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

Tetyana Fedchenko[1] and Oleksandr Petrovskyy[1]

Search and Discovery Article #70283 (2017)**
Posted August 28, 2017

*Adapted from poster presentation given at AAPG 2017 Annual Convention and Exhibition, Houston, Texas, United States, April 2-5, 2017

[1]DEPROIL, Ivano-Frankivsk, Ukraine (tetyana.fedchenko@gmail.com)

Abstract

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 dome, another problem is salt shape, which is even more challenging to map in 2D, as well as to delineate subsalt traps. In such situations, 3D gravity data give additional information about salt shape and reservoir distribution. To provide effective and meaningful interpretation of gravity data, the following requirements are to be fulfilled: 1. Physical 3D modelling in real densities must be performed for the full geological sequence from top to basement. 2. Structural and / or property inversion should be performed using observed Bouguer or Free Air gravity data. 3. Inversion algorithm should be redefined. Formal mathematical regularization (for example regularization of the academician Tikhonov A. N.) must be substituted by geologically driven one, which implies that prior information does not only constrain but guides the inversion, resulting the unique solution of the inverse problem. 4. Maximum available G&G information like seismic, well log, petrophysical and other data must be involved into the joint inversion. We will present two examples from different salt basins. These examples show application of the described approach for the cases when (1) initial 3D model is built on the base of 3D seismic, well logs and petrophysical data; and (2) for the case when initial 3D model is built using 2D seismic lines and general petrophysical relationships for geological sequence of the area (no log data used). For both cases, 3D modeling was performed basing on joint inversion of 3D gravity data with seismic and additional available geological and geophysical information. We will compare two workflows and will discuss validity of the inverted 3D models, as well as the results of their posterior verification by exploration and production drilling.

SUBSALT 3-D MODELLING AND HC RESERVOIR PREDICTION WITH SCARCE 2-D SEISMIC DATASETS: CAN WE OBTAIN RELIABLE RESULTS?

Oleksandr Petrovskyy, Tetyana Fedchenko
DEPROIL, Ivano-Frankivsk, Ukraine

DEPROIL
DETAILED OIL & GAS PROSPECTING

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 dome 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 prospecting. This is the result of huge advances in seismics, which began with introduction of the CDP method, leading to a chasm between geological outcome of seismic vs. gravity data interpretation. Recent publications 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.

Inversion of one geophysical field

Inactive inverse problem

$$\begin{cases} A(x)=y,\ x\in D(A)\subset X,\ y\in Im(A)\subset U \\ J(x)\rightarrow min \\ x\in M\subset D(A), \end{cases}$$

where:
x – parameters of model (density values or density horizon depth)
X – metric space of models
y – observed geophysical (gravity) field or its functional
U – metric space of geophysical fields
$A(.): X\rightarrow U$ – in general case nonlinear for structure task and linear for properties task operator acting from models' space to space of geophysical fields
$D(A)$ – domain of operator $A(.)$ – open subspace in space X, wide enough to ensure adequate approximation of real geological model
$Im(A)$ – open subspace in space Y, wide enough to ensure adequate approximation of geophysical field
M – ensemble of possible geologically meaningful models x
$J(.): X\rightarrow R$ – convex functional acting on X, and containing priory geological and geophysical information

Such reformulation of gravity inversion implies fulfillment of the following conditions for inactive scheme:

- full-earth (from top to basement) inversion
- real density for 3D property model and inversion
- using of observed gravity
- 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.)

Inversion of two geophysical field

Active inverse problem

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

where:
$\xi(x), \eta(x)$ – parameters of model
X – metric space of models
u, y – observed geophysical fields or its functional
U, Y – metric spaces of geophysical fields
$A(.): X\rightarrow U, B(.): X\rightarrow Y$ – in general case nonlinear operators acting from models' space to space of U, Y geophysical fields
$D(A), D(B)$ – domain of operator $A(.), B(.)$ – open subspace in space X, wide enough to ensure adequate approximation of real geological model
$Im(A), Im(B)$ – open subspace in space U, Y, wide enough to ensure adequate approximation of geophysical field
M, N – set of possible geologically meaningful models $\xi(x), \eta(x)$,
$J(.): X\rightarrow R$ – convex functional acting on X, and containing priory geological and geophysical information

...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, density log) 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)

GEOLOGY

Transcarpathian Trough is Miocene molasse basin, underlayed by Paleo-gene-Mezozoic basement. Few gas accumulations known at the time. Within the study area producing reservoir intervals of Solotvino gas field confined to Neogene tuffs below salty-clastic sequence of Tereblja Formation. Salt pierces Neogene clastic sequence and outcrops to the west from the field. Due to alternation with clastics top and bottom of salty sequence are not imaged on the seismic data (Figure 1).

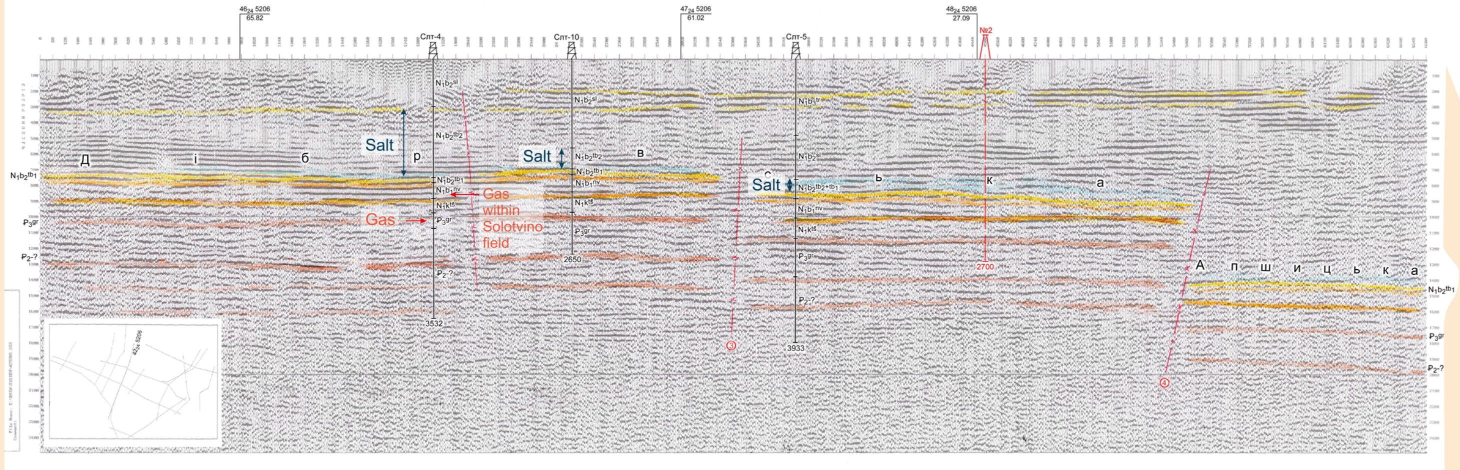


Figure 1. Seismic cross section

To the west from Solotvino field in proximity to the salt dome two wells #4 and #22 penetrated gas reservoir in Paleogene (Dibrivka gas field). Structurally wells were 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 consisted 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 refi ned 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)

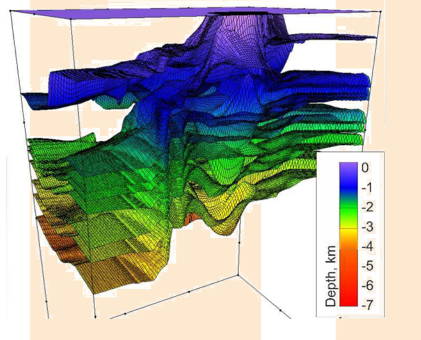


Figure 2. Initial structural model by 2D seismic data

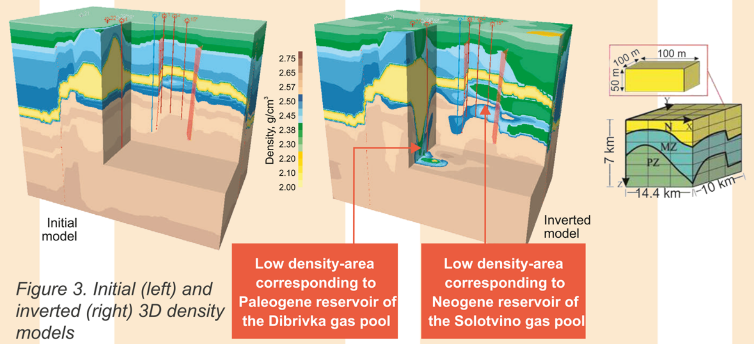
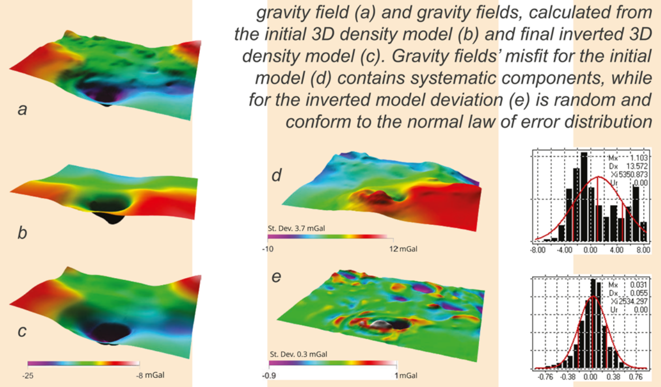


Figure 3. Initial (left) and inverted (right) 3D density models

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



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 inflow 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, corresponding to quality HC reservoir. Commercial gas inflow from Neogene reservoir confirmed the density model of Neogene gas pool (2005), which have showed wider extension of gas saturated reservoirs to the east.

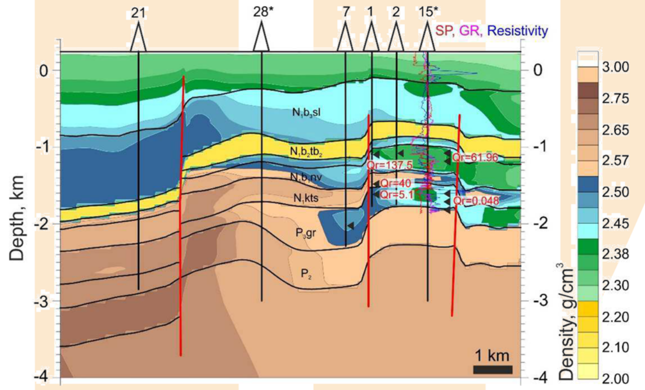


Figure 5. Conformal density slice within Paleogene

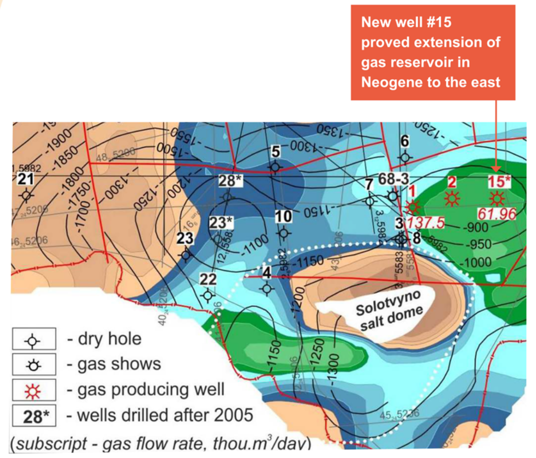


Figure 6. Conformal density slice within Paleogene

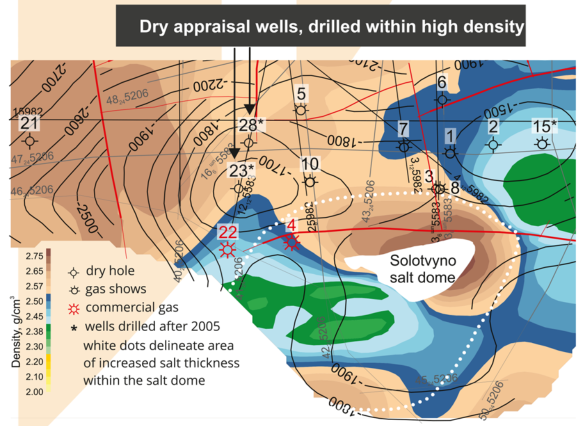


Figure 7. Conformal density slice within Paleogene

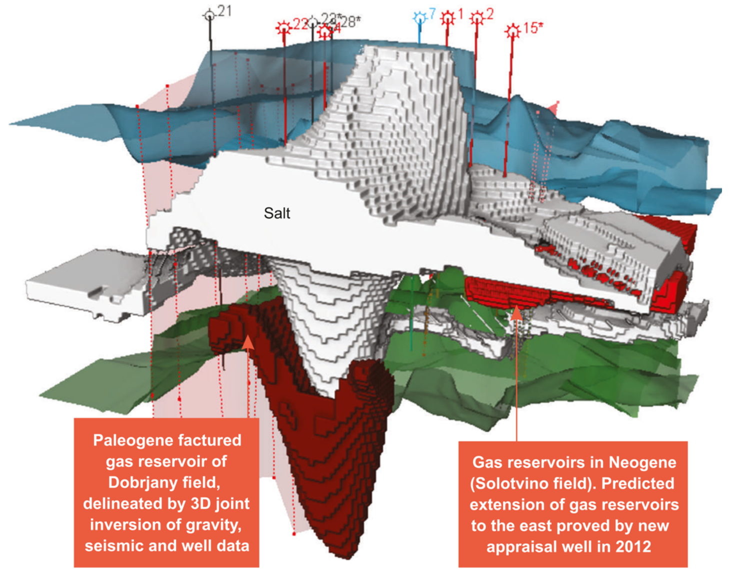


Figure 8. Neogene salt (in gray), Neogene and Paleogene gas pools (in red and dark red respectively), extracted in form of bodies from the inverted 3D density model