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Estimation of the pore space structure of tight gas reservoirs of the Moscovian stage locates in DDB Eastern part using a limited well logging dataset.

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SUMMARY

During the exploration, productive intervals identification, and development of tight gas reservoirs fields, an important part is the accurate determination of the capacity, and the structure of the pore space.

For the first time, the technique of Prodaivoda G., Vyzhva S. and Bezrodna I. was used for determining the pore structure of the tight gas reservoirs (porosity cutoff is 4%).

The authors have synthetically generated bulk density and S-wave velocity logs through the multi-mineral model and using the Greenberg-Castagna equation.

According to a limited of well logging dataset, the authors have determined the tight gas reservoirs pore structure of the Moscovian stage in the Spivakivskyi gas-bearing region which locates in the Eastern part of the DDB.

It is established that the void space of the investigated gas reservoirs is mainly composed of tight pores (PHI,tight - 4-7.8%). Fractures are in the intervals of 4136.9-4137.1 m and 4127.9-4128.6 m and PHI,fr is 0.25% and 0.1% respectively. Intergranular pores are almost absent, but in some intervals PHI, int.gr is 0.1-0.9%.

Estimation of the space structure of the given rock intervals provides additional valuable information for further wells stimulation in order to obtain hydrocarbon inflows.

Keywords: tight gas, reservoir, space pore structure, well logging.

Introduction

A considerable number of traditional oil and gas fields of the Dnieper-Donetsk Basin (DDB) are depleted. The prospect of increasing the production of hydrocarbons is the development of deep deposits and tight gas reservoirs.

Identification and development of tight gas reservoirs is a difficult task due to the low porosity, permeability and high content of capillary and absorption bound water. There are several solutions of this problem: determination cutoffs of the filtration-capacity values, at which these intervals after intensification give the hydrocarbons inflow and also the assessment of the pore space structure.

The purpose of this work is to assess the pore space structure of tight gas reservoirs of the Middle Carboniferous Moscovian stage in Spivakivskyi gas-bearing area which locates at the Eastern part of the (DDB).

Methodology

The complex of well logging data used by the authors in this work, includes radioactive methods - gamma- (GR) and dual-spacing neutron-neutron logging (DNNL), acoustic logging (DT), caliper logging (Caliper), focused and unfocused lateral logging(LLD) with different lengths.

The authors calculated the coefficients: clay volume (V_{cl}) - using the Larionov equation for "older rocks", effective porosity by the neutron method (NPHI), taking into account the corrections for the diameter of the wellbore and gas saturation (S_g) using the "Dual water" equation.

The structure of the pore space was determined using the methodology developed by the researchers G. Prodaivoda, S. Vyzhva, and Bezrodna I. at the Institute of Geology. This method is based on the inversion of the results of acoustic and capacitive petrophysical studies of rocks based on the nonlinear optimization methods for solving a forward problem and a method of conditional moments for solving an inverse problem. As a result of interpretation is set of different pore types (fractures; caverns; tight, tensile, and intergranular pores), which form the total porosity of the samples by which determined the type of reservoir rock. Also the perspective intervals are defined during the assessment and identification of hydrocarbon deposits (Shynkarenko, Bezrodna, & Vyzhva, 2017).

The necessary input data for determining the structure of the pore space are bulk density, open porosity and also S- and P-waves velocities, by which the elastic modules of the rocks matrix are calculated. Considering that RHOB and Vs were not measured during the logging studies in this well, they were modeled by the authors.

The multi-mineral model of intervals which are represented by tight gas reservoirs, was built using the statistical approach in the Quanti.Elan module of Techlog software. This module allows to implement a consistent approach using a system of linear and nonlinear equations. These equations describe the relationship between the logging tools and bulk components of the petrophysical model, such as minerals, fluids and their petrophysical properties. Table 1 represent the petrophysical parameters of minerals and fluids used for volume mineralogical modelling and forecasting synthetic density curve.

The authors used the Greenberg-Castagna (1992) empirical equation to determine the S-wave velocity:

$$V_s = \frac{\left(\Sigma_{mineral\_i} \dfrac{Vfi}{\left(a_i V_p^2 + b_i V_p + c_i \right)} \right)^{-1} + \Sigma_{mineral\_i} Vfi \left(a_i V_p^2 + b_i V_p + c_i \right)}{2},$$

Where Vp and Vs (in km / s) – shear and primary waves velocities respectively in 100% saturated by formation water layer, a_i, b_i and c_i - the empirical coefficients established for each mineral (Table 1), *Vfi*- the volume content of minerals (quartz, calcite, and clay minerals), which is modeled in the process of constructing the multi-mineral model.

Table 1.

Lithology	**a_i (quadratic coeff.)**	**b_i (linear coeff.)**	**c_i (constant coeff.)**
Sandstone	0	0.80416	-0.85588
Shale	0	0.76969	-0.86735
Limestone	-0.05508	1.01677	-1.03049

The Greenberg-Castagna equation allows to model Vs in a 100% water-saturated interval. However, the presence of gas in the formation has a significant effect on Vs. In order to address this the calibration of the obtained and known values is conducted but in this work, the authors did not do that. However, such data are available on tight gas reservoirs of neighboring fields and will be taken into account in future work.

The methodology for determining the structure of the void space consists of:

● Preparing of input information. For this purpose, samples of the same (in terms of the pore space structure) intervals are formed and cross-plots of the following functions are constructed: $Vp = f(NPHI)$, $Vs = f(NPHI)$ and $RHOB = f(NPHI)$. After that, calculation of the initial approximation of the rock matrix - the bulk (K), the shear modulus (G) of elasticity, bulk density of rock matrix (RHOB) and pore filler parameters.

●Inversions of acoustic studies data into the pore distribution curve of different formats, which includes finding initial approximations of the pore space structure, inversion of acoustic data, and quantitative determination of porosity types of the studied intervals.

Results

In a result of the logging data (GR, Neutron porosity and LLD) interpretation using the Techlog software the authors distinguished intervals: 4107-4118 m, 4120-4122 m and 4125-4140 m, which are represented by tight gas reservoirs - sandstones with thin layers of siltstone and limestone (Fig. 1). The calculated petrophysical parameters of the prospect objects are follows: Effective Porosity for Neutron Log - 4,5÷%, Gas saturation - 50÷60%.

There were obtained gas inflow with a formation water (which confirms the correctness of the calculated parameters) during the test of selected intervals after hydraulic fracturing. That is why for more complex reservoir characterization, which will be useful in the development process, the authors decided to determine the structure of the pore space.

The multi-mineral model built by the authors corresponds to the geological environment, which is confirmed by the core data, logging curves and drilling information (Fig. 1, 6 track). Also, there was obtained a synthetic bulk density curve (Fig. 1, track 4), which is differentiated in the sandstone intervals and correlates with DT and LLD.

Using the multi-mineral model and the Greenberg-Castagna equation allowed to model Vs curve (Fig. 1, Track 4), which correlates with the measured cross-dipole array acoustic studies in the neighbor reservoir.

During the previous data processing for the calculation of the pore space structure the intervals 4107-4118 m, 4120-4122 m and 4125-4140 m were divided on 29 sublayers depending on the change in the appearance of the Vp curves and the calculated NPHI values.

The construction of cross-plots $Vp = f(NPHI)$, $Vs = f(NPHI)$ and $RHOB = f(NPHI)$, (the coefficients of determination (R^2) are 0.58, 0.65 and 0.99, respectively) allowed to calculate the elastic properties of the rock matrix. The choice of the initial approximation of the pore space structure was made using literature sources.

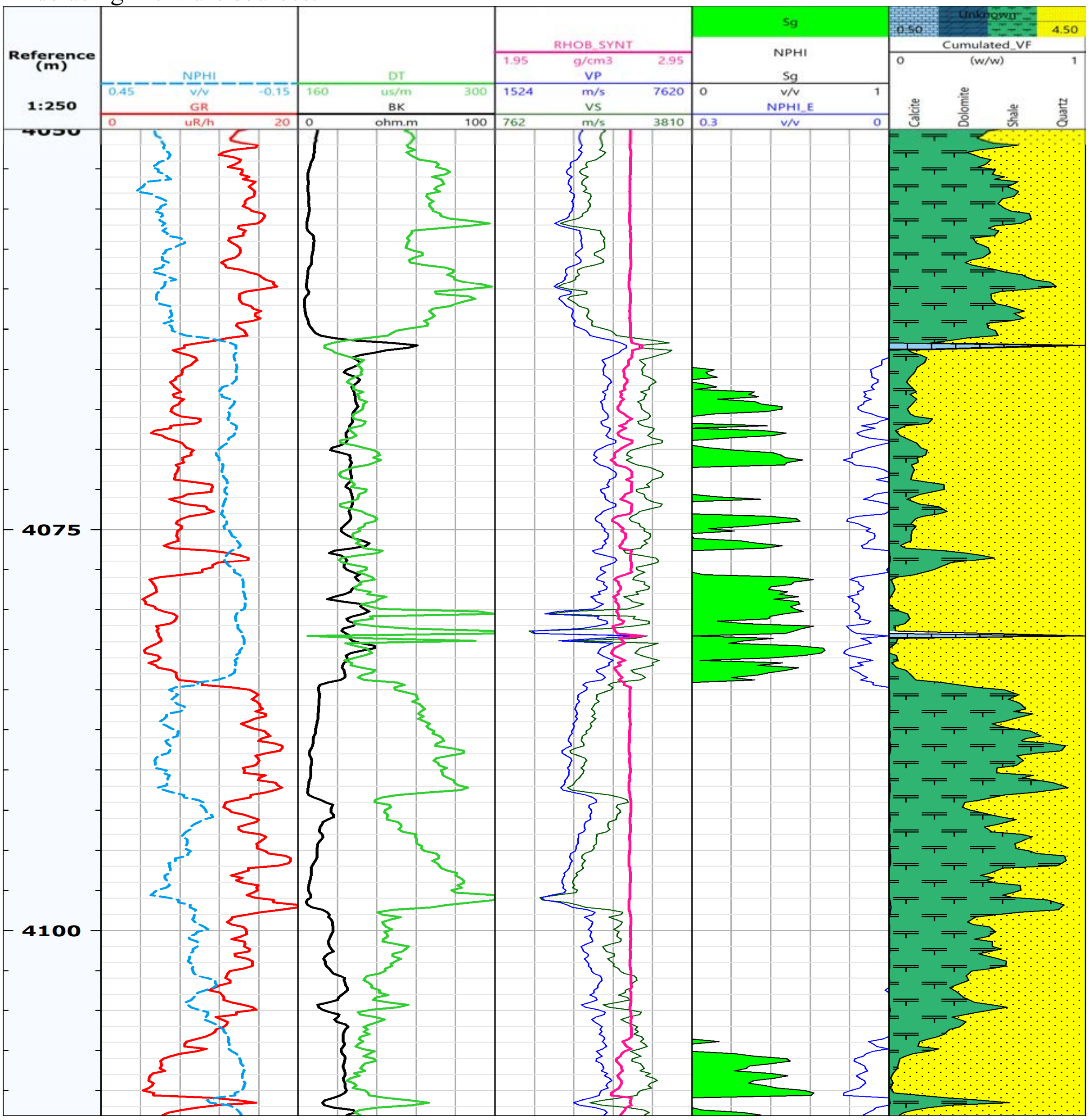

Figure 1*. Summary diagram of logging studies (GR, NPHI, DT ma BK), calculated petrophysical parameters (NPHI_E, Sg), modeled data (Vs, RHOB_SYNT) and multi-mineral model.*

As a result of the acoustic data inversion into the pore (different formats) distribution curve, the authors found that the pore space of the studied reservoir rocks is composed mainly of tight pores ($PHI,_{tight}$ - 4-7.8%). Fractures are in the intervals of 4136.9-4137.1 m and 4127.9-4128.6 m and parameter $PHI,_{fr}$ is 0.25% and 0.1% respectively. Intergranular pores are almost absent, but in some intervals $PHI,_{int.gr}$ is 0.1-0.9%.

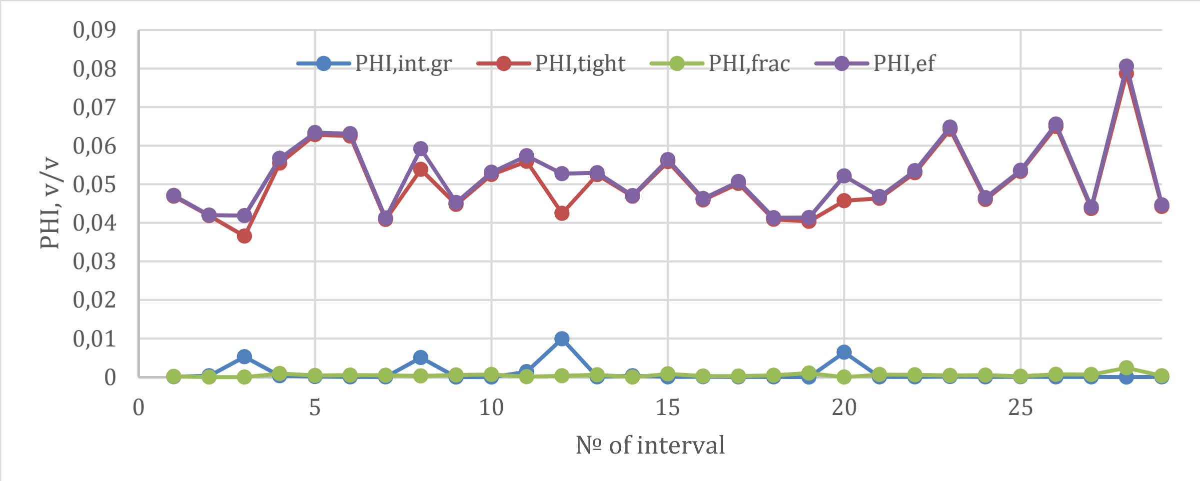

Figure 2. *Results of determining the structure of pore space in tight gas reservoir intervals.*

Conclusions

According to a limited set of logging data, the authors have determined the tight gas reservoirs pore structure of the Moscovian stage in the Spivakivskyi gas-bearing region which locates in the Eastern part of the DDZ.

In the process of interpreting logging data, the intervals 4107-4118 m, 4120-4122 m and 4125-4140 m are represented by the reservoir rocks. In Techlog software a multi-mineral model of selected intervals designed and later used in conjunction with logging data to model S-wave velocity using the Greenberg-Castagna equation.

As a result of the acoustic data inversion into the pore (different formats) distribution curve, developed by Prodaivoda, S. Vyzhva, and Bezrodna I. Authors established that the pore space of the studied reservoir rocks is composed mainly of tight pores ($PHI,_{tight}$ - 4-7.8%). Fractures are in the intervals of 4136.9-4137.1 m and 4127.9-4128.6 m and parameter $PHI,_{fr}$ is 0.25% and 0.1% respectively. Intergranular pores are almost absent, but in some intervals $PHI,_{int.gr}$ is 0.1-0.9%.

Estimation of the space structure of the given rock intervals provides additional valuable information for further wells stimulation in order to obtain hydrocarbon inflows.

The continuation of this study is to determine an amount of absorption and capillary bound water, pore through sizes of tight gas reservoirs which are common in DDB (Sivila, 2013) and also determining the pore space structure of the tight productive reservoir interval 4066-4081 m and comparison of results.

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