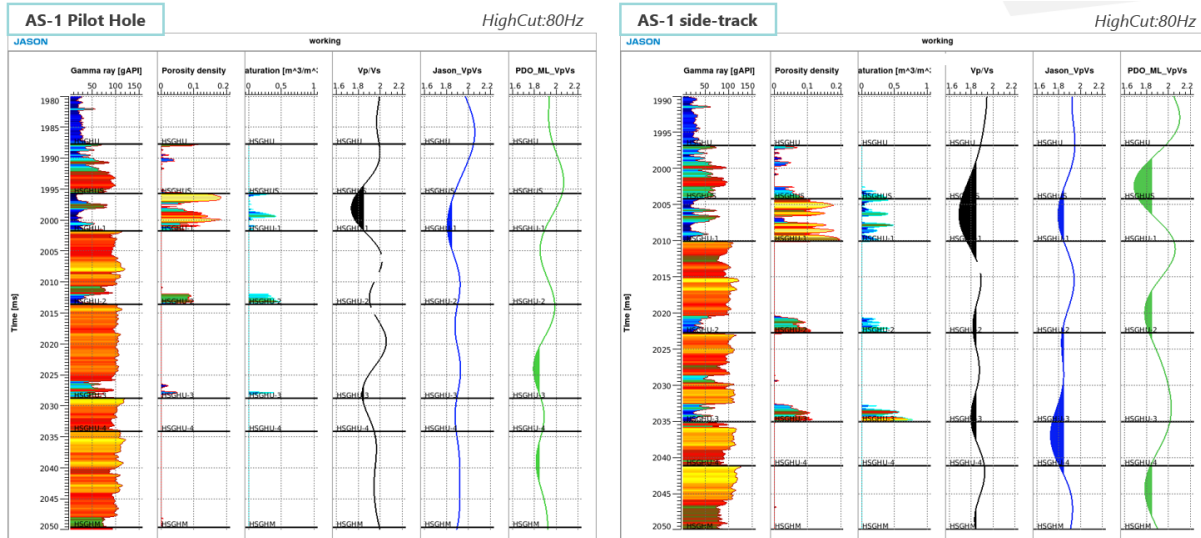


Figure 5 Well results of AS-1 pilot hole (left) and side-track (right) showing minimal UG3 sand at the pilot hole and more at the side-track.

Conclusions

This study demonstrates that:

- Seismic data quality is key to robust inversion results.
- At seismic scale, Vp/Vs is the most reliable attribute for sand–shale discrimination.
- ML-based inversions can capture relative trends but may struggle with absolute property recovery.
- Conventional geostatistical AVO inversion remains a robust benchmark for thin-bed characterization.
- Integrated QC and post-drill validation are essential for de-risking ML-based inversion results.
- Pre-drill inversion predictions were validated by drilling outcomes, supporting the recommended sidetrack direction. The results provide confidence in the integrated inversion workflow and offer practical guidance for applying ML inversion in similar thin-bed fluvial settings.

References

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