Subsalt 3-D Modelling and HC Reservoir Prediction with Scarce 2-D Seismic Datasets: Can We Obtain Reliable Results?

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Introduction

Lack of geological and geophysical data in exploration process is rather a rule than a random situation. Dealing with 2D seismic data is usual for initial stages of E&P, under a complicated topography, where 3D seismic measurements are physically impossible, when 3D is not economically sound, which is usual for mature oil and gas provinces with relatively small undiscovered reserves, or under a press of low oil prices.

Problem of 2D data sets in general is associated with higher structure uncertainty in inter-line space. In case of salt presence, another problem is salt shape, which is even more challenging to map in 2D, as well as to delineate subsalt traps. In such situation, 3D gravity data give an additional information about salt shape and reservoir distribution.

Gravity for oil & gas exploration. Current state...

In spite of being the first geophysical method to be used in oil & gas exploration, gravity is practically not used today for detailed study of subsurface structure and oil and gas exploration. This is the result of huge advances in seismic, which began with introduction of the CDP method, leading to a chasm between geological outcome of seismic vs. gravity data interpretation. Recent publications (for example, Nabighian, M.N. et.al. 2005) evidence that during the last decades we saw considerable advances in gravity instruments and field survey techniques, but not so big advances in the interpretation techniques. Thus filtration, regional-residual separation, analytical upward-downward continuation, Fourier and wavelet transforms are still used for gravity data interpretation in attempt to link directly gravity anomalies with target geological objects or features, which fundamentally cannot be done due to additive character of gravity field and nonuniqueness of geophysical inversion. More sophisticated approaches, which use physical modelling of the subsurface either stop on forward modelling with partial gravity fit to local/regional anomalies, or construct inversion algorithms using A. M. Tikhonov's regularization theory to obtain stable solution. Inappropriateness of the last one is caused by exotic properties of harmonic function as the natural uniqueness class.

...and the way ahead - joint inversion of gravity, seismic and well data

To obtain geologically meaningful results for gravity data inversion, the 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 a space of all possible solutions (Petrovskyy, O.P., 2005).

Depending on the geological task and initial data available, inversion can be run in so-called active or inactive mode. To be effective for HC exploration gravity inversion in both modes imply fulfillment of the following conditions:

- full-earth (from top to basement) inversion;
- real density for 3D property model and inversion;
- using of observed gravity (full fit of modelled-to-observed gravity data);
- quantifying uncertainties for all the geological sequence;
- involving maximum additional data into initial property model (like structure by seismic, petrophysics, logs, layering according to expected stratigraphy, well test results etc.).

For the active inversion this additionally implies:

- simultanious (active) use of gravity and seismic data for inversion to refine the shape of geological structures, including top and bottom of the salt bodies;
- simultanious (active) use of well logs (including gravity log, density log etc.) for high accuracy models of up to 1 meter depth resolution, prediction of porosity, current oil and gas saturation.

Case study for Transcarpathian Trough, Ukraine (2005)

Transcarpathian Trough is Miocene molasse basin, underlayed by Paleogene-Mezozoic basement. Few gas accumulations known at the time (see L.F. Hafych, A.A. Kitchka and O.I. Gafych, 2006 for details on geological settings). Within the study area producing reservoir intervals of Solotvino gas field are confined to Neogene tuffs of Novoselitsa formation below salty-clastic sequence of Tereblja Formation. Salt pierces Neogene clastic sequence and outcrops to the west from the field. Due to salt and clastics alternation top and bottom of salty sequence are not imaged on the seismic data (Figure 1).

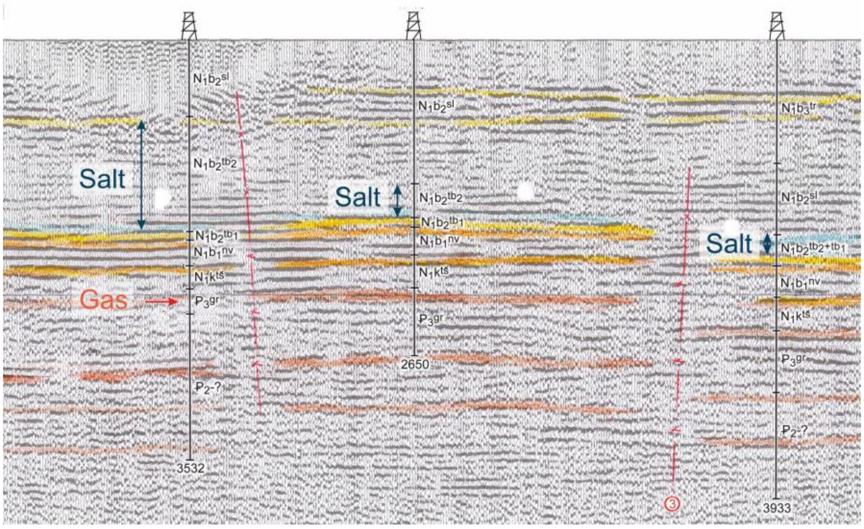


***Figure 1** Example of seismic image within Solotvino-Dibrivka area. Neither top nor bottom of the salt is a stable reflector*

To the west from Solotvino field in proximity to the salt dome two wells #22 and #4 penetrated gas reservoir in Grushiv formation of Upper Paleogene (Dibrivka gas field). Structurally wells are placed in south periclinal part of the four-way dip closure. Main objective of the study was to delineate extension of Paleogene pool.

Inversion workflow

3D structural framework was built using 20 2D seismic lines. Structural model consists of 7 surfaces, featuring the structure of Neogene and Paleogene (Figure 2). 3D property model (Figure 3) was build using generalized petrophysical dependencies and consisted of 2 million cells (single cell dimensions were 100x100x50 meters). Initial misfit between observed and calculated gravity by forward problem solution was 3.7 mGal (Figure 4). Salt dome and salt bed were refined through 3D structural (nonlinear) inversion of gravity data. That reduced deviation between observed and calculated gravity fields to 1.15 mGal. At the next step full-depth 3D linear inversion of gravity data for property model was run, resulting final misfit of gravity fields' less then 0.3 mGal (Figure 4).

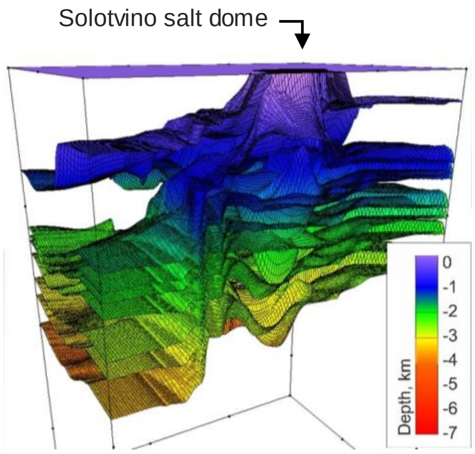


***Figure 2** Initial structural model by 2D seismic data*

Exploration results

In the result of the inversion salt dome shape was refined. In the inverted 3D property model areas of low density were mapped in Neogene and Paleogene, indicating presence of quality reservoir with gas saturation (Figure 5-8). It was determined that gas pool in Paleogene is confined to fractured reservoir and is distributed in immediate proximity to the wall of the salt dome and beneath the salt (Figures 7, 8). In 2005 new appraisal well #23 was drilled in the crest of the anticline structure, at the distance from the salt body. No HC infow obtained during well testing. In 2011 another appraisal well #28 was drilled in similar structural position to that of the well #22, in the northern periclinal part of the structure. The well was dry. According to the density model of Paleogene sequence (Figure 7). Both wells were placed within the areas of high density, which evidences tighten of rocks and absence of quality reservoirs.

Thus drilling results have fully confirmed accuracy of 3D model, built in 2005.

In 2012 new appraisal well #15 was drilled within the Solotvino field. The well was located in the area of low density similar to density in the area of productive wells #1 and #2 (Figures 5, 6, 8). Thus quality HC reservoir with high probability of gas saturation was expected here. Commercial gas inflow from Neogene reservoir confirmed correctness of the density model of Neogene gas pool (2005), which have showed wider extension of gas saturated reservoirs to the east.

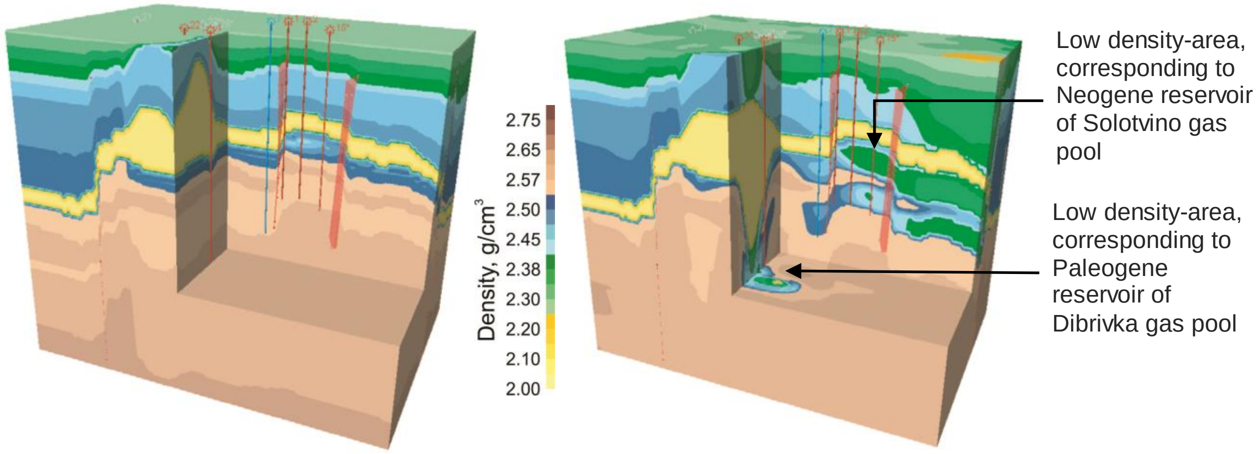


Figure 3 *Initial (left) and inverted (right) 3D density models*

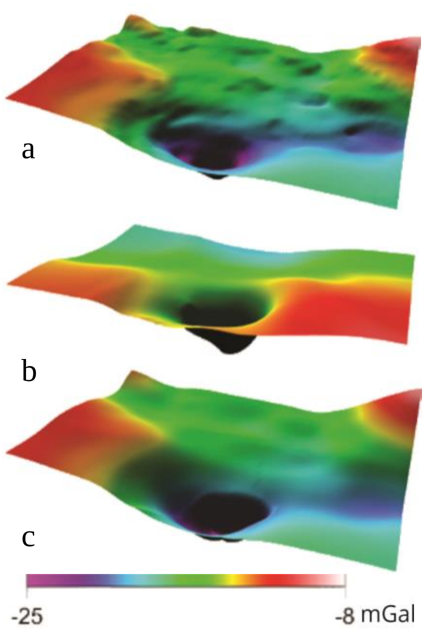
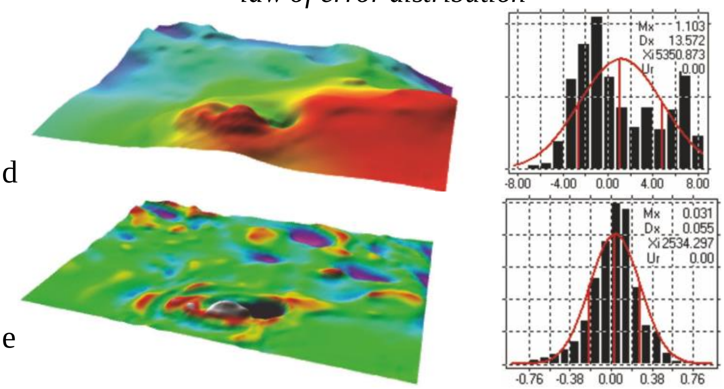


Figure 4 *Correspondence between observed gravity field (a) and gravity fields, calculated from the initial 3D density model (b) and final inverted 3D density model (c). Gravity fields' misfit for the initial model (d) contains systematic components, while for the inverted model deviation (e) is random and conform to the normal law of error distribution*



Conclusions

Introduction of new techniques of gravity data inversion together with seismic and well information to exploration process proved to be a valuable tool both for refining salt shape and to map near- or below-the salt HC pools, filling the gaps of sparse 2D seismic data. As proved by wells in the case study for Solotvino-Dibrivka area, being an independent source of information such joint geophysical inversion allows to reduce risks significantly and to cut exploration, appraisal and production expenses in cases, where quality 3D seismic measurements are physically impossible under a complicated topography or economically not sound under a press of low oil prices.

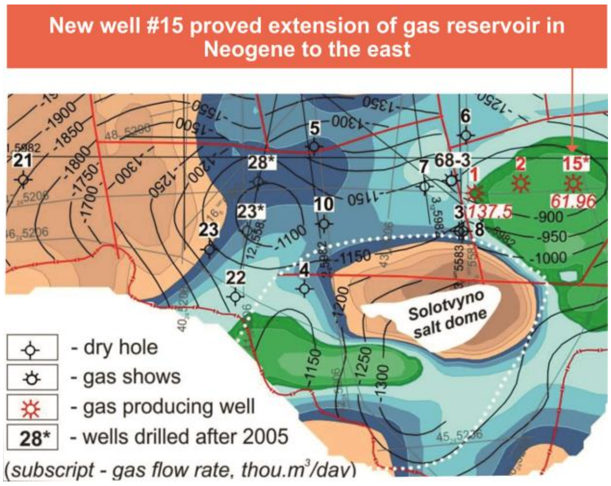


Figure 5 *Conformal density slice within Neogene*

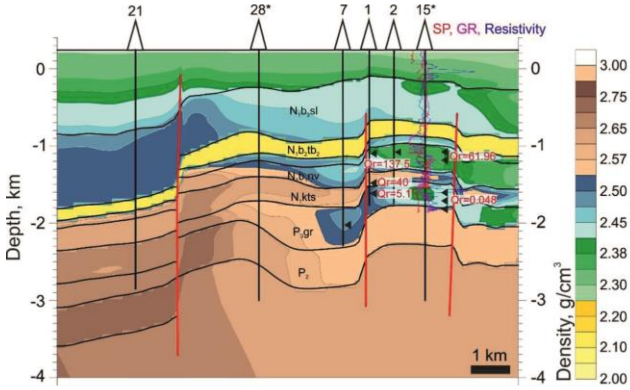


Figure 6 *Density cross-section through new dry well 28 of Dibrivka field and new productive well #15 of Solotvino field*

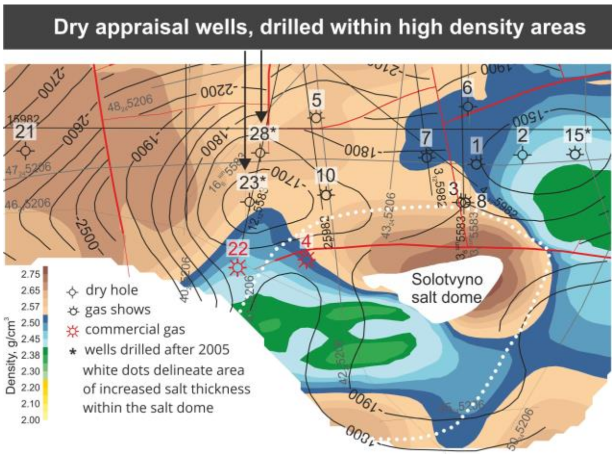


Figure 7 *Conformal density slice within Paleogene*

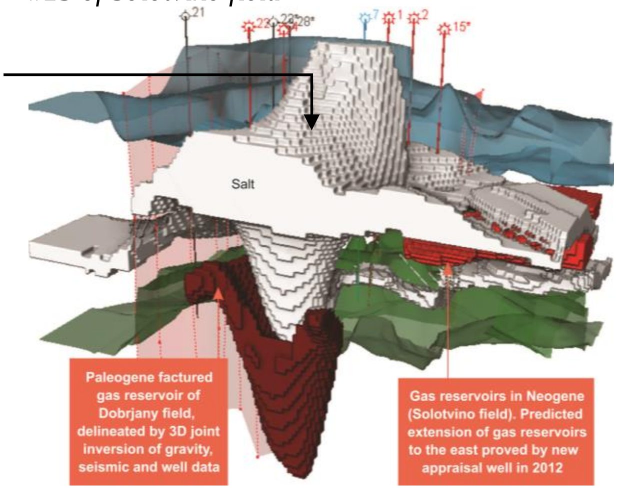


Figure 8 *Neogene salt (in gray), Neogene and Paleogene gas pools (in red and dark red respectively), extracted in form of bodies from the inverted 3D density model*

References

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