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?

Introduction

Lack of geological and geophysical data in exploration process is rather a rare than a common situation. Dealing with 2D seismics data is usual for initial stages of E&P, under a completion topside, where 3D seismicic measurements are physically impossible, when 3D is not economically sound, which is usual for mature oil and gas provinces with relatively small unexplored reservoirs, or under a period of low oil prices. Problem of 2D data sets in general is associated with higher structural uncertainty in inter-layer space. In case of salt dome another problem is salt trap, which is even more challenging to map in 2D, as well as to delineate subsalt traps. In such situation 3D gravity data gives an additional information about salt shape and reservoir distribution.

Gravity for Oil & Gas Exploration. Current State.

In spite of having the first geophysical method to be used in oil & gas exploration, gravity is practically not used today for detailed study of subsurface structures 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 chain between geophysical outcome of seismic vs. gravity data interpretation. Recent publications evidence that during the last decades we see considerable advances in gravity instruments and field survey techniques, but not 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 attempts to directly derive gravity anomalies with target geologic events or features, which fundamentally cannot be done due to addition of gravity field by non-passive geophysical processes.

More sophisticated approaches, which use physical modeling of the subsurface either step by step or following model with partial gravity fit to borehole anomalies, or construct inversion algorithms using A. M. Yashunsky's regularization theory to obtain stable solution. Inappositeness of the last one is caused by exotic properties of harmonic functions in the natural logarithmic data.

...and the Way Ahead – Joint Inversion of Gravity, Seismic and Well Data

To obtain geologically meaningful results for gravity data inversion, the inverse procedure should be modified so that 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

\[
\begin{align*}
\min_{\mathbf{u}} & \quad \mathbf{u}^T \mathbf{K} \mathbf{u} \\
\text{subject to} & \quad \mathbf{H} \mathbf{u} = \mathbf{d}
\end{align*}
\]

where

- \(\mathbf{d}\): observation data
- \(\mathbf{H}\): forward modeling operator
- \(\mathbf{K}\): geophysical kernel

Such reformulation of gravity inversion implements fulfillment of the following conditions for active scheme:

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

Inversion of two geophysical fields

Active inverse problem

\[
\begin{align*}
\min_{\mathbf{u}} & \quad \mathbf{u}^T \mathbf{K} \mathbf{u} \\
\text{subject to} & \quad \mathbf{H}_1 \mathbf{u} = \mathbf{d}_1
\end{align*}
\]

where

- \(\mathbf{d}_1\): observed gravity data

...for the active inversion this additionally implies:

- simultaneous (active) use of gravity and seismic data for inversion to refine the shape of geological structures, including top and bottom of the salt bodies
- simultaneous (active) use of well logging (including gravity, density log) for high-resolution models of up to 1 meter in depth-resolution, prediction of porosity, oil and gas saturation

Inversion Workflow

3D structural framework was built using 20 seismic lines. Structural model consisted of 7 surfaces, featuring the structure of Nenogape and Paleopogae (Figure 2). 3D property model (Figure 3) was built using generalized petrophysical parameters and correlated of 2 million cells (single cell dimensions were 10x10x30 meters). Initial ROI (between observed data) was 3.7 Mrad for calculation resolution 3.7 mrad (Figure 4). Salt dome and salt bed were well tied through 2D structural (isopach) inversion of gravity data. That reduced migration between observed and calculated gravity fields to 1.15 mrad. At the next step full-depth 3D inversion workflow was used for data prediction run was running resulted final model of gravity fields less then 0.3 mrad (Figure 4)

Case Study for Transcarpathian Trough, Ukraine (2003)

Geology

Transcarpathian Trough is Mesozoic reseaerch basin, underlain by Paleogene-Miocenic basement. Few gas accumulations at the bottom. Within the study area producing reservoir intervals of salt domes gas field connected to Nenogape fault below salt-clastic sequence of Ternava Formation. Salt percolates Nenogape clastic sequence and displaces the oil to the west from the field. Due to accumulation with clastic top and bottom of salt-castic sequence are not imaged on the seismic data (Figure 1).

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 Nenogape and Paleopogae, indicating presence of quality reservoir with gas saturation (Figure 3). It was determined that gas pool in Paleopogae is confined by fractured reservoir and is standadized in immediate proximity to the wall of the salt dome and beneath the salt (Figures 7, 8). In 2006 new appraisal well W25 was drilled in the crest of the anticlinal structure, at the rimage of the salt frack. No HC-fract obtained during well testing. In 2011 another appraisal well W28 was drilled in similar structural position to Field of salt dome W25, in the northern peripheral part of the structure. The well was dry. According to the density model of Paleopogae sequence (Figures 7, 8). Both wells were placed within the areas of high density, which enhancement ties of rocks and absence of quality reservoirs. Thus drilling results have fully covering reality of 3D model, built in 2003.

In 2012 new appraisal well W76 was drilled within the Sokolovska field. The well was located in the area of low density, corresponding to quality HC reservoir in the Paleopogae sequence. In 2014 new appraisal well W2 has been drilled in Nenogape gas pool (2003), which has allowed wider extended of gas saturated reservoirs to the west.