Derisking of Lithological Pools Exploration by Introducing Gravity to Joint Inversion with Seismic and Well Data

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Introduction

The Dnieper-Donets basin is a major petroleum province of Ukraine, taking the lead among other hydrocarbon-prone regions due to its proven reserves, remaining potential resources and cumulated hydrocarbon production. The main oil and gas prospects here are related to the Carboniferous sediments. Within its Northern Flank commercial productivity is also associated with Pre-Cambrian rocks of the crystalline basement.

Despite the large number of discovered fields, Northern Flank is evaluated as explored only by 18% due to the complexity of its geological structure, which is reflected in structural unconformities in sedimentary cover and development of the tectonically screened, anticlinal and lithological traps. As evidenced by drilling results the latter are predominant in the Lower Carboniferous Serpukhovian and Visean sediments, containing most of HC reserves within the Northern Flank. Still in spite of abundant drilling data and modern 3D seismic available delineation of HC pool is challenging, leading to significant number of dry wells and cost increase of E&P. The situation worsens for prospects located in the areas with complicated topography, where only scarce 2D seismic is physically possible. Taking into account small resources of deposits (in spite of large quantity) to stay cost-effective and decrease E&P risks traditional geophysical set of seismic and well logging data needs to be accomplished by non-seismic methods.

When considering to use non-seismic data in HC exploration the main questions geoscientists are dealing with are amplitudes of physical changes in HC saturated rocks comparing to non-productive ones, amplitudes of geophysical anomalies and possibility of their registration by modern equipment, as well as appropriateness of interpretation procedures to ensure identification of target anomalies related to HC pools.

In this study we illustrated possibilities of gravity applicably to HC exploration using case study for Horoshevo prospect, located within the Northern Flank of the Dnieper-Donets basin (Figure 1). Target horizons of Serpukhovian, Visean and basement here are located at the depth of 2.8 - 3.8 kilometers (Figure 2). By 2D seismic data potential trap structurally is presented by faulted half-anticline.

***Figure 1** Location of the investigated area*

Interpretation approach

When applying gravity data for HC exploration following factors are critical for E&P success:

- Value of gravity data is only when inverted together with seismic, well, petrophysical and geological information.
- Inversion based on the Tikhonov's regularization provides stable, but unmeaningful solution, because of the exotic properties of harmonic function as the natural uniqueness class for linear inverse problem solution.
- Inverse problem should be redefined so the inversion is not only constrained by prior information, but driven by it, so that additional geological information is used as a guiding rule to select the single geologically meaningful model from the space of possible solutions correspondent to observed gravity field.
- Full-depth structural and property inversion (from surface to basement or Moho for basin scale).

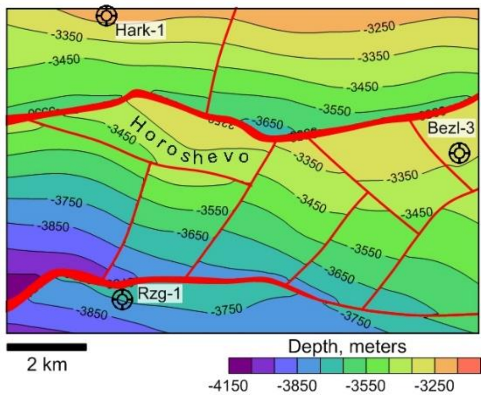

***Figure 2** Structural settings of Horoshevo area, Visean of Lower Carboniferous*

- Using of real density for inversion.
- Quantifying uncertainties, variability, constraints for all the geological sequence and involving structure by seismic, petrophysics, logs, layering according to expected stratigraphy.
- Inversion for observed gravity field (full fit of modelled-to-observed gravity data).

Basing on this, general formulation and solution of the inverse problem for integral interpretation of geological and geophysical data stipulates determination of optimal model parameters $\xi(x)$ to fit best gravity data $u(s)$ and set of available geological and geophysical information formulated as an optimality criterion $J(\xi(x) - \eta(x)) \Rightarrow min$ relatively to initial model $\eta(x)$:

$$\begin{cases} A\big(\xi(x)\big) = u(s) \\ J(\xi(x) - \eta(x) \Rightarrow min \end{cases},$$ where $A(.)$ – equation for direct geophysical problem solution.

3D modelling workflow and results

Study area was selected to include 3 wells from nearby Bezludivka field, Rzgavets and Harkiv prospects, located in the marginal parts of the territory (Figure 2). That gave a possibility to use well logs as an active component in the inversion, which means to fulfill demand of density model correspondence both to gravity and to log data (Figure 3). Model's uniqueness and geological meaningfulness was provided by including geological data and constraints into process of interpretation like information about productive intervals, constraints on densities etc. High precision gravity data (measurement error 0.0066 mGl) adjusted with Bouguer reduction and terrain corrections were used as controlling function in inversion.

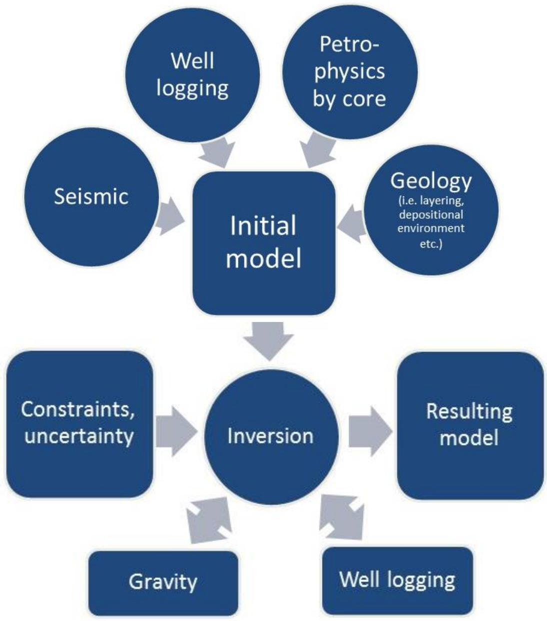

Figure 3 *Inversion scheme*

In the process of inversion gravity fields misfit decreased by 63 times, from 3.5 mGal to 0.05 mGal (Figure 4). As a result of the inversion one unique density model was obtained (Figure 5), which is geologically meaningful and consistent with seismic information, well data, petrophysical information, wells' tests and gravity data. In particular final gravity misfit is presented by mostly random function with normal Gausian distribution. Correlation of the well densities from initial logs to that from the final density model for three wells are R^2=0.44, 0.75 and 0.98. Density characteristics of wells are in agreement with drilling results. Particularly the Serpukhovian and Visean sequences in proximity of well #1 of Rgzavets prospect are characterized by highest densities around 2.63 g/ccm (Figure 5, 6), typical for tight sandstones, silty and clayey rocks. The well #1-Rgzavets was dry by testing results. Intermediate densities near the wells #1-Kharkiv, #3-Bezludivka (2.35 – 2.45 g/ccm, Figure 5) are characteristics of good water-saturated reservoir, which is proved by well data. While within the area of Horoshevo prospect densities decrease to 1.99 g/ccm to 2.38 g/ccm, characterizing quality gas-

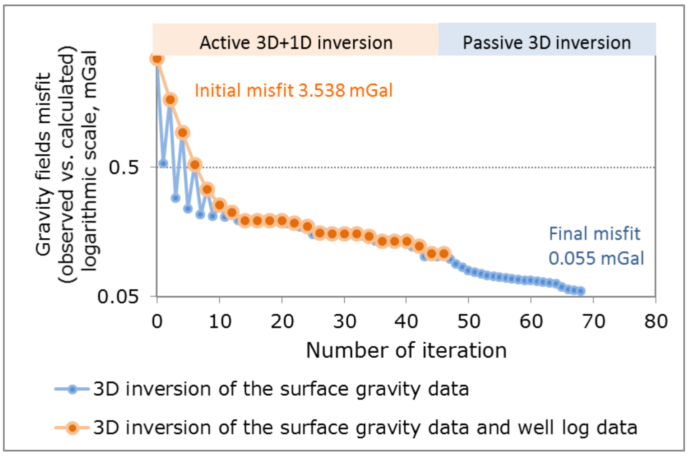

Figure 4 *Convergence of the inversion process*

saturated reservoir with porosity around 22%, penetrated by wells within nearby Bezludivka field further to the east. At the same time spatial density distribution within the target horizons (Figure 6) evidence heterogeneity of the reservoir within the Horoshevo prospect as was expected, with denser part at the crust of the anticline, which can be caused either by decrease of reservoir properties of the sandstone and / or by increasing its of clayey content.

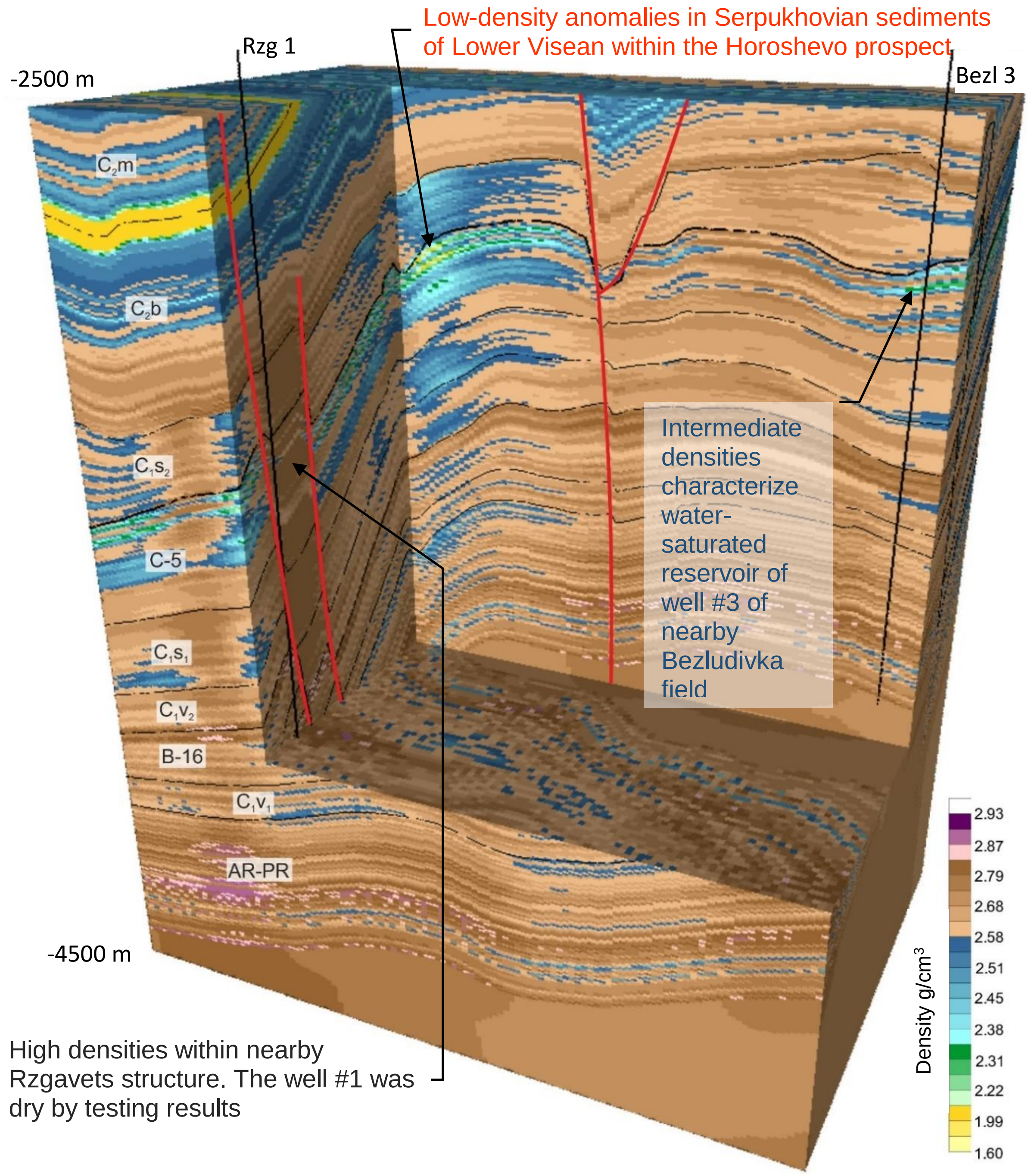

Figure 5 *Final 3D density model of Horoshevo area, obtained as a result of joint inversion of gravity, seismic and well data. Model size is 11.9 x 8.2 km laterally and 8 km in depth. Model discretization is 100 meters laterally and 5 meters vertically. Total number of sells is 15.9 million. 5 meters vertical resolution of 3D model (which is comparable to average reservoir net thickness) was obtained due active introduction of well logging data to the inversion. Structural framework is by 2D seismic data. Usage of real densities allows model calibrations to core data and well logs, while 3D high accuracy gravity data provides space control of the distribution of density anomalies.*

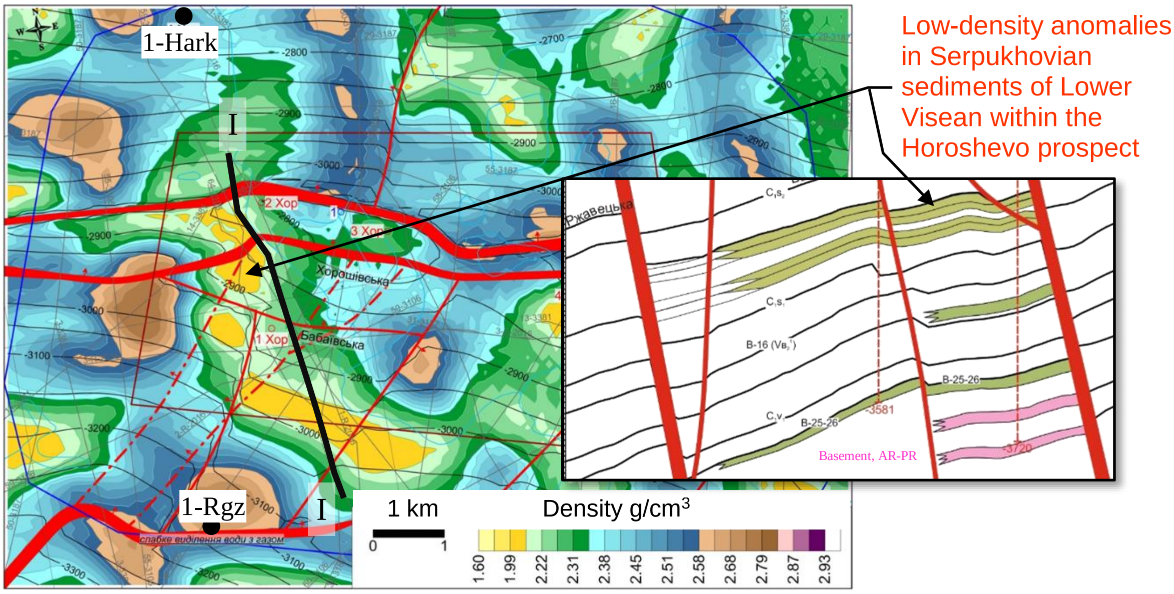

Figure 6 *Slice of the final 3D density model of Horoshevo area conformal to the top of the Serpukhovian sediments of Lower Visean (left), with location of new prospected areas (yellow color – sandstones with density from 1.99 g/cm^3 to 2.38 g/cm^3). Horoshevo prospect (pointed by black arrow) on the map and geological crossection across the Horoshevo prospected area (right). Total resources of new lithological HC prospects in Serpukhovian sediments of Lower Visean estimated as 1.860 bcm of gas.*

Conclusions

Lithological pools are the known, but challenging objects for future increase of HC resources in sedimentary basins in the world, and in the Dnieper-Donets basin as well. Taking into account that independent use of seismic survey for prediction of this type reservoirs is characterized by high level of exploration risks, especially when using 2D measurements, for derisking of lithological pools exploration expanding the set of geophysical methods by including high resolution gravity survey showed its high efficiency within the Northern Flank of DDB. Efficiency of gravity introduction, based on the technology of joint adaptive 3D inversion for gravity, seismic and well log data applicably to exploration of HC pools for Horoshevo prospect in Dnieper-Donets basin, has shown its high efficiency for prediction of reservoir quality and saturation type within the prospect, both in space and depth, and resources estimation for all type of reservoirs including small sized accumulations.

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