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Basement Reservoirs - Interpretation of Seismic, Gravity and Well Data in Single 3D Model as an Effective Tool to Decrease Exploration Risks

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Summary

On the case study for one of the fields of Dnieper-Donets Basin we illustrate the effective method and workflow of joint inversion of gravity, seismic and well data to study reservoirs in crystalline basement. Model validity is ilustrated by comparison to posterior drilling results.

Introduction

To present time commercial productivity of the crystalline basement is known worldwide over all continents except Antarctica, in 54 countries and more than 100 sedimentary basins. Among 450 discovered commercial deposits (number by Gavrilov et al., 2010, cited from Halimov Ju. E.) there are a number of highly proliferous ones of such well known fields as La-Pas - Mara (Maracaibo basin), Carmopolis (Sergipe-Alagoas), Augila-Nafoora (Sirte), Oymasha (Manghyshlak), NE Beruk (Sumatra), White Tiger (offshore Vietnam), Clair (the Atlantic frontier) and other unique HC accumulations (see Gutmanis, J. et al., 2015 for the comprehensive overview).

Still despite multiple discoveries, most of them were made accidentally or upon exploration mistake. Complicated geology, lack in understanding of sourcing and trapping mechanisms, low quality of seismic image in basement altogether make exploration in crystalline basement extremely challengeable. Effectiveness of non-seismic methods to reduce exploration risks, also for basement targets, is usually underestimated. The aim of the research presented was to estimate the value of gravity data for identifying HC deposits in fractured and weathered basement by numerical modelling of associated gravity anomalies.

Modelling workflow

Study was based on rich data from the Northern Flank of the Dnieper-Donets basin (Ukraine), which is one of the few basins in the world where exploration for Precambrian crystalline basement was run intentionally since 1990-s resulting drilling over 360 wells penetrating basement and discovery of over 16 commercial fields and sub-commercial deposits in Precambrian (see Chebanenko, I.I. et al. 2005 for detailed description).

Three basic types of basement reservoirs are recognized in practice as following:

- weathered crystalline crust resembling sedimentary reservoir rocks (disintegration & leaching zone of full weathering profile) sealed by the non-reservoir rocks of kaolinization / hydromication zones (see Figures 1, 2);
- fractured and hydrothermally altered reservoirs where secondary porosity is triggered by tectonic dilation and/or mineral transformations of the bedrock;
- vein-like (or fault-related) reservoirs hosting hydrocarbon accumulations of a complex morphology (see example on Figure 1).

Modelling workflow included building of geological and geophysical models of hydrocarbon (HC) reservoirs in weathered crystalline crust (WCC), calculation of density anomalies related to additional porosity of crystalline rocks and their hydrocarbon saturation, and forward modelling of associated gravity anomalies.

Forward gravity modeling was performed using two methods:

- deterministic physical modeling of known hydrocarbon deposits in WCC for two fields of the Northern Flank of the DDB using “Technology of Integral Interpretation of Seismic, Well and Gravity Data for Oil & Gas Exploration” and GCIS software (Petrovskyy O. P., 2005; Petrovskyy O. P., 2003) see example for Khuhra field on the figure 1).
- stochastic simulation by Monte Carlo method, which allowed to estimate the range of gravity anomalies for a wide range of depths and deposits’ sizes, defined by geometric parameters of traps in basement (areal size, thickness), and reservoir properties, and to estimate sensitivity of gravity anomalies amplitudes to variation of all mentioned parameters. For stochastic modeling generalized geological-geophysical model of WCC HC was approximated by the model of set of material horizontal disks (Figure 2), which parameters correspond to the parameters of the hydrocarbon saturated reservoirs as follows (see Table for the range of parameters variation):
    - h is thickness of reservoir / seal in WCC;
    - D corresponds to the size of oil and gas saturated trap;

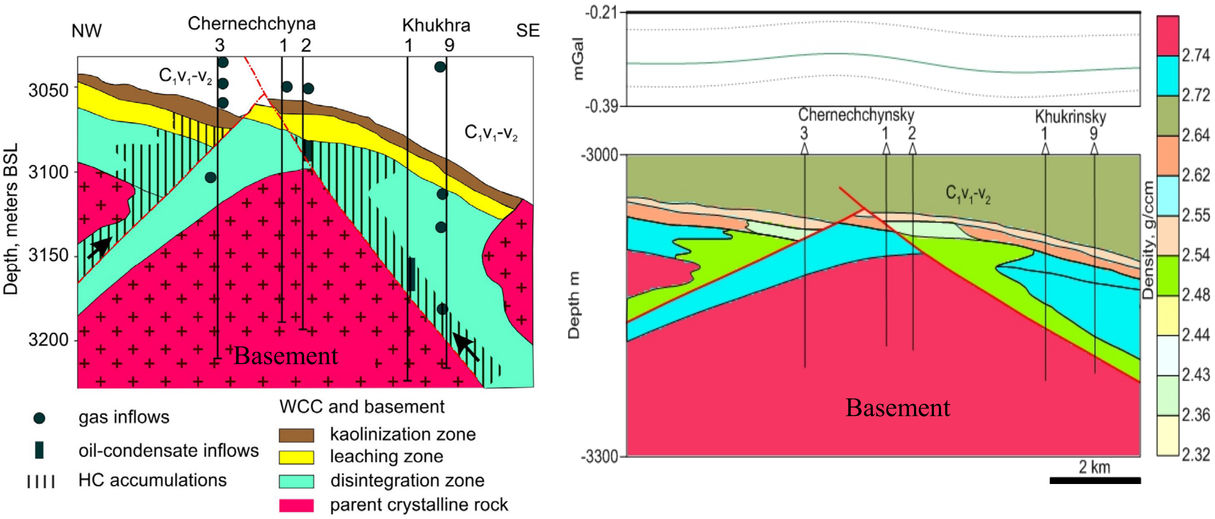
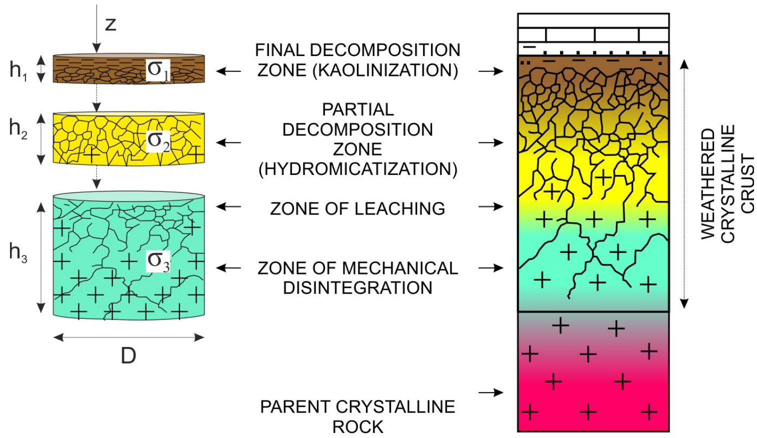


Figure 1 *Khukhra oil-gas-condensate field, Northern Flank of the DDB: geological model (left), density model of condensate deposit in linear fault-related weathered crust (right bottom) and associated gravity anomalies (top right, green line. Dashed lines below and above show gravity anomalies associated with the same reservoirs in case of their gas- and water saturation correspondingly).*

Figure 2 *Generalized model of WCC (right) and its approximation with horizontal material disks, used for the stochastic simulation of gravity anomalies associated with oil and gas reservoir in WCC. Kaolinization zone represents seal, while hydromicatization, leaching and disintegration zones represent potential reservoirs*



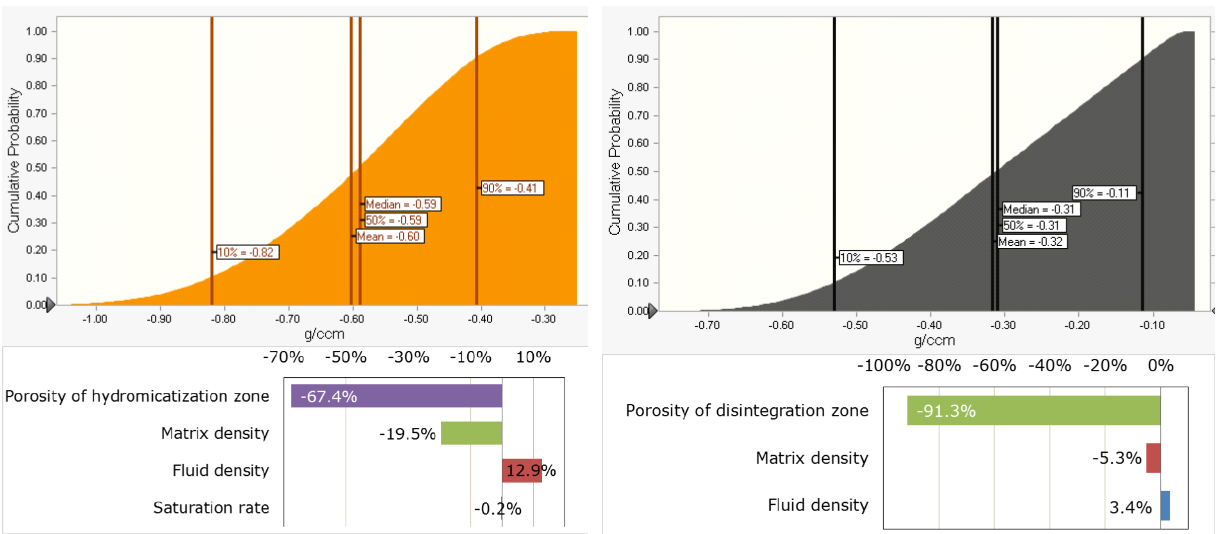


Figure 3 *Density anomalies associated with reservoir in hydromicatization (left) and disintegration (right) zones of WCC by Monte Carlo simulation. Correspondent sensitivity charts are shown below the probability charts*

Parameter	Variation range	
The depth to basement, m	1164	4775
Thickness of kaolinization zone, m	1	32
Thickness of hydromicatization zone, m	1	46
Areal deposit size (disk diameter), km	1.5	6
Density of hydromicatization zone, g/cm^3	2.54	2.73
Density of disintegration zone, g/cm^3	2.53	2.81
The density of kaolinization zone, g/cm^3	2.38	2.8
Matrix density of acid rocks, g/cm^3	2.59	2.7
Matrix density of basic rocks, g/cm^3	2.96	3.54
Water density, g/cm^3	1.104	1.162
Gas density, g/cm^3	0.256	0.316
Oil density, g/cm^3	0.82	0.85
Porosity ratio of reservoirs in hydromicatization zone	0.17	0.36
Porosity ratio of reservoirs in disintegration zone	0.03	0.25
Oil and gas saturation ratio	0.73	0.938
Depth to disintegration the zones below WCC, m	2559	3570
Number disintegration the zones below WCC	1	5
Thickness of disintegration zones below WCC, m	0	223

Variations in h/D ratio allows to approximate different trap geometries: for the veined and stockwork types h→max and D→min; for the quasi-layered trap type D→max, D≫h;

− z is depth to the top of WCC;

− σ is degree of relative density decrease of the WCC reservoirs comparing to parent rock.

Calculation results

− Obtained values of density anomalies evidence that major factor influencing WCC rock density is porosity (Figure 3). Peak density anomalies are associated with gas deposits.

− Amplitude of gravity anomaly is most sensible to pool size, depth and reservoir properties (Figure 4).

− Gravity anomalies, associated with hydrocarbon-saturated reservoirs by 27-50 % exceed anomalies associated with water-saturated reservoirs. Gas reservoirs create gravity anomalies of the biggest magnitude, independently

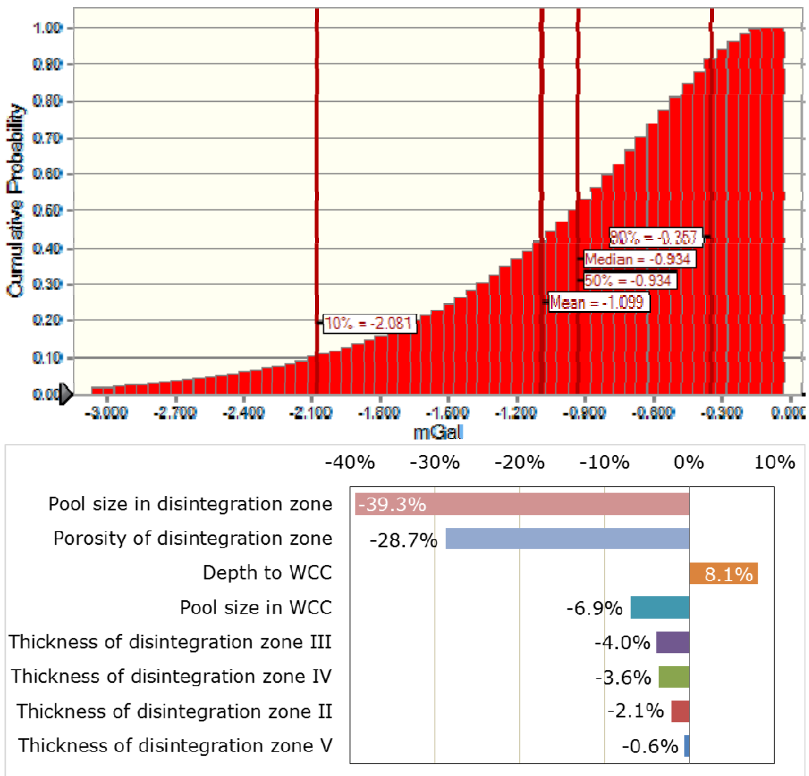


Figure 4 *Stochastic estimation of gravity anomalies, associated with gas reservoirs in weathered crust and disintegration zones (above). Sensitivity chart (below).*

of reservoir location (hydromicatization or disintegration zones) and type of parent crystalline rock. The lowest amplitude of gravity anomalies is associated with water-saturated reservoirs.

- Gravity anomalies associated with hydrocarbon reservoirs in basic rocks exceed gravity anomalies from the same quality reservoir in acid rocks in average by 30%.
- Additional disintegration zones deeper WCC increase magnitude of gravity anomaly.
- Even in pessimistic case (P90), amplitudes of gravity anomalies reach hundreds of microgals (Figure 4), thus greatly exceeding gravity survey error, equal to 0.005 – 0.007 mGal for modern onshore survey with Scintrex CG-5 and offshore sea-bottom gravity survey.
- In the most probable case (P50) the amplitudes of gravity anomalies tenfold exceed gravity survey error for onshore / offshore sea-bottom measurements. For the cases of oil and gas saturation, associated gravity anomalies are comparable and exceed the error of offshore shipboard gravity survey equal to 0.7 – 0.8 mGal.
- For the optimistic case (P10) assuming big hydrocarbon accumulations, associated gravity anomalies are higher than gravity survey error for both onshore and offshore gravity surveys.

Conclusions

The study evidence that magnitude of gravity anomalies associated with hydrocarbon-saturated reservoirs in crystalline basement is intensive enough to be used in exploration process.

Still effective use of gravity data for oil and gas exploration is only possibly through its inversion with seismic, well data, petrophysical and geological information, under the following conditions:

- Renunciation of Tikhonov's regularization. Redefinition of the inverse problem, so the inversion is not only constrained by prior information, but the latter is used as a guiding rule to select the single geologically meaningful model from the space of possible solutions correspondent to observed gravity field.
- Full-depth structural and property inversion (from surface to basement or Moho for basin scale).
- Using of real density for the inversion.
- Quantifying uncertainties, variability, constraints for all the geological sequence and involving structure by seismic, petrophysics, logs, layering according to expected stratigraphy.
- Inversion for the observed gravity field.

References

Gavrilov, V.P. el al. [2010] *Granitoid reservoirs and petroleum potential offshore the South Vietnam*, **2**. GazpromZarubezhNeftegaz STL. Nedra Publ. Moscow, 294 (in Russian).

Gutmanis, J. et al. [2015] Hydrocarbon Production From Fractured Basement Formations, Ver. 11: *GeoScience Ltd*., 45.

Halimov Ju.E. [2012] Commercial Oil And Gas Deposits In Granitic Reservoirs. *Oil and gas Geology. Theory and Practice*, **7** (4) (in Russian)

Petrovskyy, O.P. [2005] Mathematical model of integral interpretation of geological and geophysical data. *Geophisical Journal. National Academy of Science of Ukraine*, **27**, Kiev, 900-904 (in Russian)

Petrovskyy, O.P., Kobrunov, O.I., Gangenko N.S., Sujatinov, V.M. [2003] Automated System of Quntitative Complex Interpretation of Geophysical Data GCIS as a Basis of Technology of Integral Interpretation of G&G Data For Oil & Gas Exploration. *Geoinformatics*, **2**, 25-34 (in Russian)

Chebanenko, I.I. et al. [2005] Discoveries of commercial petroleum accumulations in the Precambrian basement of the Dnieper-Donets basin. In Krayushkin V.A. (ed.): *Petroleum in the basement of sedimentary basins*. Kiev. EKMO Publ., 256.