New Prospective Plays Offshore Ukraine as result of 3D Geo-modeling & Geophysical Inversion

Oleksandr Petrovskyy, STF "BIPEKS LTD"*
Tetyana Fedchenko, Ivano-Frankivsk National Technical Oil and Gas University
Oleksandr Kitchka, CASRE NASU

Summary

An approach of integral geological and geophysical modeling has been applied to study the Black Sea (south of Odessa Gulf and offshore Crimea Peninsula) shelf and continental slope to delineate its potential hydrocarbon prospects and leads. Geophysical 3D Earth model was built integrating all available geo-data including geodynamic studies, seismic, well and gravity data. New prospects and leads were delineated on the base of density model analysis. Verification of the model with known gas fields proved correctness of the model built and reliability of new prospects. One of the most promising prospect mapped within continental slope and toe corresponding with higher probability to a submarine Neocomian canyon and fan incised into Jurassic bedrock.

Introduction

High cost of offshore drilling and especially deepwater one makes exploration risk decrease the highest priority. In case of immature petroleum provinces like Black Sea region offshore Ukraine we usually deal with regional seismics and scarce well data. This makes quiet challengeable task to reveal plays in complex sedimentary and tectonic environments. Number of unsuccessful wells in Turkish sector in the Black Sea prove the complexity of the problem. While new discovery on Romania deepwater offshore keeps this region as one of most promising.

In this situation the necessity to supplement seismics with additional geophysical data is quiet obvious. Multidisciplinary approach have gained general recognition on today most commonly meaning integration with EM methods and creation a 3D unified Earth models. While other geophysical information carried by gravity and magnetic data are not widely used in exploration process.

This presentation illustrates general principals and results of 3D geophysical Earth Model construction for Black Sea northwestern shelf and adjacent deepwater sector in the Ukrainian economic zone (Fig.1) (Petrovskyy et al., 2009). 3D model is based on seismic and well data and implication of geologically constrained gravity inversion. Obtained 3D density model interpreted in terms of reservoir properties proved to be a powerful tool to reveal new prospects particularly beyond the hinge of continental shelf and to attain exploration goals.

Method and its realization

Interpretation process includes construction of heterogeneous 3D density model as the result of inverse problem solution for gravity data in combination with seismic data, well log data and other geological information (Petrovskyy O.P., 2005).

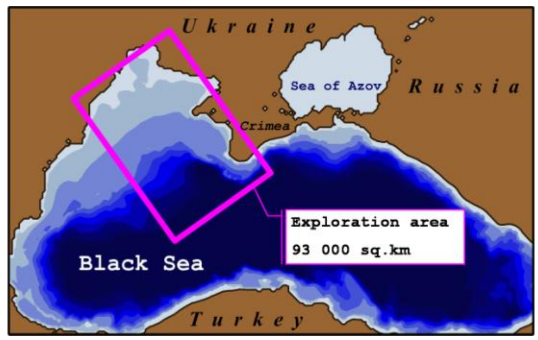

Figure 1: Exploration area

Physical Background for Reservoir Properties and Saturation Characterization

3D geophysical model is described in terms of density. As a rock physical parameter density contains information about lithological composition of rocks, porosity, type of fluid in reservoir porous space. Thus changes of rock density caused by lithology variations do not exceed 15 %. While porosity increase up to 40 % causes 25 % decrease of rocks bulk density. Moreover density decrease can reach 40 % if this reservoir is gas saturated (Fig. 2).

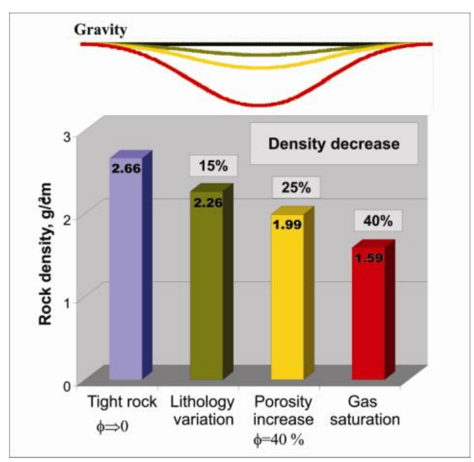

Figure 2: Exploration area

DOI http://dx.doi.org/10.1190/segam2012-1545.1

This fact indicates density being an effective informative parameter to use for mapping areas with enhanced reservoir properties and allows estimating expected rock saturation type.

Calculated direct gravity effects (forward modeling) for known gas and oil fields in the Black Sea – Crimea region have shown existence of negative anomalies up to 1-2 mGal (Petrovskyy et al., 2010) confirming this concept.

Inversion Method

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 consists of the initial 3D integral model $\eta(\mathbf{x})$ construction. Parameters of this model reflect all available geological and geophysical data set. Initial model is presented in form of structural model and physical property model (heterogeneous density model). Seismic 3D and 2D information, well logging data, petrophysical information, wells production data are used as initial input information for 3D model construction.

Mathematical description of the structural model and property (density) model is realized in form of discrete 2D grids and 3D regular meshes (so called voxel model). Rectilinear mesh is used for discretization and model accuracy is ensured by cell mesh cells decreasing. Actually size of grid cells in every case depend on the geological task (regional/exploration/production stage) and spatial resolution of involved geological and geophysical data.

Addiitional geological information (for instance evolution history of sedimentary basin, sedimentary environment, stratigrafic characterization of reservoirs and seals and their spatial distribution within studied area, expected types of the traps and fluids etc.) is formalized in terms of optimality criterion and being used in the process of gravity data inversion, ensuring the uniqueness and geological appropriateness of the final 3D model $\xi(\mathbf{x})$.

Gravity data $u(s)$ adjusted with Bouguer reduction and terrain correction are used as controlling function in inversion.

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

Input data

Geological and geophysical information used for building initial 3D model of Black Sea offshore and included in gravity inversion is stated below:

- 3D structural model based on 2D seismic data for surfaces of Neogene, Paleogene and Cretaceous sedimentary cover up to Precretaceous basement. On the assumption of different crust types (oceanic crust is assumed within Western Black Sea depression) which implicates different crust thicknesses, rocks composition and densities we included Moho interface into model.
- Heterogeneous 3D density voxel model built on the base of petrophysical data from onshore and offshore wells, seismic velocities.
- Additional geological information was introduced in form of geological constraints on final model parameters, confidence criteria regarding initial data and optimal parameters of inversion procedure;
- Gravity data in Bouguer anomalies. Spacing of gravity data observation point varied from 2 000 meters on coastal strip and internal shelf to 2.5 kilometers within deepwater territory.

Inversion results

3D model size was 250x372 kilometers laterally and 70 kilometers in depth. Inverse problem was solved for 23 250 equations and mesh of 32.55 millions of 3D density model cells (unknowns) (Fig. 3). Inversion of gravity, geological and geophysical data aimed to adjust densities of the mantle masses and form of Moho interface, properties of the basement and sedimentary rocks. Result of inversion is unique 3D density model of North-Western Black Sea shelf (Fig. 4) with gravity misfit standard deviation equal to 0.6 mGl (Fig. 5).

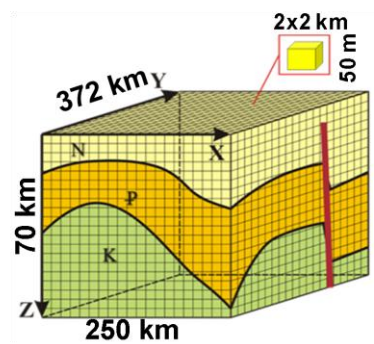

Figure 3: Parameters of 3D model approximation

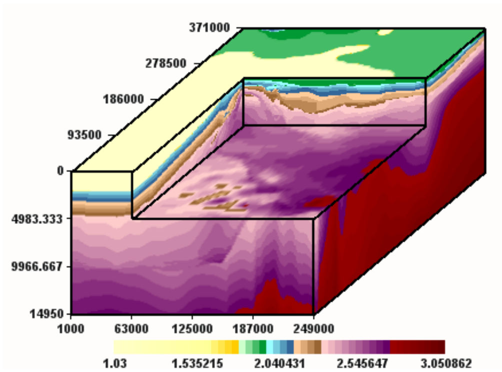

Figure 4: Resulting 3D density model

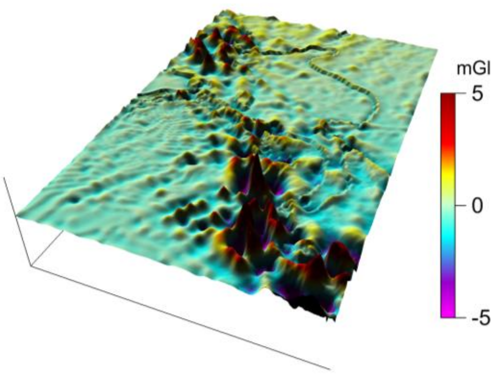

Figure 5: Gravity misfit

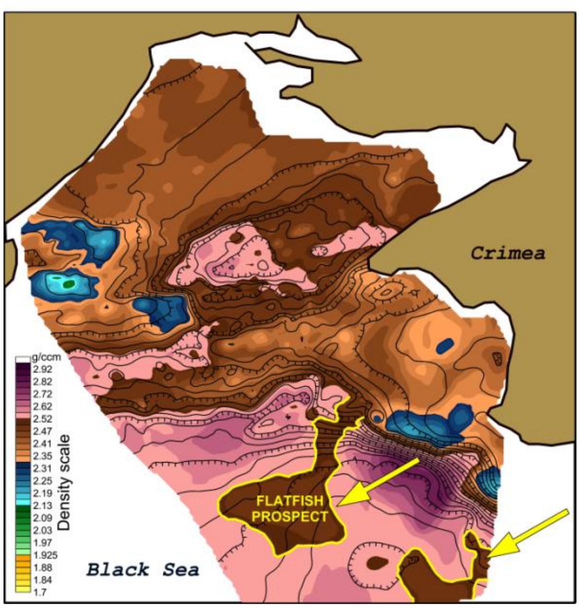

Figure 6: Low-density anomalies in pre-Cretaceous rocks, northwestern shelf and slope (paleo-fans are indicated by yellow arrows)

Geological interpretation

Joint analysis of basement density properties with independent geo-dynamics studies and geotectonic features showed good mutual correspondence. This allowed to make prospects identification in the Cretaceous and Paleogene-Neogene sedimentary sequences by mapping low density anomalies within each stratigraphic layer.

Reflection of known eight gas fields within internal Black Sea shelf in obtained 3D density model as local low density zones proved validity of the model. Model verification with 75 well tests results in different plays showed 78 % correspondence.

This allowed to perfom further evaluation of other low density anomalies to delineate new prospective plays confined to petroleum-prone Cenozoic and Cretaceous sediments. New prospects of different play types were identified within external shelf, its hinge and deepwater area. Some of the prospects were recognized on seismic images by seismostratigraphy analysis as well.

Deepwater prospects

Among the most interesting prospects is one located within the continental slope (Fig. 6). This sedimentary body with rather large area of approximately 2000 sq.km has very peculiar form of spade with thin neck going upward the slope that bear quite clear geological meaning. This particular form apparently speaks about subsurface existence of submarine paleofan composed by clastic turbidite material of lower density comparing to surrounding host rocks (“Kambala” or Flatfish prospect, Fig. 6). Theoretical model of such a body typical for slope and toe sedimentary environment is well-known and such prospects have top priority importance for deepwater exploration in many basins (Mattern F., 2005). Another interpretation can explain this anomaly as prograding deltaic complex. Analyzing the geodensity map for the pre-Cretaceous rocks of the Black Sea northwestern shelf it can be supposed that sedimentary fill of the paleo-canyon (or alluvial channel) and the fan (or deltaic complex) is not Jurassic or older but early Cretaceous in age, mainly Neocomian, Barremian-Valanginian, incised into Jurassic bedrock. An idealized model of the sedimentary body interpreted as turbidite fan is shown on Fig. 7.

The geo-density slice conformal to the bottom of the Cretaceous sequence depicts another anomaly of similar form to the east of the first one that may point out onto existence of system of canyons and fans along the strike of the basin paleo-margin. It is worth to mention that the Neocomian alluvial systems are known in the Crimea where their sands are quarried in several places, see Fig. 6.

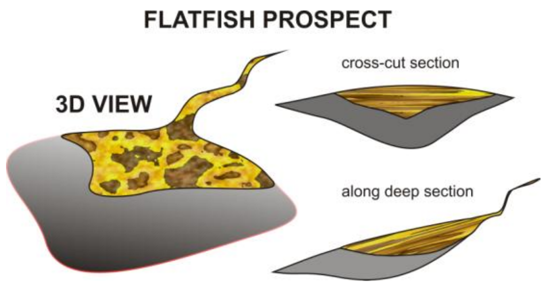

Figure 7: An outline of the clastic submarine fan on the continental slope of the northwestern shelf

Figure 8: Valanginian alluvial sands and gravels, Zuevsky quarry, the Crimea

Conclusions

The approach of integration seismic, well and gravity data into one 3D geodensity model proved to an effective tool during exploration process. Interpretation results gave new insight into deep structure and main tectonic elements of the Black Sea offshore Ukraine, its slope and toe revealing trends.

Delineated deepwater prospect could correspond with higher probability to a submarine Neocomian canyon and fan incised into Jurassic bedrock. Taking into account that the Black Sea basin is characterized by lack of reservoir rocks this type of exploration play may represent a top priority exploration target that could host a sizeable hydrocarbon field.

Results of North-Western Black Sea offshore region study proves that the methodology of 3D geomodelling and geophysical inversion can be applied during exploration process within different offshore and onshore basins.

Acknowledgements

The authors thank State Enterprise Ukrgeofizika and Daughter Enterprise Chornomornaftogaz for the access to seismic and production data.

http://dx.doi.org/10.1190/segam2012-1545.1

EDITED REFERENCES

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