3D Geomodel of Obolon Astroblem, Ukraine, as a Key for Revealing New Exploration Plays

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Summary

Among other unconventional reservoirs the Obolon astrobleme is regarded to be a promising exploration target in Ukraine. Location close to mature oil and gas province Dniper-Donetsk basin makes it the primarily astroblem for hydrocarbon exploration. Complex and poorly known structure of the 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 applied to build 3D model of the Obolon astrobleme which gave possibility to map reservoirs with high probability of hydrocarbon saturation within its crater, rim and breccia complex. Research workflow and main results are highlighted.

Introduction

Obolon astrobleme is one of seven astroblemes discovered on Ukrainian territory. For the first time the structure was revealed in 1947 by electric survey as a contrast negative local anomaly and later confirmed by local gravity anomaly. Structural depression associated with impact crater has been mapped for the first time by regional seismic survey made in 1965-1966. Two exploration wells targeting oil shales (commercial reserves of which were proved at Boltysh astrobleme in Ukraine at that time) were drilled after. Drilling results showed no commercial oil shales on Obolon structure. At the same time presence of suevites and impacted diamonds in the core has confirmed its impact nature. Question about presence of commercial hydrocarbons in the structure was not examined.

Figure 1 Situation of Obolon astroblem

Expedience of oil & gas exploration on Obolon structure including deep drilling was first grounded by Krajushkin V.A. and Gurov E.P. in 1987 resulting number of geophysical and geochemical surveys in 1990-ies. Studies made gave a vision of general structure of the crater allowing researchers to make analogy with hydrocarbon bearing Avak impact structure.

New round of ongoing exploration activities was initiated by National Joint Stock Company "Naftogaz of Ukraine" in 2011. Integration of wide data set of geophysical and geochemical surveys gave possibility to build 3D geomodel of Obolon impact structure and to validate primarily prospects.

3D modeling results, interpretation approach and main geological results are illustrated.

Method and its realization

Considering unconventional reservoir type and complex geological structure, in order to determine potential hydrocarbon prospects there was applied an extended complex of geophysical research including 3D seismic survey, high precision gravity and magnetometric surveys, indicative geochemical, emanational and thermometric studies.

3D seismic results were traditionally used to map crater structure. Seismic inversion based on spontaneous polarization logging of two wells though calibrated on velocity data from nearby wells gave more or less validated porosity estimation only in the overlaying rock complex. Prognosed porosity of breccia complex remained poorly constrained due to lack of petrophysic data and basement reservoir properties were not studied. To highlight reservoir properties of breccia and basement rocks in the first place and to verify high porosity zones in overlaying complex gravity data were used for joint geophysical inversion and 3D geomodel construction.

3D geophysical model is described in terms of density as a rock parameter strongly influenced by porosity and fluid type in reservoir porous space (Fig. 2). So density model was used as an informative parameter to map prospects as areas with low density and enhanced reservoir properties.

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At the final stage geochemistry was used to select priority prospects for exploration drilling.

Inversion Method

3D integral inversion of seismic and gravity data used is implemented as part original multicomputing and multiprocessing software developed by STF BIPEKS Ltd.

General formulation and solution of inverse problem for integral interpretation of geological and geophysical data stipulates determination of an 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 $A(.)$ – linear operator of direct gravity problem solution, $\xi(\mathbf{x})$ – resulting (target) density geomodel, $u(s)$ – observed gravity, $J(\xi(\mathbf{x}) - \eta(\mathbf{x})) \Rightarrow \min$ – optimality criterion in form of convex functional, $\eta(\mathbf{x})$ – initial density geomodel.

First stage of interpretation was construction of initial 3D model $\eta(\mathbf{x})$. Parameters of this model reflect all available geological and geophysical data set. Initial model is presented in form of structural framework consisting of 5 structural horizons resulting from 3D seismic interpretation.

Initial heterogeneous 3D density model we recalculated from porosity cube derived from seismic inversion and 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 the 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.

Additional geological information formalized in terms of optimality criterion and petrophysical constraints are used in the process of inversion, ensuring the uniqueness and geological appropriateness of the final 3D model $\xi(\mathbf{x})$.

High accuracy gravity data $u(s)$ adjusted with Bouguer reduction and terrain correction were used as controlling function in inversion. Resulting 3D model of the Obolon astrobleme is shown on figure 5. Standard deviation of observed and calculated gravity fields' misfit is 0.06 mGl.

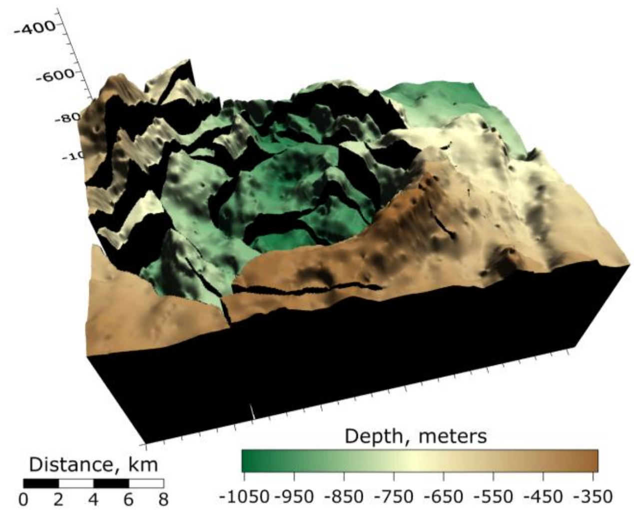

Figure 2. Structure of top breccias C_2b+T+PE complex (within crater) and top of Bashkirian C_2b (outside the rim)

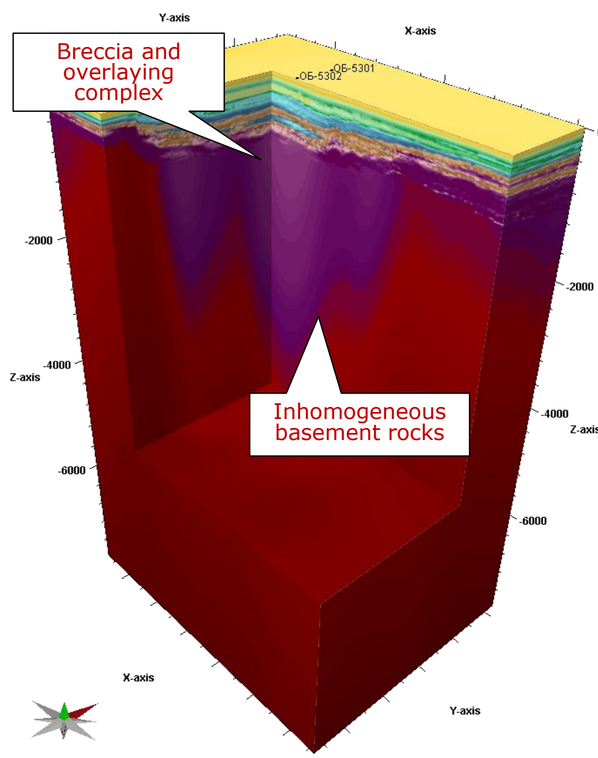

Figure 3 3D density model of the Obolon astrobleme

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Geological results

3D seismic results evidenced impact crater with shape close to isometric having 18.5x17 km in size (Fig. 2). The maximum crater depth to the basement level is 1,054 meters and on the top of breccia complex is 835 meters. Low-amplitude central uplift is mapped in the center of the crater. Breccia complex thickness reaches 190 meters in the 3D density model (Fig. 3) showed regional density decrease of basement rocks inside the crater. In the same time local inhomogenities in form of local low and high density zones are mapped. Two principal models are considered as possible reasons for density inhomogenities. First model proposed for interpretation of two major low density zones in the North-West and South-West is an assumption of two impact bodies. But taking into account almost isometric crater form more probable is the idea of influence of syn- and postimpact magmatic and metasomatic processes leading to densification of cracked rock massive. Evidence of the last is a number of local denser high magnetic areas which form elongated linear zone crossing central part of the crater. North strike of the zone corresponds to faults direction in Proterozoic-Arhean basement. This evidences fault reactivation caused by impact event and probable pore space blocking due to mineralization caused by metasomatic processes in the central part of the structure. This was an additional restriction later to consider central uplift as a primary target.

mentioned these zones are regarded to be most favorable to contain best reservoirs with high probability of hydrocarbon saturation.

Mapped zones of predicted reservoirs presence within the breccia complex, crystalline basement and overlying complex jointly with favorable structural settings were determined to select optimal sites for prospect drilling. Five prospects were mapped on different stratigraphic and structural levels.

To estimate priority of the prospects and to select the top priority one for exploration drilling additional data of geochemical, emanation and thermometric survey were involved into study. 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 for 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 the tectonically screened block within the crater rim in the South-Western part of the structure (Fig. 4). Perspective hydrocarbon reservoirs were mapped within the upper part of crystalline basement, breccia complex and Jurassic basal sandstones of overlaying complex. The first exploration well is planned to drill in the block in 2013. Other six

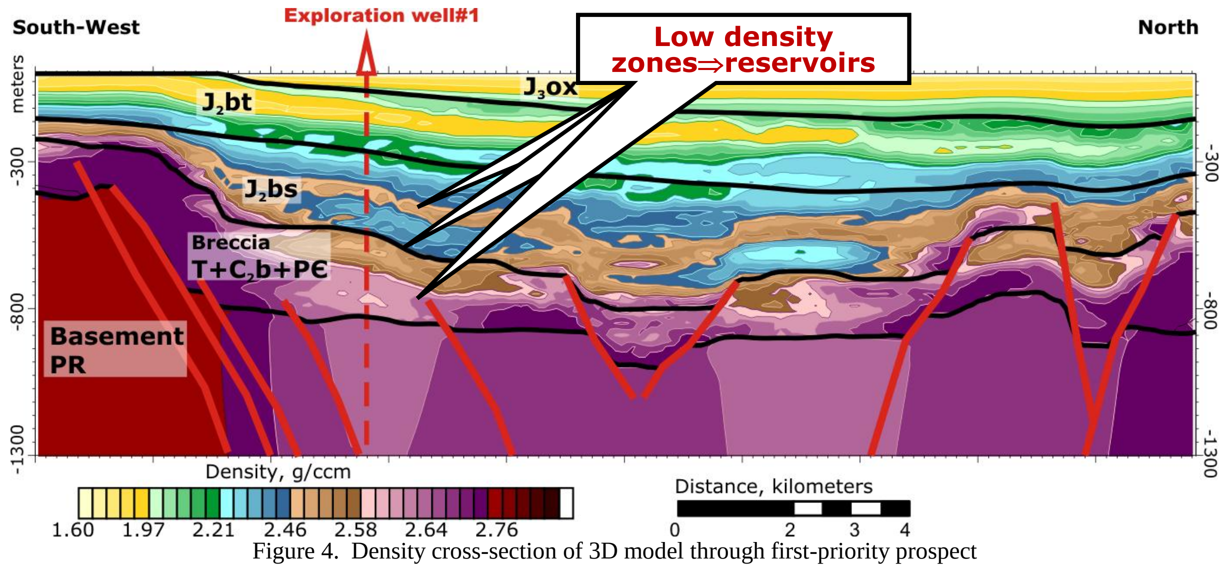

Figure 4. Density cross-section of 3D model through first-priority prospect

As a result of model analysis local low density areas within basement target rocks, ejecta and overlaying filling complex were examined and delineated. As it was

blocks were recommended for further drilling, including one deep target in the crystalline basement within the North-Western close to central part of structure and also

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several prospects within and outside the rim and breccia rocks.

Seal presence is prognosed in Jurasic shales of filling complex basing on well drilling results.

As a possible migration ways lateral and fault migration from deep shale levels of Dniper-Donetsk basin is regarded as well abiotic hydrocarbon origin due to vertical migration through laterly reactivated faults.

Conclusions

Integration of geophysical and geochemical studies has allowed delineating confidently the areas of reservoir development within the Obolon astrobleme with high probability of hydrocarbons saturation and selection of the first-priority prospect for exploration drilling. This research attests particular importance of data integration, joint geophysical inversion and analysis of multiple data sets for effective studying of such unconventional and complex exploration prospects like astroblemes.

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EDITED REFERENCES

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