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Obolon Astrobleme - An Application of 3D Geomodelling and Inversion to Hydrocarbon Exploration

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SUMMARY

Among other unconventional reservoirs Obolon astrobleme is regarded to be a promising exploration target in Ukraine. Complex and poorly known structure of astroblemes require integration of additional geophysical and geochemical data to commonly used set of seismic and well data. An effective method of joint geophysical inversion was used to build 3D model of Obolon astrobleme which gave possibility to map reservoirs with high probability of hydrocarbon saturation within crater, rim and breccia complex. Research workflow and main results are highlighted in the paper.

Introduction

Exhaustion of conventional oil and gas resources of main oil-and-gas-bearing regions of Ukraine: the Dnieper-Donets depression and the Carpathian region, cause to start exploration for unconventional hydrocarbon resources in Ukraine, including both shale gas, gas of central basin type, coal-bedded methane and hydrocarbon deposits associated with impact structures. Oil and gas production from astroblemes is proven today. Particularly, Richard R. Donofrio (1998) indicates 50% drilling success rate for impact structures located within the oil-and-gas-bearing regions of North America. Astroblemes productivity is also proven in other parts of the world. Among the seven proven astroblemes of Ukraine of greatest interest as being potentially oil-and-gas-bearing is Obolon astrobleme located in the Southern margin of Dnieper-Donets basin (Fig. 1).

Obolon astrobleme is a complex impact structure. Impact age is Jurassic. For the first time the structure was discovered in 1947 by electric survey as a contrast negative local anomaly. Later in 1951 it was confirmed by local gravity anomaly. After the regional seismic survey in 1965-66 within the mapped structural depression there were drilled two exploration wells for oil-shales. The reason for that were commercial deposits of oil-shales in another (Boltysh) astrobleme in Ukraine. Presence of suevites and impacted diamonds in the core confirmed the impact nature of the structure. Drilling results proved absence of oil-shales, but at the same time did not solve the question about oil-and-gas presence in the structure. In 2011, the National Joint Stock Company "Naftogaz of Ukraine" initiated exploration works for oil and gas in Obolon astrobleme. This paper highlights methodology used for revealing unconventional reservoirs in Obolon impact structure. Main results are listed.

Method and Realization

Unlike most identified astroblemes with proven oil-and-gas-bearing, exploration process of Obolon structure was particularly focused to reveal reservoirs of impact structure. Considering unconventional reservoir type and complex geological structure, in order to determine potential hydrocarbon prospects there was applied an extended complex of geophysical research. It included 3D seismic survey, detailed gravity and magnetometric surveys, geochemical, emanational and thermometric studies. As a result of joint geophysical and geochemical data interpretation there was created integrated 3D geologic-geophysical model of Obolon astrobleme.

Figure 1 *Prooved astroblemes of Ukraine.*

3D geologic-geophysical model was built on base of joint inversion of seismic, gravity, geological and well data. Modeling process included following steps:

Step 1. 3D structural model construction. Structural framework of Obolon astrobleme 3D geomodel was based on 3D seismic survey results, which included 5 structural horizons (Fig. 2). According to 3D seismic results impact crater shape is close to isometric and is 18.5x17 km in size (Fig. 3). The maximum crater depth on basement level is 1,054 meters and on the top of breccia complex is 835 meters. Low-amplitude (less than 30 meters) central uplift is mapped in the center of the crater. Breccia complex thickness reaches 1,900 meters in the central part of the crater.

Step 2. Construction of the initial 3D property model. Rock density was used as an informative parameter for property model as far as maximum variations of density are associated mostly with an increase of rock porosity (reservoir presence) and replacement of water fluid in porous media to hydrocarbons (Fig. 4). This statement is based on well-known petrophysical equation for rock density σ_r: $\sigma_r = \sigma_m(1-\varphi) + K_p\sigma_f$, where σ_m – matrix density, φ – rock porosity; σ_f – fluid density, and also on the fact that matrix density variations do not exceed 15% (Dortman, 1984).

To create initial 3D density model the porosity cube derived from seismic inversion was recalculated to the density cube. Then density cube was calibrated with petrophysical data from nearby wells. Obtained density was additionally calibrated with seismic velocities by performing 1D kinematic seismic modeling of the wave field for wells of Obolon area.

Model was approximated using regular Cartesian mesh. Cell dimensions were 100 meters per 100 meters laterally and 5 meters in depth. 3D model dimensions were 25.5 km per 20 km laterally and 8 km in depth. The total number of cells in model was 6,878,480.

Step 3. Determination of model's optimal parameters on the base of inverse gravity problem solution for created initial model with parameterization of inversion by additional geological and geophysical information. General formulation and solution of the inverse problem for integral interpretation of geological and geophysical data stipulates determination of optimal model parameters to fit best gravity data and all available geological and geophysical information:

$$\begin{cases} A(\xi(\mathbf{x})) = u(s) \\ J(\xi(\mathbf{x}) - \eta(\mathbf{x})) \Rightarrow \min \end{cases},$$

where $\xi(\mathrm{x})$ – target (true) geomodel, $u(s)$ – observed geophysical parameter (gravity), $J(\xi(\mathbf{x}) - \eta(\mathbf{x})) \Rightarrow \min$ – optimality criterion, $\eta(\mathrm{x})$ – initial geomodel, $A(.)$ – operator of forward problem solution. Additional geological information is formalized in terms of optimality criterion and is being used in the process of gravity data inversion,

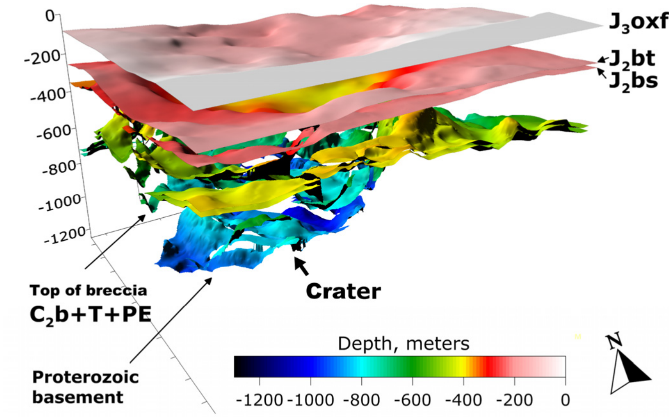

Figure 2 *3D structural model of Obolon astrobleme.*

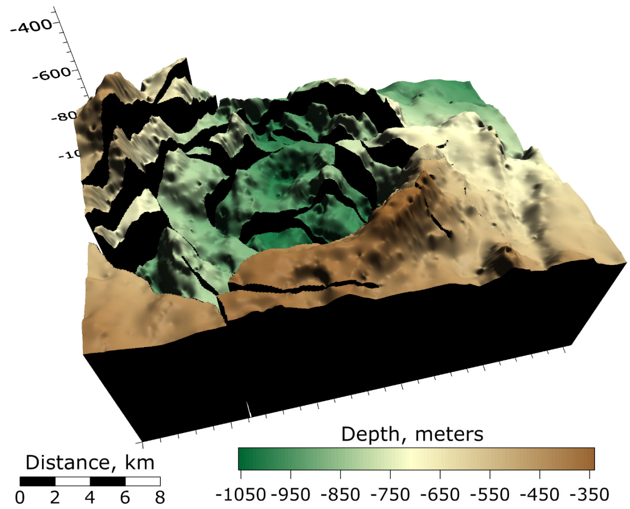

Figure 3 *Structure of top breccias $C_2b+T+PE$ complex (within crater) and top of Bashkirian C_2b (outside the rim).*

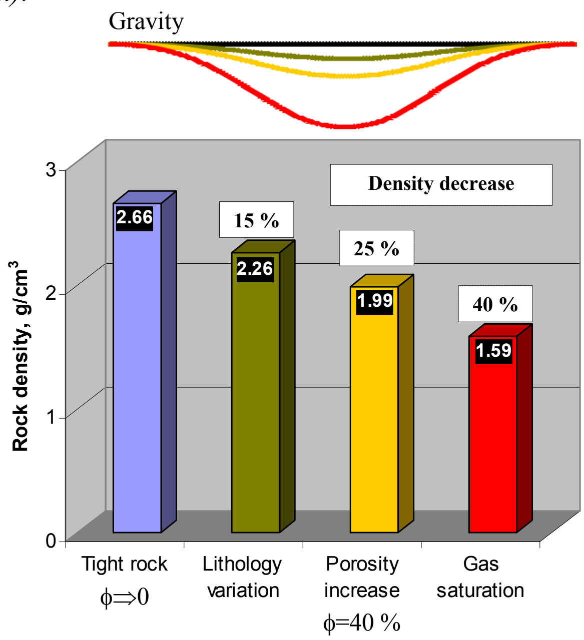

Figure 4 *Extreme density defects caused by changing of lithology, porosity and rock saturation.*

ensuring the *uniqueness and geological adequacy of the final inverted 3D model.* Thereby accuracy, completeness and adequacy of the input geological and geophysical information define the resulting model accuracy and geological appropriateness.

Resulting 3D model of Obolon astrobleme is illustrated on figure 5. Standard deviation of observed and calculated gravity fields' misfit is 0.06 mGl (Fig. 6).

Step 4. Model analysis aiming to delineate lowest density areas within target rocks, ejecta and overlaying filling complex. As it was mentioned these zones are regarded to be most favorable to contain best reservoirs with high probability of hydrocarbon saturation.

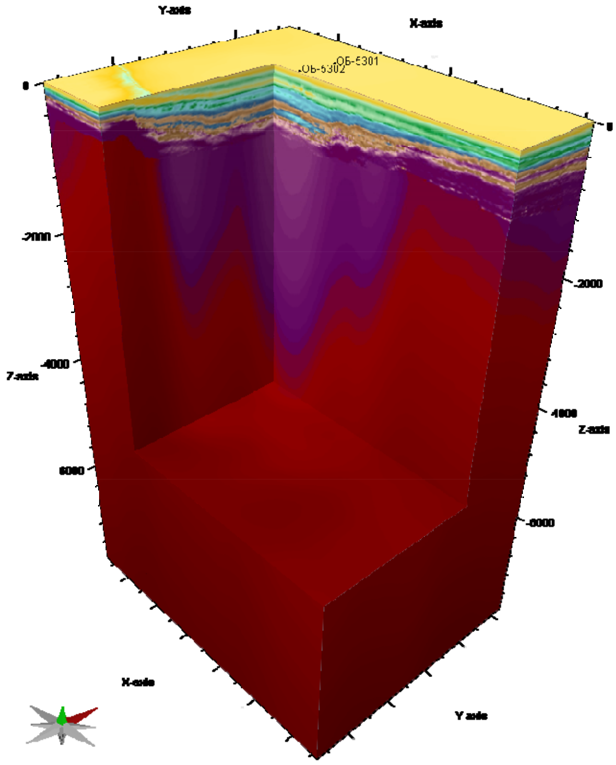

Figure 5 *3D density model of Obolon astrobleme.*

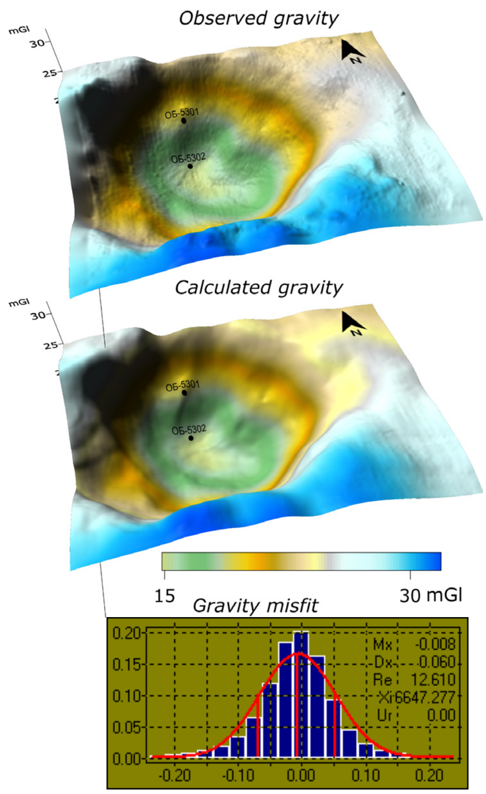

Figure 6 *Observed gravity (above), calculated gravity (middle) and gravity misfit histogram (below).*

Results

Mapped zones of reservoirs presence within the breccia complex, crystalline basement and overlying complex jointly with favorable structural settings were deterministic to allocate drilling prospects within area. Five areas of predictable reservoir development were mapped on different stratigraphic and structural levels.

To estimate priority of mapped areas and select the first-priority prospect for exploration drilling additional data were involved into study. These were the results of magnetic survey, geochemical, emanation and thermometric survey. The last ones were used as indicators of integrity/tectonic fragmentation of predicted reservoirs and as indicators of areas with potential deposits destruction, characterized by higher activities of hydrocarbon migration. As a method of geophysical and geochemical data joint analysis we used statistical methods for classifying the territory using multiple parameters.

As the first-priority object there was defined tectonically screened block within the rim in the south-western part of the structure (Fig. 7). Perspective hydrocarbon reservoirs were mapped within the upper part of crystaline basement, breccia complex and Jurassic basal sandstones of overlaying complex. The first exploration well is planned to be drilled in the block in 2013. Six more blocks were recommended for further drilling, including one deep target in crystaline basement within the center of structure and also number of prospects within the rim and breccia rocks.

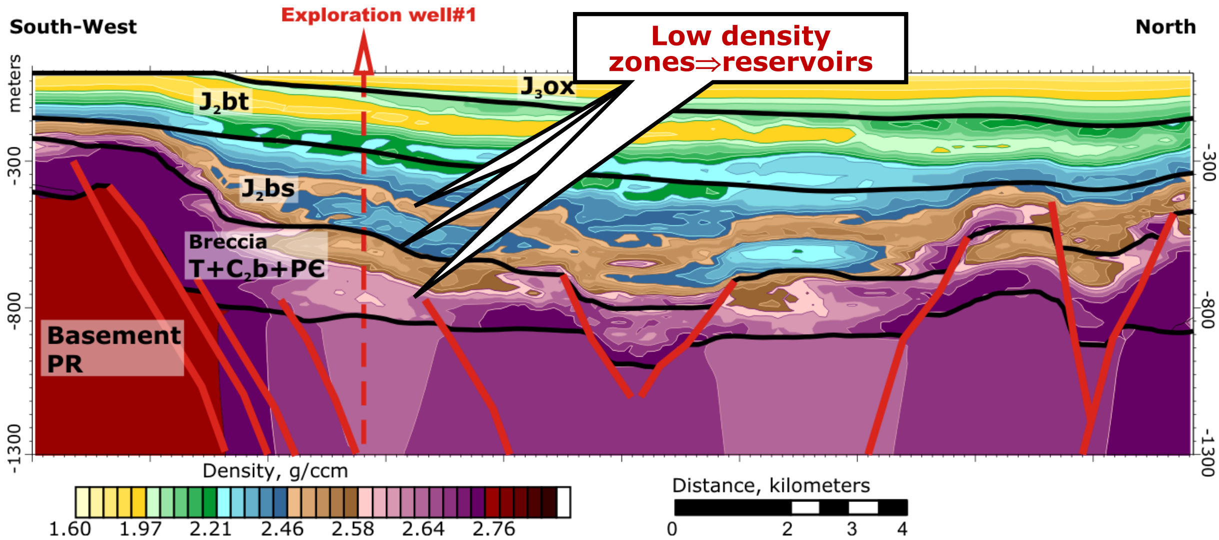

***Figure** 7 Density cross-section of 3D model through first-priority prospect.*

Conclusions

Due to extended complex of geophysical and geochemical studies it became possible to identify confidently the areas of reservoir presence within Obolon astrobleme with high probability of hydrocarbons saturation and select first-priority prospect for exploration drilling. Studies made give an evidence of especial importance of data integration, joint geophysical inversion and analysis of multiple data sets for effective studying of unconventional and complex objects which are astroblemes.

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