

QI as an important tool for mature field exploration- a case from the Carpathian foredeep, Ukraine

Introduction

In Ukraine QI (quantitative interpretation) methods have been used in the oil and gas industry for nearly two decades. Until recently, their usage was limited to the Eastern and Southern regions (Dnipro-Donetsk Basin and the Black Sea). These territories are characterized by a significant amount of geophysical data, developed infrastructure and high intensity of geological exploration work, which contributed to the faster implementation of modern analysis methods, including seismic inversion, AVO analysis and other quantitative interpretation approaches (Kuzmenko et al, 2026). On the other hand, the western part of Ukraine (Carpathian foredeep) was the only one that was not covered by quantitative interpretation studies until 2023 (Krasnikova et al, 2025). This was due to both the complex geological structure of the region and the limited amount of high-quality seismic and well data required for quantitative interpretation. At the same time, there were successful cases of using QI for the Carpathian basin in neighbouring countries (Szymańska-Małysa & Dubiel, 2019). Therefore, since the beginning of the full-scale invasion, focus to this region as a component of ensuring Ukraine's energy system independence has increased. In 2024 the authors completed the first successful seismic inversion project at a site in the Western region of Ukraine.

In addition to the complex thrust tectonics of the Carpathian region, complications in conducting QI are created by the characteristics of the reservoirs and their surrounding rocks. The region is characterized by rhythmic interbedding of sandy and clayey layers of small thickness (from several centimeters to several meters), close in values of elastic parameters. This makes the use of traditional workflows of quantitative interpretation ineffective. At the same time, for the deposits of the Carpathian region of Ukraine, the structural traps of which were discovered in the middle of the last century, QI as a means of exploring non-structural traps is extremely important.

This article demonstrates a quantitative interpretation workflow adapted to the complex geological conditions of the Carpathian region of Ukraine, combining classical seismic inversion approaches with additional analysis methods.

Methods and Theory

Hydrocarbon production from the Western oil and gas region of Ukraine has been going on for more than a hundred years. A significant part of the deposits are depleted, the Upper Miocene horizons are of interest in hydrocarbon exploration. When analyses core material, well testing, as well as data from API-standard logging methods, authors concluded that the influx of hydrocarbons occurs from thin-walled intervals of porous sandstones located in clayey strata.

The input seismic data are PSDM (PreStackDepth Migration) angle stacks after FWI (full waveform inversion) and structural interpretation of horizons. For QI purposes seismic data processing was performed using amplitude preservation techniques, and FWI was included in the processing for an object in the Carpathian region of Ukraine for the first time.

To establish a connection between elastic and petrophysical properties, as well as to model elastic parameters, petrophysical interpretation was performed using a deterministic approach. Clay content, total and effective porosity, water saturation, and rock composition were determined gradually. The bulk density curve was modelled based on the obtained composition, porosity, and saturation of intervals. The S- wave velocity (V_s) was modelled using the Greenberg-Castagna equations, which were calibrated to data from cross-dipole studies, as well as the longitudinal wave velocity curve after performing the Gassmann substitution (Fig. 1A).

The next stage of the quantitative interpretation of seismic data was the AVO analysis. A number of AVO-attribute cubes were created based on the Shuey and Fatti approximation algorithm of the Zöppritz equation. The main attributes were fluid factor and derivatives of intercept and gradient. Simultaneous deterministic inversion was performed to obtain AI, Vp/Vs and density cubes. The toolkit of AVF and spectral decomposition was used to study the spectral characteristics of saturated formations.

Examples

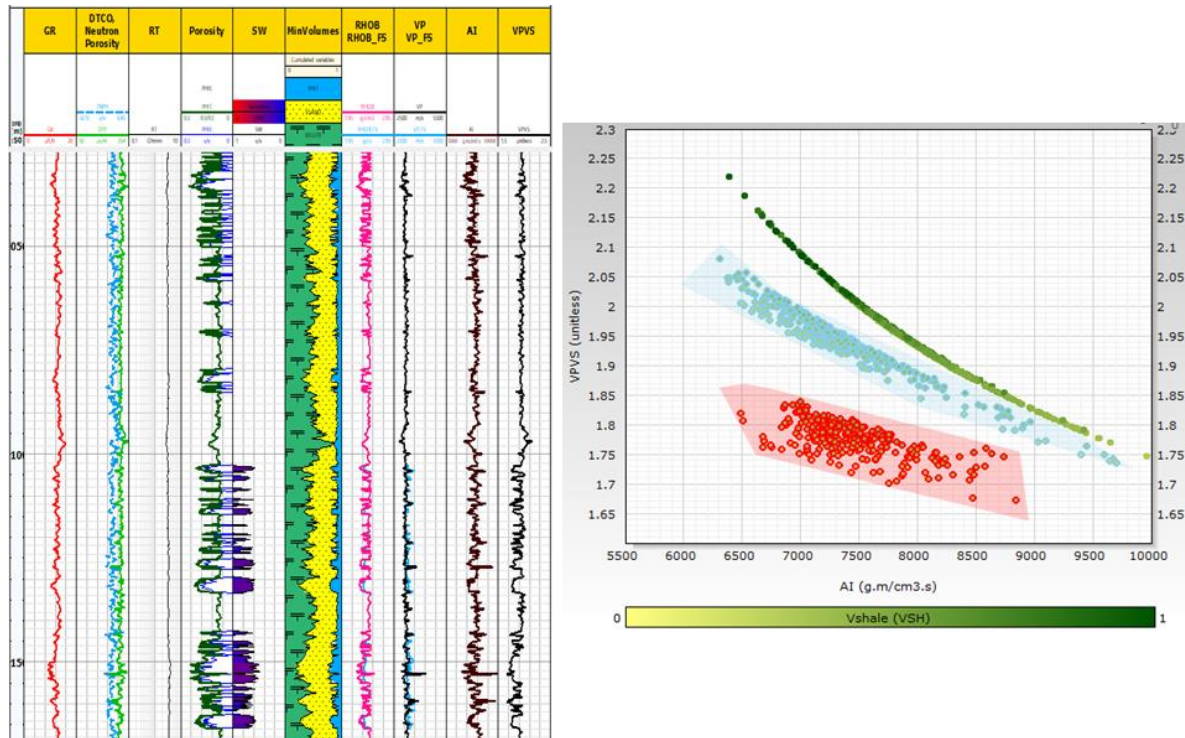


Figure 1 A – results of petrophysical interpretation and modelling of elastic properties; B – RPT for upper miocene deposits with extracted gas-saturated and water-saturated intervals.

The sandstone beds are thin-laminated, often with a thickness lower than the vertical resolution of modern logging methods. Therefore, the approach to interpretation and modelling used allows to characterize the section and convey more correct elastic properties (which are based on well tests) for further work with seismic data. Fig. 1B presents a rock physics template for the Upper Miocene interval in which the hydrocarbon influx was obtained. Clay rocks and sandy interbeddings are poorly differentiated according to AI data, but there is a difference in the simulated elastic properties: Vp/Vs of gas-saturated sandstones 1.55-1.85, water-saturated – 1.8-2.1.

AVO analysis and seismic inversion were performed to determine the spatial distribution of prospective sandstones. Since, according to the results of the analysis of rock physics parameters, sandstones in this stratigraphic interval lack contrast with the clay rocks, the traditional QI algorithm with the creation of a lithological classification based on crossplots of AI and Vp/Vs cubes cannot be applied. Fig. 2 shows the result of AVO analysis and seismic inversion near the productive well. Fig. 2A shows seismic field, 2B reflects the aforementioned lack of AI contrast in accordance with the results of rock physics. In turn, the Vp/Vs cube (2C) obtained as a result of the inversion has sufficient contrast for a qualitative assessment of prospective intervals. In this way, the AVO attribute cubes can also be characterized.

The most useful ones for the study of the distribution of reservoir properties are fluid factor (Fig. 2D) and sign (intercept*gradient) (Fig. 2E). Blind well test showed a high convergence of anomalous values

of these attributes with the vicinity of productive wells. It should be noted that fluid factor is characterized by a greater number of type II errors associated with water-bearing formations.

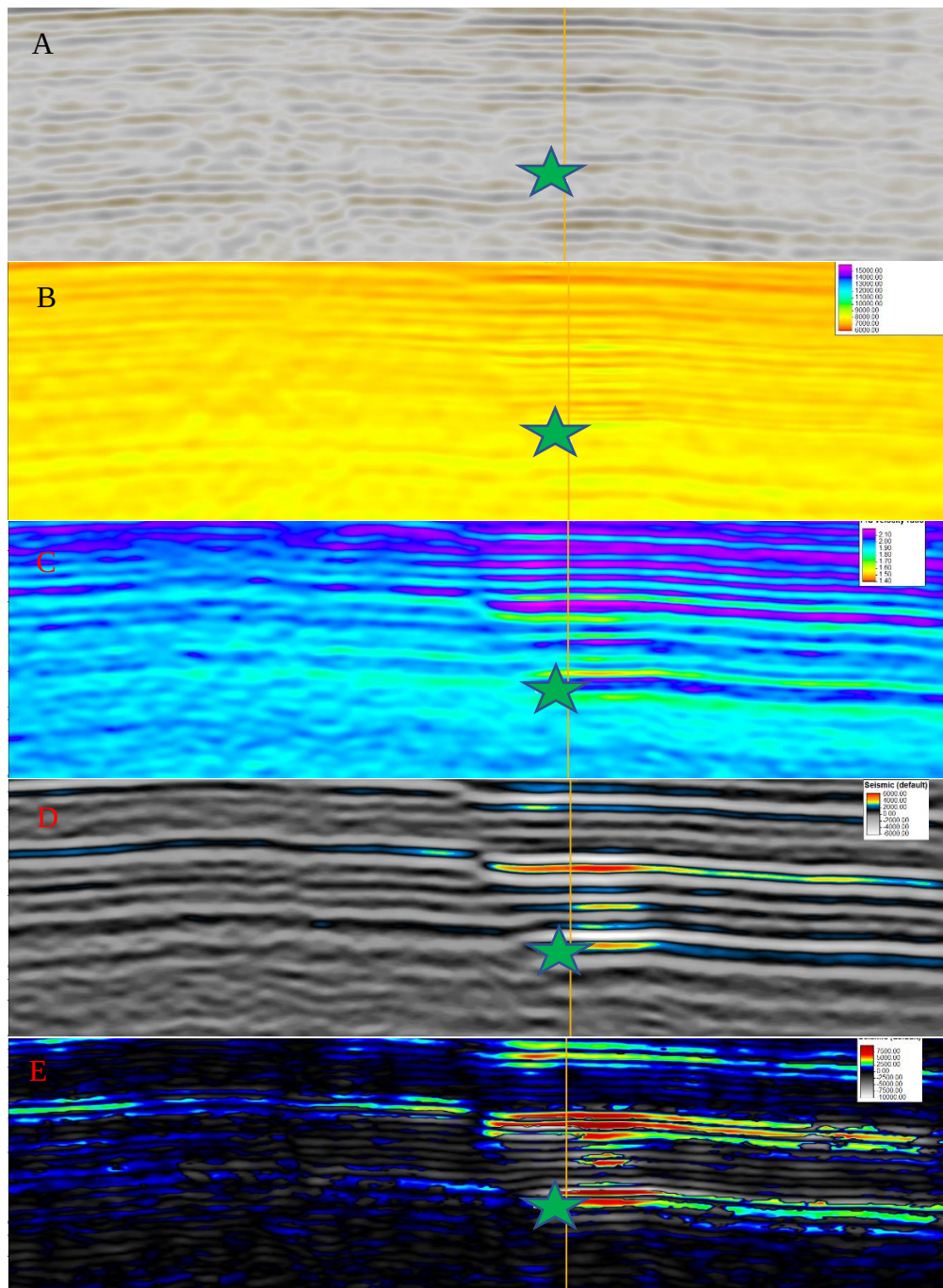


Figure 2. An intersection of the area near a productive well A: A-seismic, B- acoustic impedance, C- V_p/V_s , D-fluid factor, D- sign (intercept*gradient), a productive interval is marked with a star.

Furthermore, using AVO attributes introduced the difficulty of separating fluid types with their help. The use of AVF tools with frequency analysis of spectral decomposition data has proven to be an important tool for determining the type of fluid on the object. Even in cases where AVO anomalies were present for water-saturated formations with high porosity, peak frequency analysis allowed to effectively separate gas- and water-saturated reservoirs. Gas-saturated intervals are characterized by

peak frequencies around 25 Hz and the presence in the spectrum of a component with frequencies below 10 Hz and signs of scattering in the high-frequency component, while water saturation is associated with frequency peaks above 30 Hz, minimization of the component with frequencies below 10 Hz and a more preserved high-frequency component (Fig. 3).

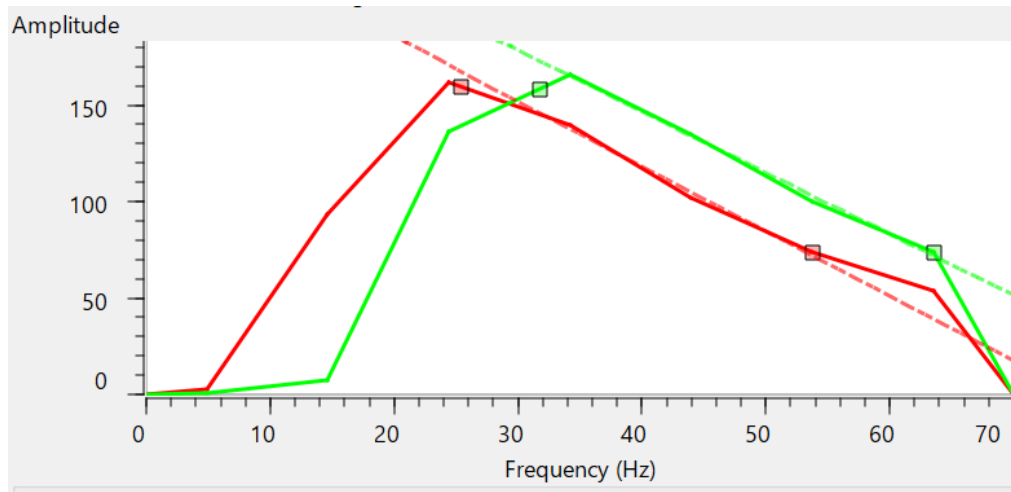


Figure 3. Comparison of frequency characteristics of water-saturated (green) and gas-saturated (red) wells with similar ranges of AVO attributes.

Conclusions

For the first time, a full-fledged quantitative interpretation workflow has been implemented for the Carpathian region of Ukraine, including PSDM data with FWI, AVO analysis and seismic inversion, confirming the possibility of effective application of modern geophysical methods in complex tectonic conditions. The key geophysical challenge of the region is the weak contrast of elastic properties between reservoirs and interbedded rocks, due to thin-layered interbedding of sandstones and clays, which significantly reduces the effectiveness of traditional approaches. Seismic inversion shown limited informativeness of AI for reservoir selection, while V_p/V_s and AVO attributes demonstrated significantly higher diagnostic ability for identifying promising intervals. AVO attributes correlate well with productive zones, but are characterized by an increased number of false positives in water-saturated formations. Integration of AVF analysis and spectral decomposition allowed to significantly increase the reliability of fluid type prediction.

References

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