

Rock Physics Feasibility of Gas Detection in Conventional and Low-Porosity Sandstones: AVO-QI Case Study, DDB

Introduction

The Dnieper–Donets Basin (DDB) is one of the main hydrocarbon-producing provinces of Ukraine, with more than 70 years of exploration and production history. As most fields are now mature, new discoveries increasingly depend on improved seismic imaging and more reliable reservoir characterization. In this setting, integrated petrophysical interpretation and rock physics modelling provide the basis for seismic feasibility analysis, AVO modelling, and quantitative interpretation, supporting risk reduction and better well placement.

This study presents a case study from a DDB prospect containing two contrasting gas-bearing reservoir systems: high-porosity Upper Middle Carboniferous sandstones and low-porosity Lower Middle Carboniferous sandstones. Building on the petrophysical and rock-physics framework for reservoir characterization in the DDB (Antoniuk et al., 2026), this study evaluates its performance across two stratigraphically stacked sandstone plays with contrasting elastic behaviour, with a particular focus on prospect-scale seismic detectability using a unified rock physics, AVO, and QI workflow.

Method and/or Theory

The workflow is based on a harmonised multi-well petrophysical model calibrated to core data and to reference wells with modern full logging suites. These wells were used to establish RHOB trends in shaly intervals and lithology-dependent V_p – V_s relationships. NMR data helped refine total porosity estimates and account for compaction effects in shales. Interpretation consistency across the well set was checked through histogram analysis and crossplots, resulting in a coherent set of effective porosity, fluid saturation, and mineral fractions, including shale, carbonate, sand, and coal components.

Rock physics analysis combined elastic property prediction from mineral composition, porosity, and saturation with pore-fluid modelling based on Batzle–Wang equations, Gassmann fluid substitution, shear-velocity prediction using empirical V_p – V_s relationships or the Krief model, and sensitivity testing to lithology, porosity, and fluid type (Mavko et al., 2020). The calibrated models were then used to generate gas- and brine-case synthetic responses, providing the basis for AVO feasibility assessment and interpretation of seismic inversion results.

Prediction of lithotypes and gas-saturated zones was supported by deterministic elastic inversion, including well-to-seismic tie, wavelet extraction, low-frequency model construction, simultaneous inversion for AI, V_p/V_s , and RHOB, and classification in AI versus V_p/V_s space. AVO analysis was performed on angle stacks of 3–14°, 14–24°, 24–32°, and 30–45°, supported by well-based forward modelling from V_p , V_s , and RHOB logs (Avseth et al., 2010).

Results

A consistent petrophysical workflow was established for all wells across the prospect. For the Upper Middle Carboniferous high-porosity sandstones (PHIE 18–25%; net pay 10–25 m), rock physics templates show a clear separation between gas- and water-bearing intervals in elastic property space. Gas-saturated sandstones are characterised by AI values of 7,600–9,000 g.m/cm³.s and V_p/V_s of 1.58–1.7, whereas water-saturated sands plot at AI = 9,000–10,500 g.m/cm³.s and V_p/V_s = 1.65–1.75 (Fig. 1).

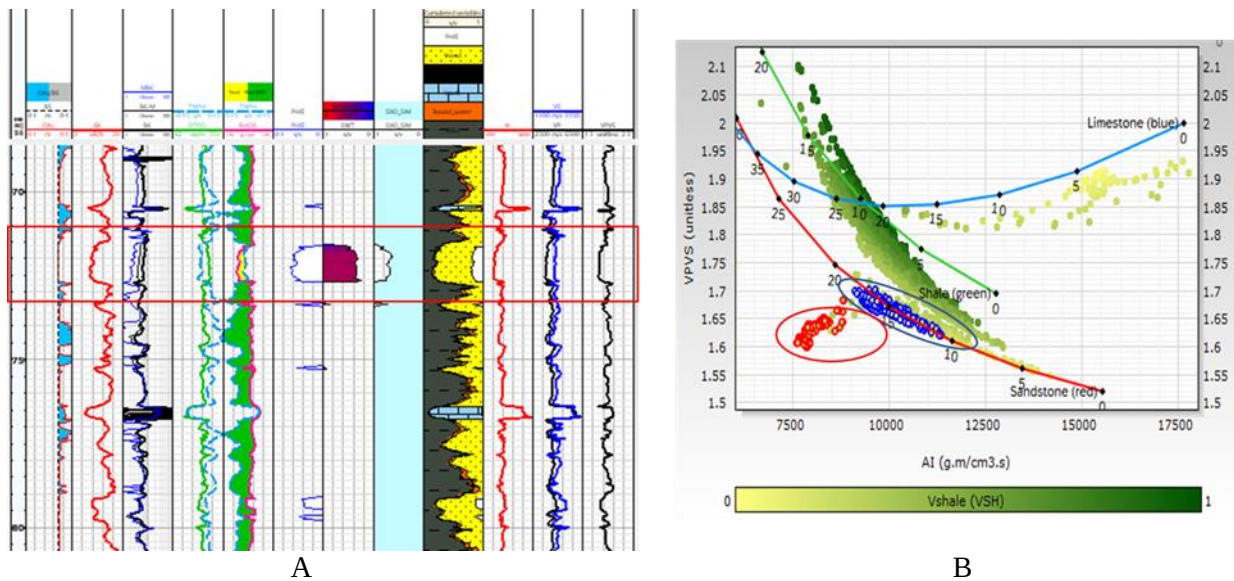


Figure 1 (A) Results of petrophysical interpretation and rock physics modelling for the Upper Middle Carboniferous interval; (B) Rock physics template showing gas- and water-saturated sandstone reservoirs.

QI results show good agreement between inverted elastic properties and well log data (Fig. 2). Use of the integrated workflow in prospect evaluation and well planning led to an approximately 70% drilling success rate in the Upper Middle Carboniferous reservoirs. The main remaining uncertainty is related to residual gas saturation, which lowers Vp/Vs and complicates separation between commercial accumulations and partially depleted intervals. The workflow also helped identify previously unrecognised gas-bearing intervals and supported subsequent development well placement.

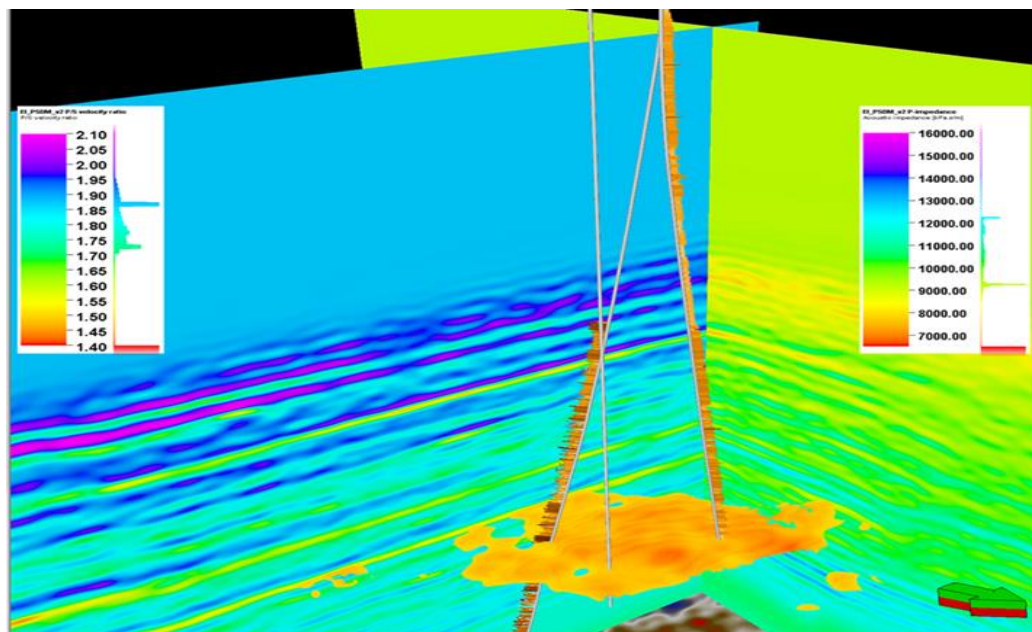


Figure 2 Elastic inversion results for predicting gas-saturated sandstone zones.

In contrast, the Lower Middle Carboniferous sandstones (PHIE 10–12%; net pay 5–15 m) show substantially weaker feasibility. Gas-bearing low-porosity sands have higher AI than the enclosing shales (9,000–12,000 versus 8,000–10,000 g.m/cm³.s), but the Vp/Vs difference between gas-saturated (1.55–1.68) and water-saturated (1.6–1.75) intervals remains small (Fig. 3).

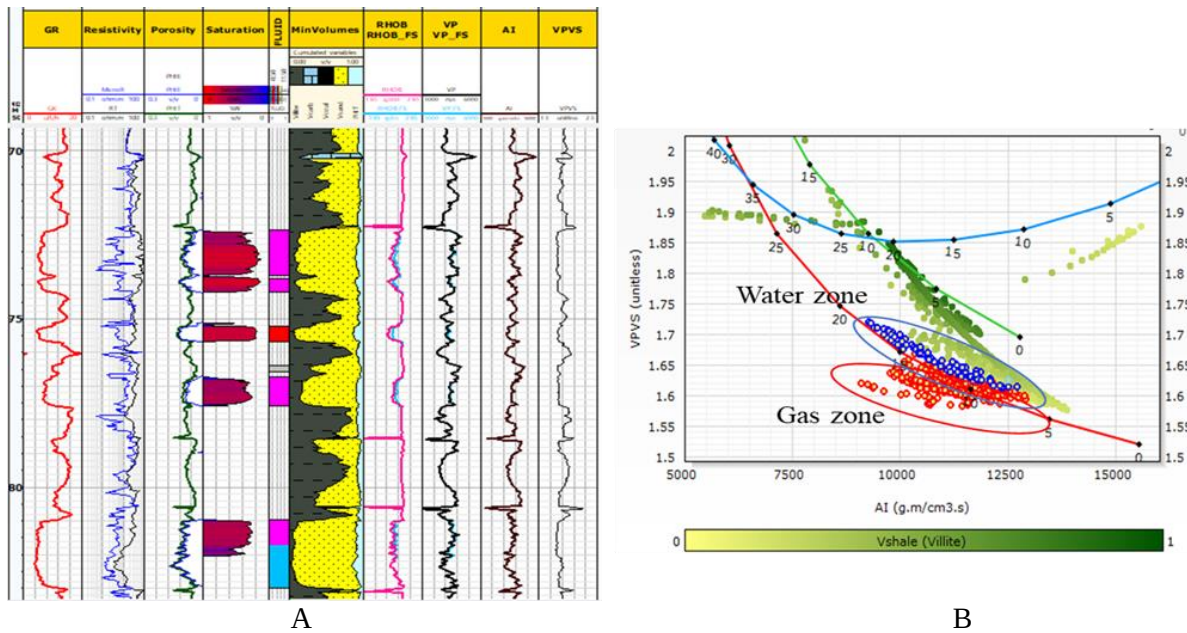


Figure 3 (A) Results of petrophysical interpretation and rock physics modelling for the Lower Middle Carboniferous interval; (B) Rock physics template showing low sensitivity of elastic properties to fluid saturation.

Figure 4 illustrates the results of AVO modelling based on seismic data with SEG negative polarity for both high-porosity and low-porosity gas-saturated sandstone intervals. The synthetic-to-seismic well-tie (SWT) correlation coefficient is 0.7 along the entire wellbore and increases to 0.85 within the target intervals.

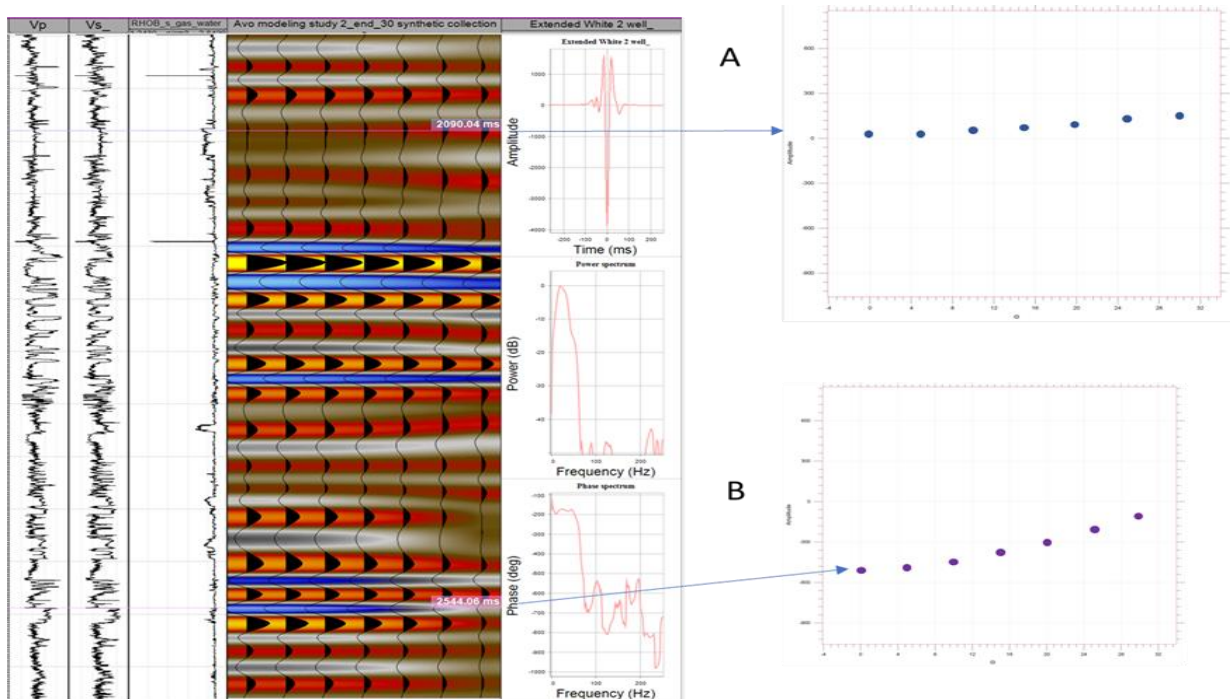


Figure 4 AVO modelling for (A) high-porosity sandstone and (B) low-porosity gas-saturated sandstone. SEG negative polarity convention.

The high-porosity interval exhibits an increase in amplitude with offset, from 50 to 150, which is characteristic of a Class II AVO response. In contrast, low-porosity sandstone interval, with porosity of 10–12%, shows a decrease in absolute amplitude with offset, from -540 to -80, consistent with a Class I AVO response. In addition, acoustic impedance analysis indicates that the porous intervals correspond to a peak on the seismic trace, implying lower acoustic impedance than the surrounding rocks, whereas the more low-porosity interval corresponds to a trough, indicating higher acoustic impedance relative to the enclosing formations.

The reduced sensitivity is controlled not only by low-porosity and elevated acoustic stiffness, but also by depositional controls on mineral composition. The high-porosity sandstone contains up to 15–20% clay minerals, whereas the low-porosity reservoir is predominantly quartz arenite, resulting in a stiffer rock frame and reduced fluid sensitivity of the dry frame.

These low-porosity reservoirs are also commercially productive, making accurate delineation of their spatial distribution critically important. Stochastic inversion and Lambda–Mu–Rho (LMR) analysis are expected to further improve gas prediction in these reservoirs.

Conclusions

The integrated use of petrophysical interpretation, rock physics modelling, AVO modelling, and quantitative interpretation provided an effective workflow for evaluating seismic gas-detection feasibility at the prospect scale within the DDB. The feasibility study revealed a fundamental contrast between the two reservoir types present on the prospect, primarily controlled by porosity, elastic stiffness, and fluid sensitivity.

For the high-porosity Upper Middle Carboniferous sandstones, the elastic contrast between gas- and water-saturated intervals is sufficiently strong to support reliable feasibility for seismic screening and prospect ranking. The predicted Class II AVO behaviour was confirmed by modelling and by subsequent drilling results, with an approximately 70% success rate on seismically selected targets.

For the low-porosity Lower Middle Carboniferous sandstones, seismic gas-detection feasibility is substantially lower because of weak fluid sensitivity, limited Vp/Vs separation, Class I AVO behaviour, and a stiffer rock frame.

The study defines a calibrated rock-physics feasibility workflow that shows where standard AVO-QI methods are reliable and where additional rock-physics-guided attributes are needed.

References

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