Fold-Thrust Belt Exploration: How to Reduce Risks When Your Seismic Data are Absent or Poor?

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Introduction

Fold–thrust belts are one of the most challenging areas for oil and gas exploration due to rugged terrain making access difficult, and both factors together causing poor quality of seismic data. Still significant hydrocarbon resources exceeding 700 billion barrels of oil equivalent (BOE) of known hydrocarbon reserves of the world fold–thrust belts (Goffey et al. 2010) keep up the interest of oil companies.

Carpathian fold-thrust belt is one of the oldest oil and gas province in the world with a difficult subsurface structure. In spite of long exploration history, more than two third of oil and gas reserves in Ukrainian Carpathians is estimated to be yet-to-find, which is around 4.5 million BOE (Vul et al. 1998). One of the least explored parts of the basin is Folded Carpathians (Figure 1). Over 90% of reserves are estimated here to be undiscovered. Only few small accumulations are discovered in its Ukrainian part to date. But recent discovery of Ljutnja gas field in Krosno unit, and the fact that within the Polish part in analogical geological settings (Silesian and Subsilesian units) there were discovered and being exploited over a 30 oil and gas fields (Dziadzio et al. 2006) brought Ukrainian oil companies back to exploration in Folded Carpathians.

Geological Background

Geological sequence of Krosno unit is represented by Cretaceous and Paleogene flysch formations. Unlike Silesian unit in Poland, in Ukrainian Krosno unit the deposits that are older than the Oligocene almost completely disappear from the surface and upper part of geological sequence, (Dziadzio et al. 2006). Ljutnja wells proved absence of Cretaceous and Paleocene-Eocene sediments in cores of the folds within two upper nappes. Thus, penetrated sequence within the study area is represented by Krosno and Menilite beds of Oligocene (Figure 2).

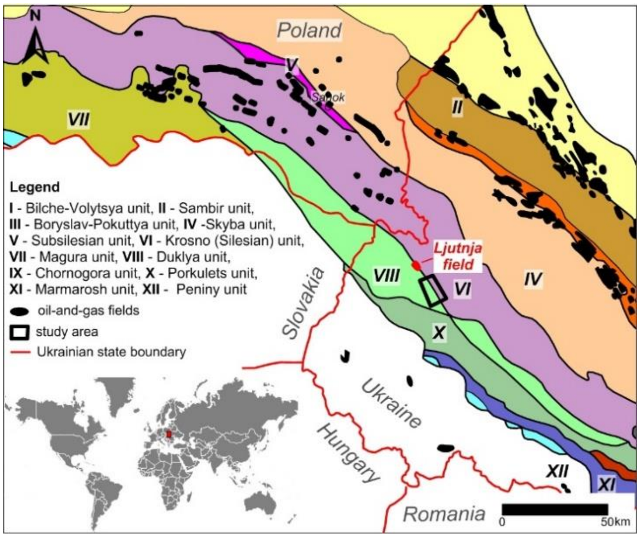

Figure 1 *Study area on the tectonic map of Ukrainian and Polish Carpathians*

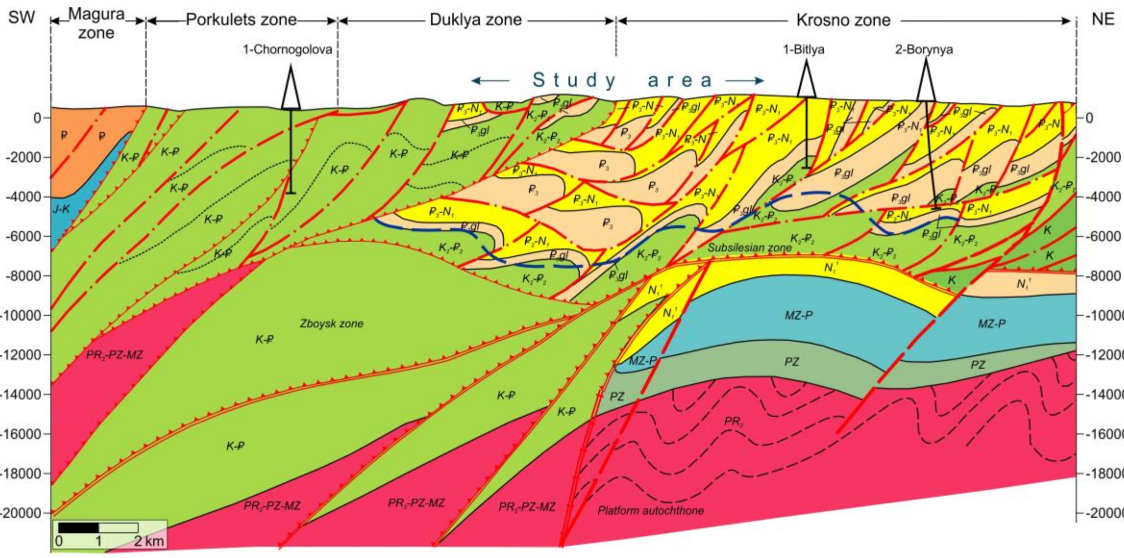

Figure 2 *Schematic geological section of studied area (after Vul et al. 1998, modified). Blue dashed line is an envelope limiting upper rock complex, where Oligocene is prevailing*

Oil and gas pools of Ljutnja field are associated with menilits of Golovetska formation. Within the Silesian unit of Polish Carpathians gas accumulations are also found in Krosno beds. Interpretation of the well logs of Ljutna field shows slightly higher porosity of Golovetska sandstones (4-11%) comparing to Krosno beds (4-8 %). At the same time data from Poland evidence presence of much better reservoirs in menilits of Golovetska formation with porosity of up to 25% and average of 12.77 % (Magdalena sandstone) (Dziadzio et al. 2006).

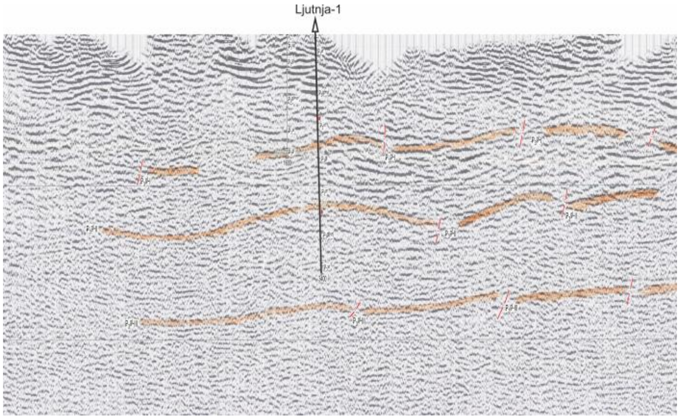

Figure 3 *Example of a seismic cross section through Ljutnja gas field*

Method and geological results

Seismic survey on the Ljutnja gas field evidenced poor data quality (Figure 3) and significant ambiguity of seismic data interpretation. Therefore for exploration of a nearby new license oil company decided to obtain alternative model, based on non-seismic data.

In order to solve geological and exploration tasks, exploration activities involved:

- high-precision gravity and magnetic surveys with modern digital gravimeters Scintrex CG-5 (Canada) and magnetometers Geometries G-859 (USA);
- comprehensive analysis and generalization of all available geophysical data set;
- creation of 3D density model based on the joint inversion of gravity and magnetic data, surface geological data, well log data, production data etc. (Petrovskyy. 2005).

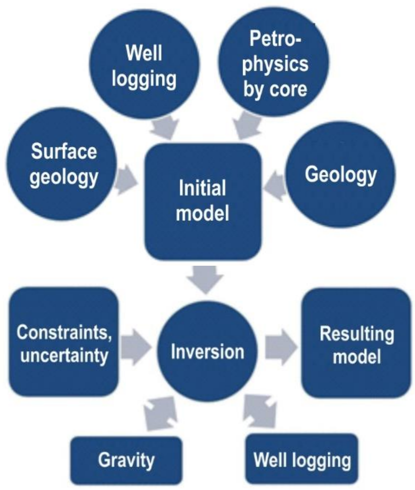

Figure 4 *Inversion scheme*

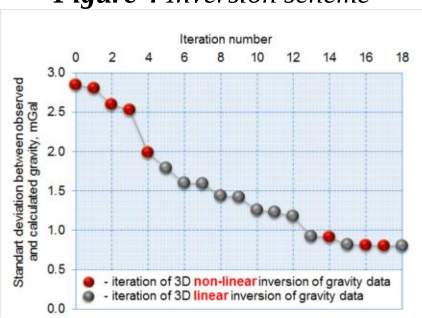

Figure 5 *Convergence of the inversion process*

Study area was selected to include wells from Ljutnja field. That gave a possibility to use well logs as an active component in the inversion, which means to fulfil demand of density model correspondence both to gravity data and to well logs (Figure 4). Model's uniqueness and geological meaningfulness was provided by including geological data and constraints into the 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 the inversion. Taking into account that ambiguity of 3D initial model was associates both with structure (no seismic data within study area, initial structural model built basing on surface geology and analogy with Ljutnja field) and with density/reservoir properties of geological section, both structural and property 3D inversions were run (Figure 5).

The results of gravity inversion are presented by 3D geo-density model (Figure 4), which has been quantitatively agreed with all available geological and geophysical data. Resulting 3D density and structural models were used to refine deep geological structure of the area and to predict distribution of potentially gas-saturated reservoirs within Golovetska and Verkhovynska formations of Oligocene.

Two important regional geological features resulted from the inversion:

1. presence of an uplifted block in the crystalline basement which raises up to 7.6 km depth (Figure 6);
2. presence of Oligocene sediments of Krosno unit far to the sothwest under the overlapping Duklya unit to the distance of about 11 km from the border of Dukla and Krosno units (Figure 6). This increases the chances to discover new prospects alike Ljutnja gas field beneath the Dukla nappe.

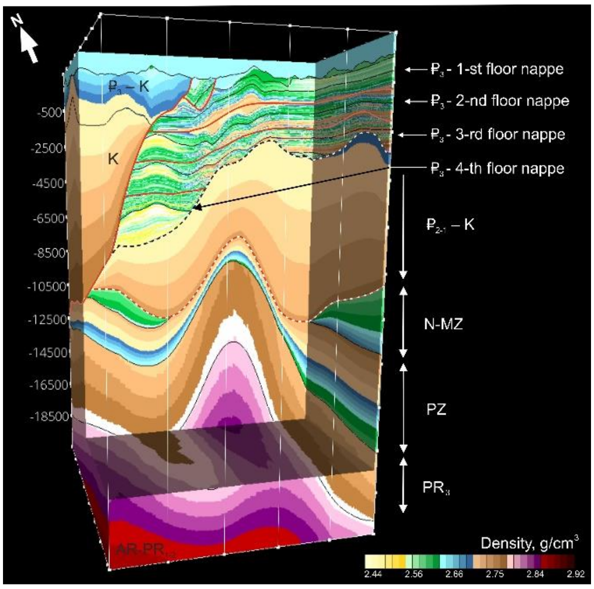

Figure 6 *3D inverted density model*

Three prospects have been mapped within the study area – two anticline folds and one lithological and tectonically screened trap. Hydrocarbon prospects of the objects are associated with Oligocene nappes of the 2, 3 and 4-th floors.

To rank new prospects by their priority to make recommendations for well position we performed estimation of porosity, gas saturation and gas reserves for each prospect. Estimation of porosity (Figure 7) and gas saturation were done basing on 3D density model, core data, and well logs, using an equation for rock density σ:

$$\sigma=(m*(1-\varphi)+w*\varphi*(1-s)+g*\varphi*s),$$

where matrix density m was taken from core data; φ, s – porosity and gas saturation correspondingly, with variation range limited by well log interpretation data. In-situ gas density g was calculated as a 3D function from PT conditions, while the latter were estimated as a linear functions from depth basing on measurements in wells. Boreholes of Ljutnia gas field, were used as an analog for the calibration of petrophysical relations and volumetric parameters.

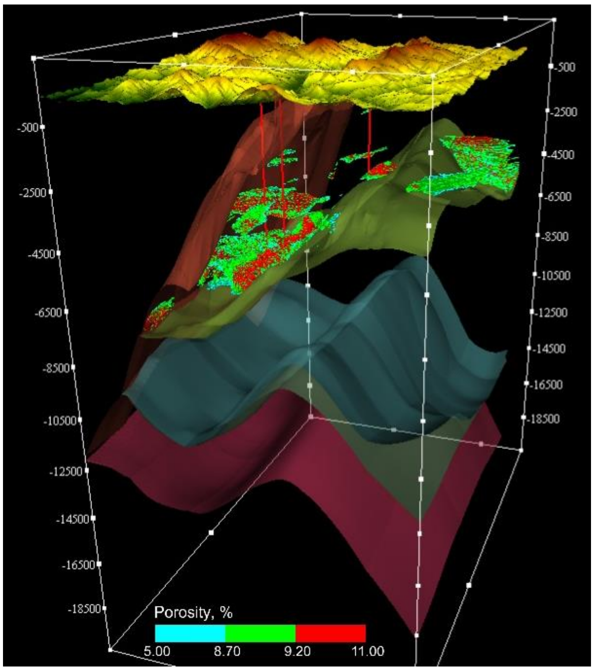

Figure 7 *3D porosity model of Oligocene sequence of Krosno unit within 2-4 floors of nappes*

The most promising prospect totaled area of 57,8 km^2. Depth of the perspective Golovetska and Verkhovynska beds here varies from 2.7 to 6.1 km.

Reserves estimation has been performed by two methods. The first method – Monte Carlo simulation. The second method – volumetric – is based on 3D density model derived from inversion of gravimetric, geological and well log data. Volumetric approach made it possible to take into account spatial variability of porosity within each prospect.

In particular, gas resources of the most promising Polonyna-Runa prospect depending on the estimation method vary in between 1.7 to 3.6 bil.m^3 of gas (Figure 8). Golovetska formation of the 2-nd floor nappe contains gas pools in Ljutnja field and its resources within Polonyna-Runa prospect has been estimated to be in the range from 295 to 798 mil.m^3 of gas. It is almost as much as in Ljutnja gas field. Thereby, Oligocene reservoir rocks of the upper nappes can be considered as independent drilling targets.

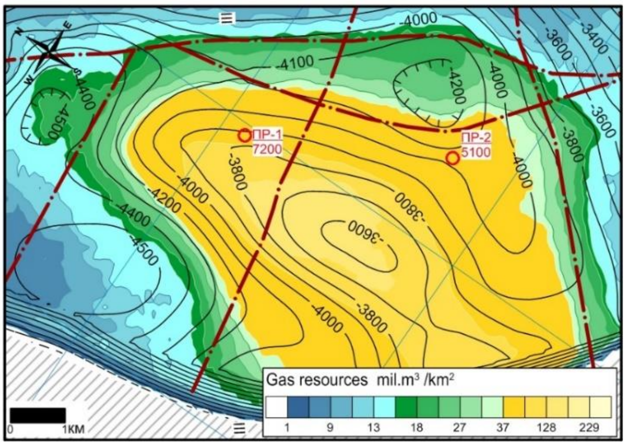

Figure 8 *Density of gas reserves of Polonyna-Runa prospect*

Apart from Polonyna-Runa prospect, two more prospects have been identified within the study area. Although, prospective resources of gas are estimated to be lower than the resources of Polonyna-Runa prospect, they increase an overall investment attractiveness of the study area.

Conclusions

Illustrated case study shows that even under a rugged terrain and thrust-fold structure, with poor seismic data, exploration risks can be significantly decreased by involving high precision gravity and magnetic data to the interpretation process, and applying adequate inversion technologies. Depending on quantity and quality of initial data both subsurface structural model and reservoir distribution can be studied to outline the most promising prospects, estimate most probable saturation type and hydrocarbon reserves.

Acknowledgements

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