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# THE ASSOCIATION OF PHYSICAL PROPERTIES OF DEEP RESERVOIRS WITH THE GEOMAGNETIC FIELD AND FAULT-BLOCK TECTONICS IN THE HLYNSKO-SOLOKHIVSKYI OIL-AND-GAS REGION

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**Purpose of the study.** To study physical properties of the reservoir rocks of Semyrenkivske field in the Hlynsko-Solokhivskyi oil and gas region (OGR) of the Dnipro-Donets Aulacogene with the aim of evaluating their filtration-capacitive properties as well as to justify the relationship of oil and gas fields with sources of local magnetic anomalies that occur during the passage of hydrocarbons. **The research methodology** consists in the experimental study of rock samples (cylinders), namely, measuring the magnetic susceptibility with the MFK1-B kappabridge and determining the density and open porosity according to standard methods, analyzing, and comparing the obtained data with the geological-tectonic maps of the study area. **Results.** The obtained values of magnetic susceptibility, density, and open porosity of reservoir rock samples were obtained from 11 wells in the Semyrenkivske field, which are represented by sandstones, aleuritic sandstones, aleurolites, and limestones. The distribution of these parameters with depth was investigated, and their correlation dependences were calculated. In all wells, the inverse correlation between open porosity and density for all types of rocks is fixed. No clear patterns regarding the relationship of magnetic susceptibility and density have been identified. The integrated approach used to conduct experimental studies together with theoretical data, and analysis of the geomagnetic field and fault-block tectonics made it possible to comprehensively analyze and clarify the current state of oil and gas potential in the Hlynsko-Solokhivskyi OGR, to formulate criteria for the deep oil and gas content of the Earth's crust of the studied region, and to identify the vertical migration routes of hydrocarbons. **Scientific novelty**. Petrophysical studies of rocks in combination with the analysis of the magnetic field and fault tectonics of the territory were carried out for the first time for the Semyrenkivske field, namely, magnetic and filtration-capacitive characteristics of reservoir rock samples were obtained, which make it possible to more thoroughly and comprehensively study the hydrocarbon potential of this area. **Practical value**. The obtained results supplement the information on the petrophysical properties of the rocks of the region under study. For the Semyrenkivske field, on the basis of the presence of a local magnetic anomaly and a node of the intersection of the Kryvorizko-Krupetskyi and sublatitudinal faults, it is possible to forecast the presence of an "echeloned" gas condensate deposit, including the bottom of the sedimentary cover and the crystalline basement.

*Key words*: physical properties of rocks; magnetic susceptibility; local and regional anomalies of the magnetic field; Semyrenkivske field; hydrocarbon deposits.

## *Introduction*

In recent decades, the state of the industrial oil and gas content of sedimentary complexes at depths of more than 4 km has been estimated in different regions of the world, particularly in the United States and Vietnam [Tectonics..., 2015; Lukin, et al., 2011; Lukin, & Shchukin, 2005]. The largest gas debits from deep-seated reservoirs of the Dnipro-Donets Aulacogene (DDA) in Ukraine were obtained at several gas-condensate fields, in particular, Rudivs'ke (from well 1, interval 5750-5790 m, horizon T-1) with a debit of 1020 thousand m$^3$/day [Lukin et al., 2011]. In this regard, it is important to search for criteria for the deep oil and gas potential of the Earth's crust. One of such criteria is the experimentally revealed change in the magnetization of rocks on the paths of hydrocarbons [Orlyuk, 1999]. Such changes were studied on rock samples in different regions of the world, particularly in China [Liu, et al., 2006], Colombia [Costanzo-Álvarez, et al., 2012], Venezuela [Aldana, et al., 2003], United Kingdom [Abubakar et al., 2015], and other countries. Experimental studies revealed elevated values of magnetic susceptibility and remnent magnetization of sedimentary rocks (syderites, argillites, sandstones, limestones) from hydrocarbon deposits. The authors believe that such a phenomenon is connected with the formation of magnetic minerals – magnetite, hematite, and pyrrhotite. In particular, in [Abubakar et al., 2015], during heating of clay samples with kerogen content, at 250 °C a peak was observed in the formation of new magnetic minerals, at 300 °C there was a decrease in their content, and at 320 °C - an increase again. The authors explain such jumps by the formation of pyrrhotite, although they do not exclude the presence of magnetite and greigite. The size of the newly formed grains is (<10 nm), which make it possible for them to migrate with hydrocarbon fluids

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and to form sources of magnetic anomalies over hydrocarbon deposits. A similar experiment was also carried out on samples of sedimentary rocks in the Central part and of the Chernigiv segment of the Dnipro-Donets Aulacogene (DDA). A sharp increase in the magnetic susceptibility was also observed at 250 °C [Orlyuk, 1999; Drukarenko, 2017]. Regarding the Chernigiv segment of DDA, it is shown that a certain change in the magnetization of rocks on the paths of predicted migration of deep hydrocarbons and in the locations of their deposits occurs throughout the section of the Earth's crust, including the sedimentary layer [Drukarenko, 2017; Orlyuk, Drukarenko, 2018]. Here, for the majority of studied wells, at different depths, decompressed rocks of different types with increased magnetic susceptibility, including argillites near the crystalline basement, were identified. The prospects of the identified zones within the sedimentary cover are justified by the confinement of these zones to magnetic sources in the crystalline basement, as well as the connection with the DDA boundary faults, the Kherson-Smolens'k transregional tectonic suture, and the accompanying faults, which are considered as pathways of the deep hydrocarbons.

There are also studies on the role of living organisms (microbes) in the formation of magnetic minerals in the presence of crude oil [Aldana et al., 2003, Costanzo-Alvarez et al., 2006]. A detailed analysis of studies of the relationship between magnetic mineralogy and oil biodegradation using the example of sedimentary oil-bearing rocks from Colombia, Great Britain, Canada, and Indonesia is presented in [Emmerton et al, 2013]. It was concluded that low-quality oil is characterized by a high content of multi-domain magnetite in its composition, as well as the presence of hematite. Biodegradation is a double process in which, firstly, aliphatic carbohydrates are removed, which reduces the quality of the oil, and secondly, magnetic signs (markers) are formed and destroyed. According to the authors, these complex processes make it possible to clarify some contradictions regarding the relationship of hydrocarbon deposits to magnetic minerals.

Magnetics and gravity for direct detection of hydrocarbon pools and delineation of various hydrocarbon structures and signatures were effectively applied in the Muradkhanli, Arabkubaly and Jafarly oil deposits of central Azerbaijan [Gadirov, & Eppelbaum, 2012]. Special attention was paid to investigating the subvertical zone over a hydrocarbon deposit. Changes of physical properties of the rocks in sections of Muradkhanli and Jafarly fields are recorded. Thus, in [Gadirov, 2013], obtained data from different stratigraphic complexes from oil and empty wells were analyzed. The magnetic susceptibility of rocks above and below the hydrocarbon deposits differs dramatically from those ones in the environments surrounding the reservoir. This parameter decreased from 1.5 to 8 times in different deposits in the areas of reservoir location.

The study of the magnetic characteristics of sedimentary rocks turned out to be effective for other oil and gas regions of Ukraine, in particular, the central part of the DDA, Peredkarpats'kiy bending, Volyno-Podillia [Maksymchuk, & Kuderavets 2009; Maksymchuk, et al., 2006; Kuderavets, et al., 2014]. According to theoretical studies and the results of experimental studies of rock samples in conjunction with geomagnetic data and fault-block tectonics, we can explain the current oil and gas potential of the Hlynsko-Solokhivskyi region and identify the channels of vertical migration of hydrocarbons, as well as forecast their presence in the bottoms of the sedimentary cover and crystalline basement.

In particular, in [Seiful-Mulyukov, 2012] an emphasis is placed on the vertical migration of hydrocarbons as the only possible route for the entry of hydrocarbons from the depths of the Earth. According to the author, evidence of this is in rocks in the sedimentary layer of the Earth's crust, which contain carbon in small concentrations, in sediments of both the Paleozoic and Cenozoic ages.

The Semyrenkivske field is located within the boundaries of the Lokhvyts'ka regional magnetic anomaly (with an intensity of 300 nT) of the south-west strike, coordinated with the strike of the Central graben of the Dnipro-Donets Aulacogene (Fig. 1.b.). Scheme of the Hlynsko-Solokhivskyi oil-and-gas region and Semyrenkivske field location see Fig. 1.a. This field is located at the junction of the Central longitudinal, Krivoriz'ko-Krupets'kiy transverse faults [Pashkevich, et al., 2014], which are regional criteria for oil and gas [Starostenko, 2015]. According to Fig. 1.c, almost all the fields of the Hlynsko-Solokhivskyi oil and gas region are located within the limits of positive local magnetic anomalies, while the Semyrenskivske field itself is located within a local anomaly of sublatitudinal intensity of 90 nT. Thus, even for this region, the regularity of the occurrence of deposits to the locations of positive magnetic anomalies is valid [Orlyuk, 1999; Orlyuk, & Pashkevich, 2011].

## Research methodology

The studies were conducted on samples of cylindrical rock (310 samples) from 11 wells, which are lithologically represented by sandstones, aleuritic sandstones, aleurolites, and limestones. Samples were taken from depths in the range from 3,741 m (well 1) to 6,535 m (well 17). They belong to the productive horizons V-16, V-17, V-18, V-19, V-24, V-26 (Visean), B-8-9, B-10-11, B-12 (Bashkirian) and partly to horizons S-6, S-9, S-19-20, S-21, S-22-23 (Serpukhovian and Famennian). The bulk density of the studied rocks in the dry state was determined by weighing and calculating the geometric dimensions of laboratory samples (cylinders and cubes), and saturated samples using the hydrostatic weighing method according to standard methods [Dortman, 1984] at the petrophysical laboratory of the Institute of Geology of the Kyiv Taras Shevchenko National University. In laboratory studies, the open porosity coefficient was determined by the gravimetric method with saturation of rock samples with NaCl solution with a salinity of 160 g / l and gas using standard techniques. Digital analytical scales WPS 360 / c / 2 (accuracy 0,001 g) were used for the measurements. The average relative error in determining the porosity coefficient was 1.2 %. The measurement of the volume magnetic susceptibility $\chi$ was carried out using a MFK1-B kappabridge with a sensitivity of $6*10^{-8}$ CI in the in the Central Scientific Center “Magnetic Station of the Demydiv” of the Institute of Geophysics NAS of Ukraine.

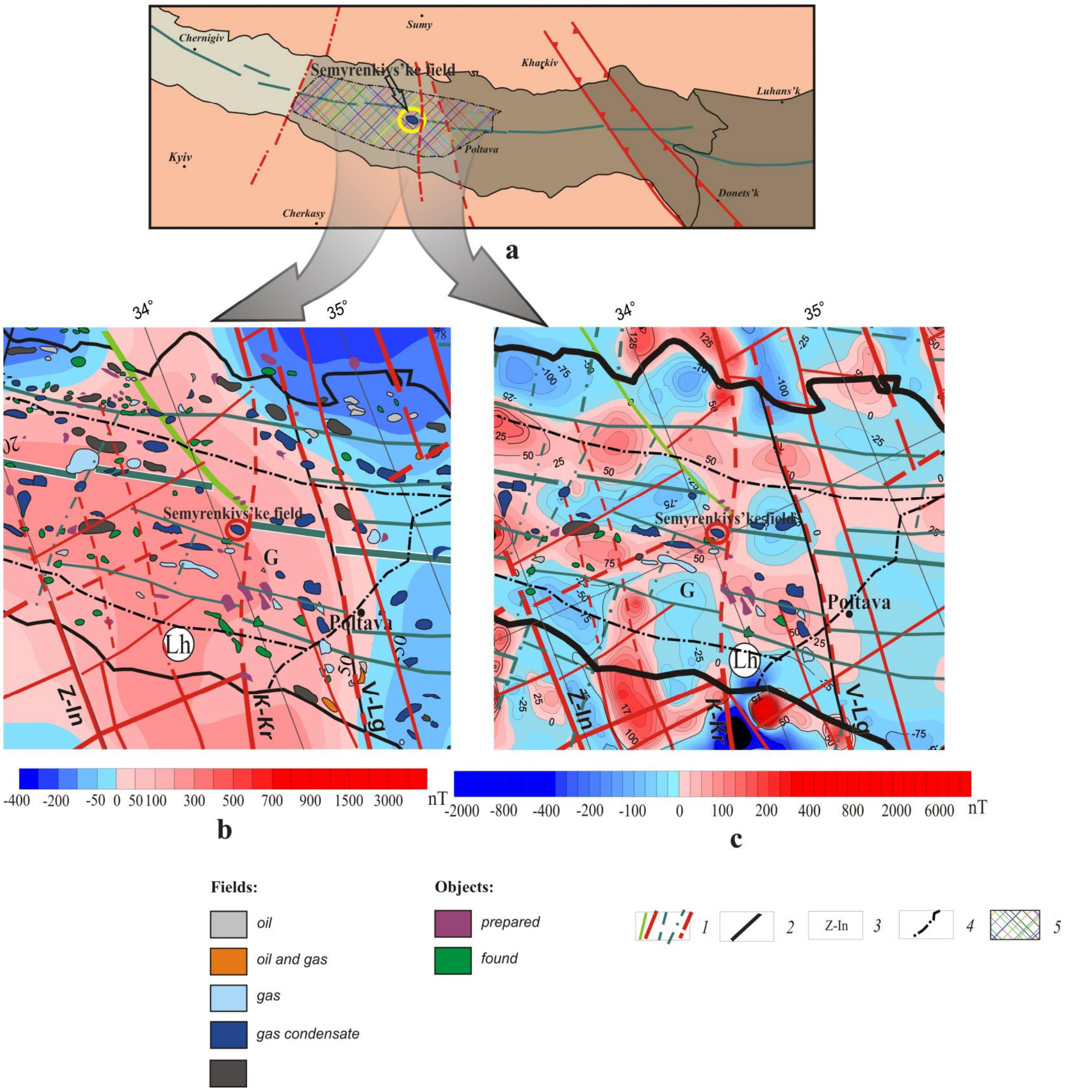

**Fig. 1.** Scheme (a) and maps of regional $(\Delta T)_{a,reg}$ (b) and local $(\Delta T)_{a,loc}$ (c) components of geomagnetic field of the Hlynsko-Solokhivskyi oil-and-gas region and Semyrenkivske field location
Legend: 1 – main faults; 2 – the border of the DDA; 3 – faults: K-Kr – Kryvorizko-Krupetskyi, Z-In – Zakhidno-Inguletskyi, V-Lg – Verkhovtsevsko-Lgovskyi; 4 – border of Hlynsko-Solokhivskyi oil-and-gas region; 5 – Hlynsko-Solokhivskyi oil-and-gas region (on scheme); Lh – Lokhvytskyi segment of the DDA; G – Hlynsko-Solokhivskyi oil-and-gas region; fields location, faults and oil-and-gas location by [Tectonics…, 2015; Map…, 2009]

As already noted, the magnetic susceptibility, density, and porosity of rock samples were experimentally investigated and correlation dependencies between these parameters were calculated. According to the results of studies, diagrams of parameters distribution with the depth of each well were plotted and their correlations among themselves were analyzed, both within individual horizons of reservoir rocks and amongst them.

## ***The results***

The results of the research are presented in the form of diagrams of the distribution of magnetic susceptibility, thickness, and porosity of rocks depending on the depth and their correlations among themselves. The average values of the parameters studied are presented in Table 1 and 2. Let us consider in more detail the physical properties of the rocks in the individual wells.

*Table 1*

**Average values of parameters of sandstones**

| Well number | Magnetic susceptibility $10^{-5}$ SI | Density kg/m$^3$ | Open porosity % |
|---|---|---|---|
| 1 | 16.21 | 2526 | 6.55 |
| 5 | 3.9 | 2517 | 5.96 |
| 18 | 10 | 2557 | 4.48 |
| 21 | 4.22 | 2474 | 7.5 |
| 67 | 1.94 | 2408 | 9.36 |

*Table 2*

**Average values of parameters of aleuritic sandstones**

| Well number | Magnetic susceptibility $10^{-5}$ SI | Density kg/m$^3$ | Open porosity % |
|---|---|---|---|
| 16 | 6.23 | 2510 | 6.1 |
| 18 | 13.7 | 2560 | 5.09 |
| 21 | 6.08 | 2480 | 6.68 |
| 64 | 5.33 | 2476 | 6.6 |
| 67 | 2.54 | 2406 | 9.2 |

In *well 1*, samples were taken from the depths of 3741–5070 m, although there are several fairly powerful intervals from which the core was not taken. Several horizons are distinguished; rocks are presented by sandstones and aleurolites. From top to bottom: horizon B-8-9 (4 samples) are characterized by the highest values of $\chi$ – (18–42)*$10^{-5}$ SI, although there is a sample with an anomalously low value of 0.23*$10^{-5}$ SI. The horizon B-12 is the most magnetic – (31.6–46.3)*$10^{-5}$ SI (4 samples). In the horizon C-6 there are 3 samples – (5.2–6.8) * $10^{-5}$ SI, in the horizon C-9 - 1 sample with $\chi$ = 24.2*$10^{-5}$ SI. Horizon C-19-20 m is represented by 3 samples with increased magnetic susceptibility (18.8–26.6)*$10^{-5}$ SI. In the horizon C-21 - 3 samples (6.4–21.8)*$10^{-5}$ SI, in the horizon C-22-23 there are also 3 samples with magnetic susceptibility within (7.8-9.2)*$10^{-5}$ SI, in the horizon V-16 there are also 3 samples with $\chi$ = (8.9–14.9)*$10^{-5}$ CI. It is possible to note the horizon C-19-20 with increased values of magnetic susceptibility against the background in the range of 4360-4538 m, which includes 2 samples from horizons C-21 and C-9 (Fig. 2). There is a slight increase of density with depth, and magnetic susceptibility decreases with depth (r = -0,58). The correlation coefficient between $\chi$ and density is 0.32; between porosity and density - (-0,84). There are 2 layers of aleurolites with elevated values of magnetic susceptibility in the range of 3964–4220 m - (29-46)*$10^{-5}$ SI and open porosity – 5.9–7.3%, and low values of $\chi$ (5.3–6.8)*$10^{-5}$ SI and a porosity of 1.7-3.6% (4222–4360 m). The density of these rocks in the first interval is lower - 2542 kg/m$^3$, in the second is higher – 2529-2627 kg / m$^3$. The average value of $\chi$ of aleurolites is 22.5*$10^{-5}$ SI. The correlation coefficient between magnetic susceptibility and porosity for aleurolites is 0.81.

In *well 2* there are only 5 samples of sandstones with $\chi$ in the range (1,.1–1.42)*$10^{-5}$ SI (Fig. 3).

In *well 4*, the $\chi$ values of sandstones of the V-17 and V-18 horizons (2 samples) vary within (3.2-35)*$10^{-5}$ SI, there is a sample with a high value ($\chi$ = 60*$10^{-5}$ SI). In the horizon V-17 (5180–5278 m), the values are smaller than in V-18 (5381–5552 m). The average value of magnetic susceptibility is 18.2*$10^{-5}$ SI (Fig. 4).

In *well 5*, samples were taken from depths of 5150–5699 m. The highest magnetic susceptibility values of sandstones are observed in the V-16 horizon (5.3–6.9)*$10^{-5}$ SI at a depth of 5160–5285 m. The V-17 horizon is characterized by lower values – (2.7–5)*$10^{-5}$ SI; in the horizon V-18 there are two samples with very low values of $\chi$: 0.45*$10^{-5}$ SI and -0.05*$10^{-5}$ SI. The lowest values of $\chi$ are in the V-19 horizon – (1.6–3.2)*$10^{-5}$ SI. That is, it is possible to indicate a decrease in magnetic susceptibility with depth (r = -0.54) against the background of an increase in density (Fig. 5). The correlation coefficient between porosity and density is (-0.99).

In the *well 9*, there are only 5 samples of sandstones of the V-16 horizon and they are characterized by magnetic susceptibility values in the range 0.8–3.4*$10^{-5}$ SI.

*Well 16* (5080–5317 m). In the interval (5216–5236 m) of the V-17 horizon, the values of magnetic susceptibility and density of auleritic sandstones are greater than in the interval (5300–5316 m) of the V-18 horizon: (1.5–14.3)*$10^{-5}$ SI and (1.9–8.8)*$10^{-5}$ SI accordingly (Fig. 7). Magnetic susceptibility decreases with depth (r = -0.45), just like density (r = -0.55), open porosity increases with depth – (r = 0.47). The correlation coefficient between porosity and density is -0.93.

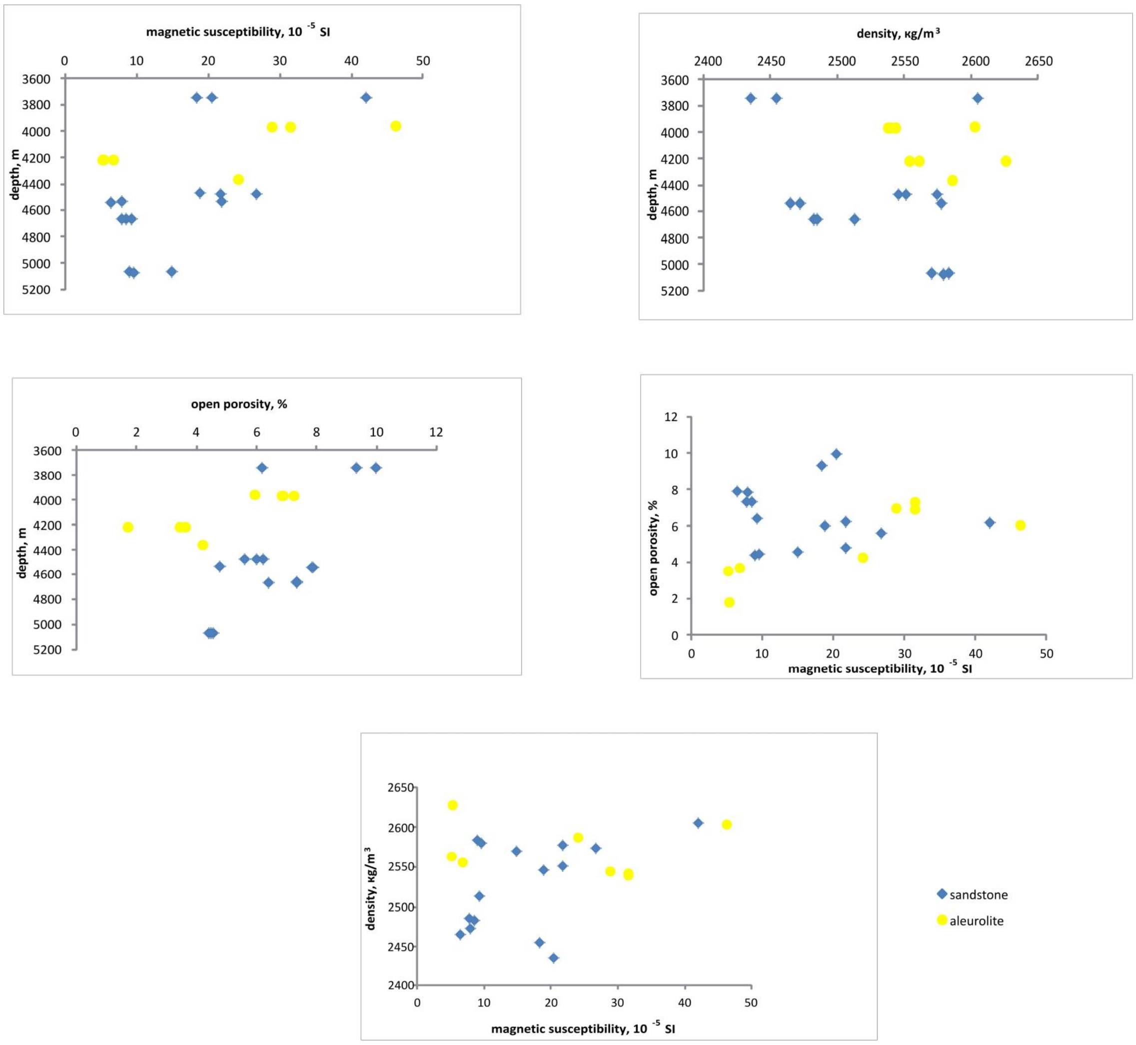

**Fig. 2.** Diagram of distribution of magnetic susceptibility, density, and open porosity of the rocks from bore-hole 1

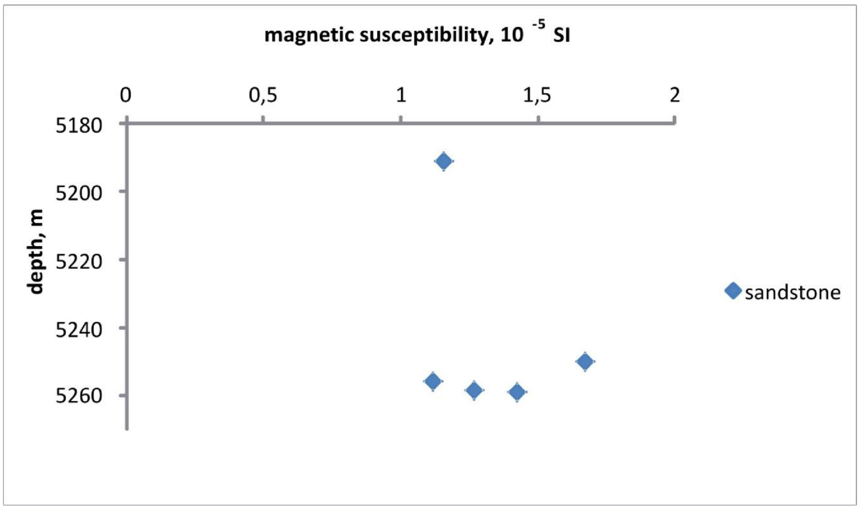

**Fig. 3.** Diagram of distribution of magnetic susceptibility, density, and open porosity of the rocks from bore-hole 2

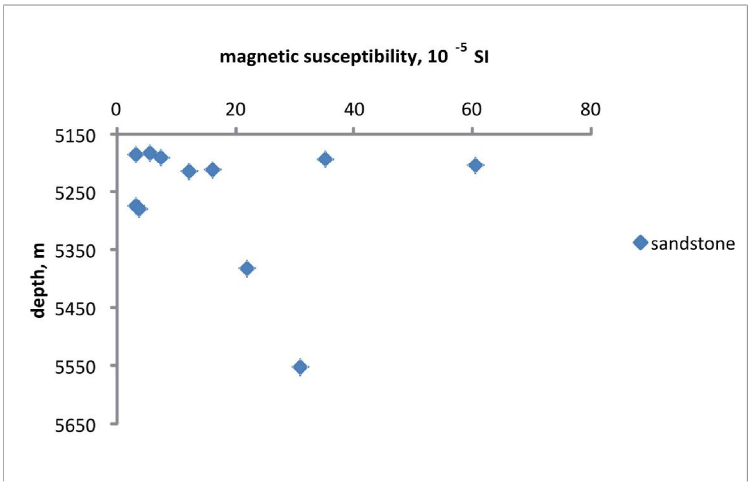

**Fig. 4.** Diagram of distribution of magnetic susceptibility, density, and open porosity of the rocks from bore-hole 4

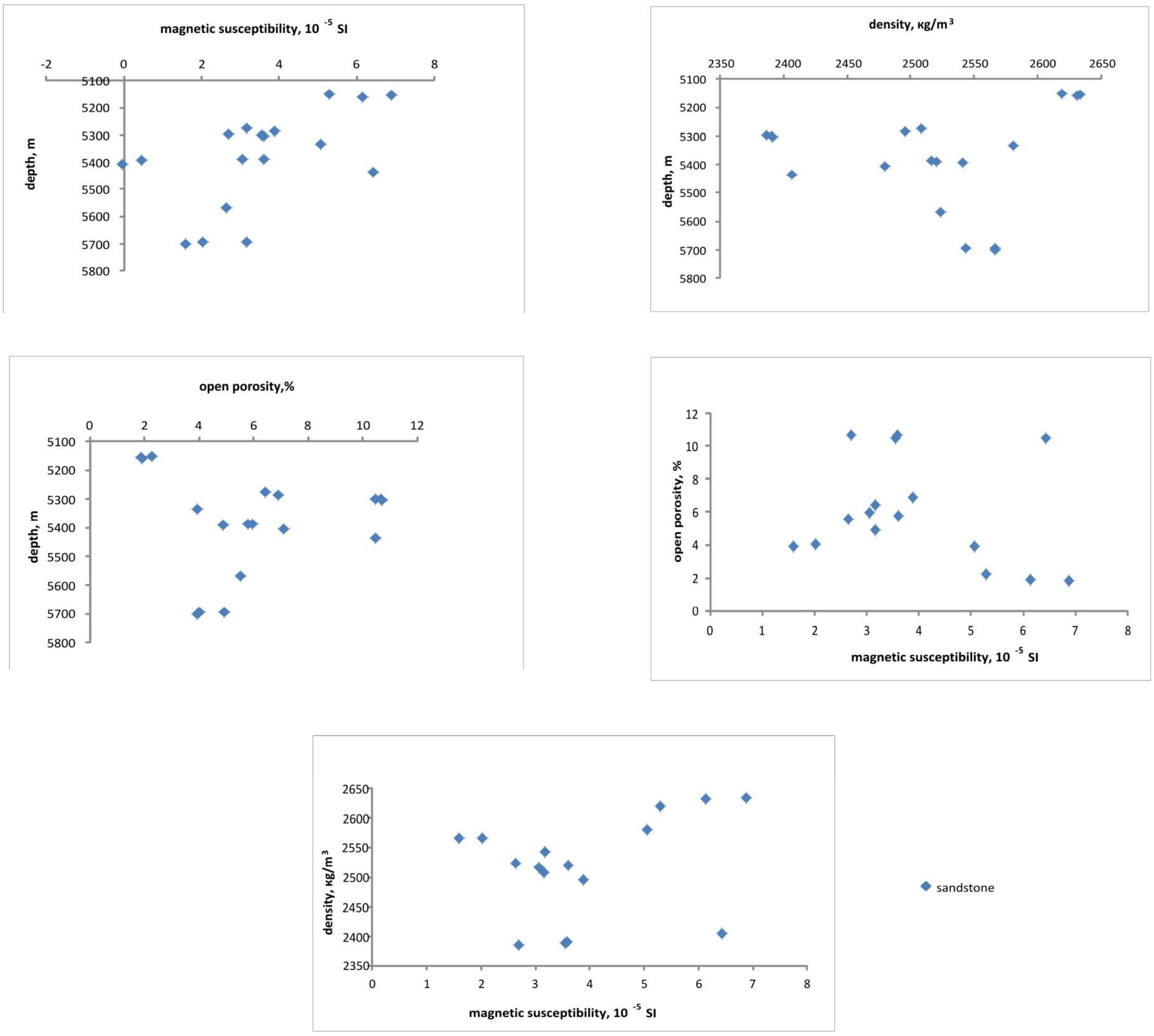

**Fig. 5.** Diagram of distribution of magnetic susceptibility, density and open porosity of the rocks from bore-hole 5

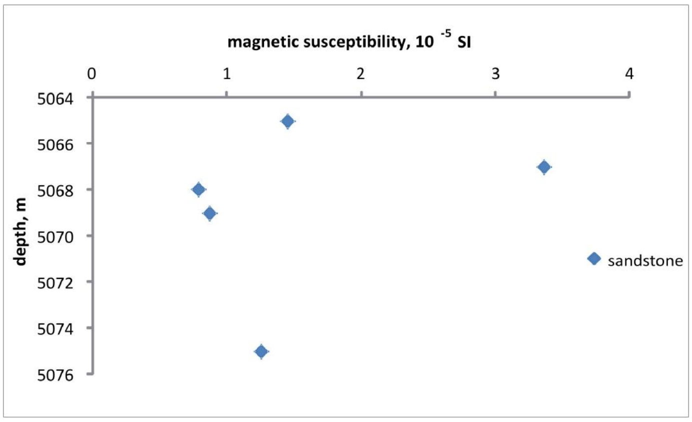

**Fig. 6.** Diagram of distribution of magnetic susceptibility, density and open porosity of the rocks from bore-hole 9

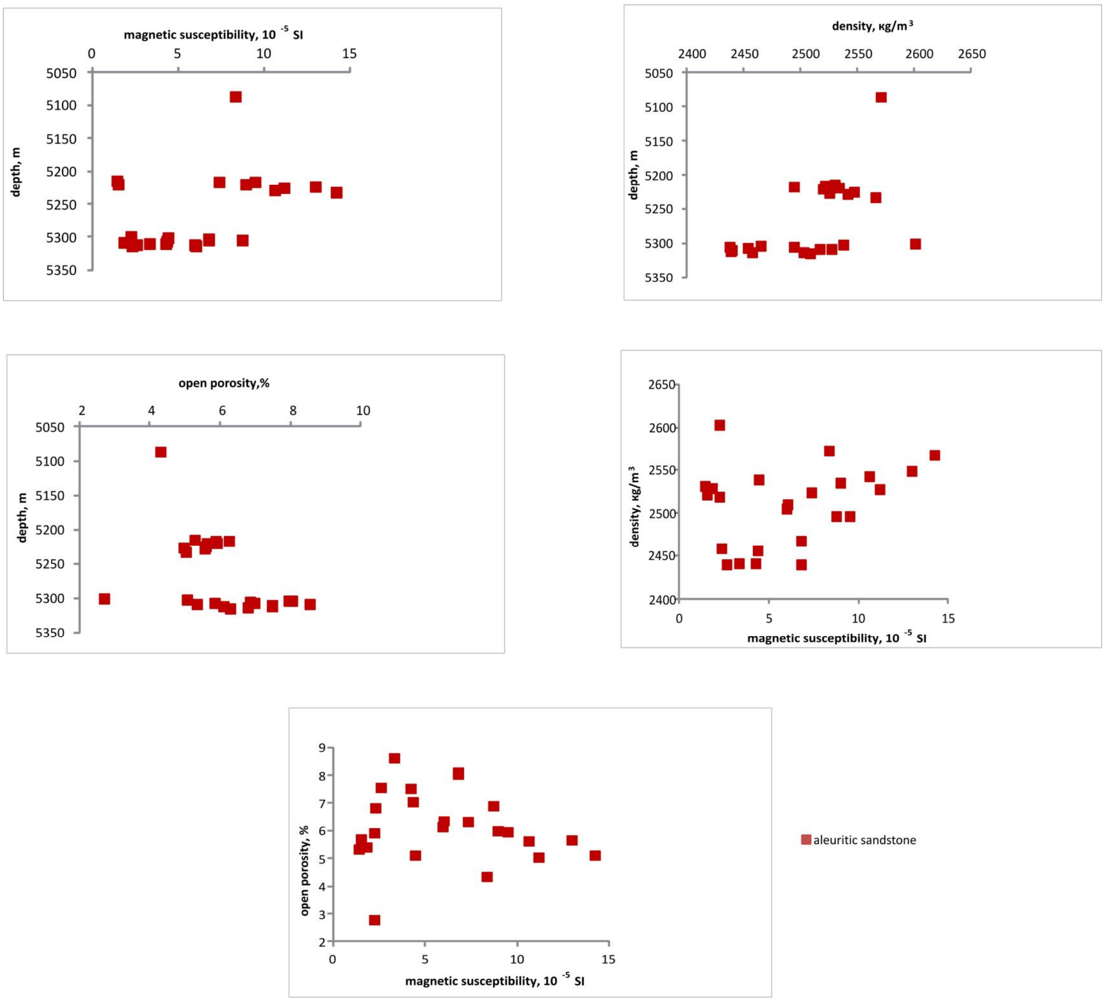

**Fig. 7.** Diagram of distribution of magnetic susceptibility, density, and open porosity of the rocks from bore-hole 16

*Well 17* (5960–6532 m). In the sampling intervals of the V-24 and V-26 horizons, the samples are represented by limestones, in the F horizon – auleritic sandstones (2 samples), and are characterized by very low χ values (-0.8–2.8)*$10^{-5}$ SI (Fig. 8). The correlation coefficient between porosity and density is -0.9, there are no correlation dependencies among other parameters. As is known, limestone consist mainly of calcite [Pecherskiy, 1985]. Calcium carbonate ($CaCO_3$) is characterized by negative values of molar magnetic susceptibility - up to -40*$10^{-6}$ $cm^3mol^{-1}$ [Landolt-Bornstein, 1986]. This may explain the negative values of the magnetic susceptibility of limestones. According to the authors

[Lukin et al., 2011], the oil and gas potential of the lithosphere is controlled by metasomatism zones. The widespread manifestation of petrometasomatism depends primarily on the mineral and chemical composition. Petrophysical properties of the rocks that make up its substrate are also observed in carbonate rocks, for example, metasomatic oil-bearing dolomites developed in biogenic limestone. The authors note that pure biogenic and crystalline granular limestones form a substrate on which all superimposed processes are clearly manifested, including the metasomatic replacement [Lukin et al., 2011].

Strength and high density are also emphasized, with reduced primary porosity of rocks with manifestations of metasomatism, such as, for example, in quartzitic sandstones with which the productive horizons of the lower Carboniferous of the central part of the DDA are connected. The limestones in this study have the highest density and the lowest open porosity among all rocks. The negative values of the magnetic susceptibility of these limestones can be further explained by the presence of hydrocarbons, since, as is well known, oil is diamagnetic. Therefore, they can be a typical representative of the secondary collector, but for this it is necessary to conduct mineralogical studies to investigate the mineral and chemical composition and structure of these rocks.

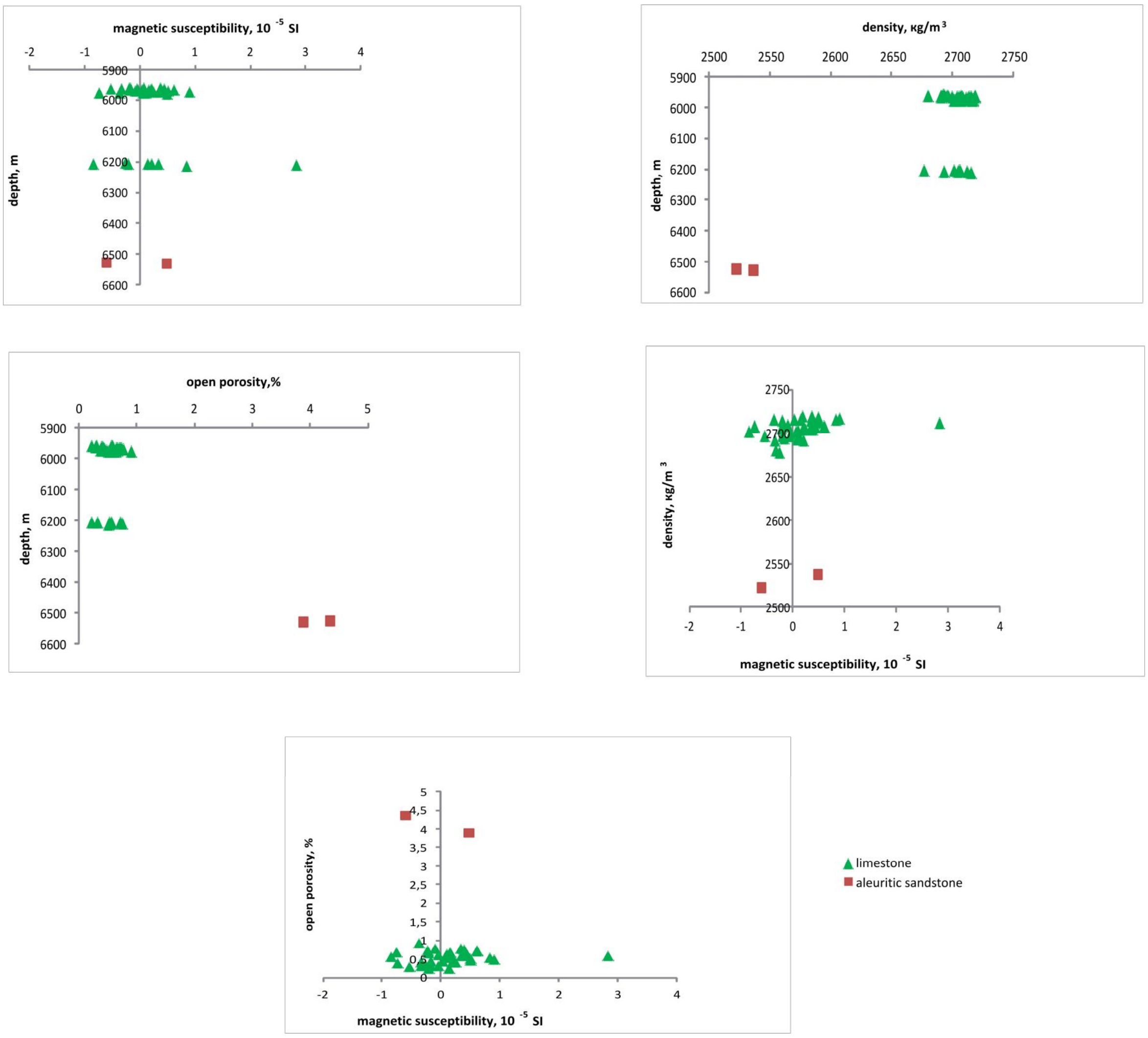

**Fig. 8.** Diagram of distribution of magnetic susceptibility, density, and open porosity of the rocks from bore-hole 17

*Well 18* (5570–5620 m). Magnetic susceptibility of aleuritic sandstones and sandstones within the V-19 horizon naturally increases with depth, reaching values of $\chi$ = (22-26)*$10^{-5}$ SI in the interval 5605–5612 m, dropping further to 9*$10^{-5}$ SI (5615m) (Fig. 9). The density of rocks naturally decreases with a depth of 2630 kg/$m^3$ at a depth of 5590 m to 2500 kg/$m^3$ – by 5615m. Naturally, a substantial inverse relationship was found between porosity and density (r = -0.89).

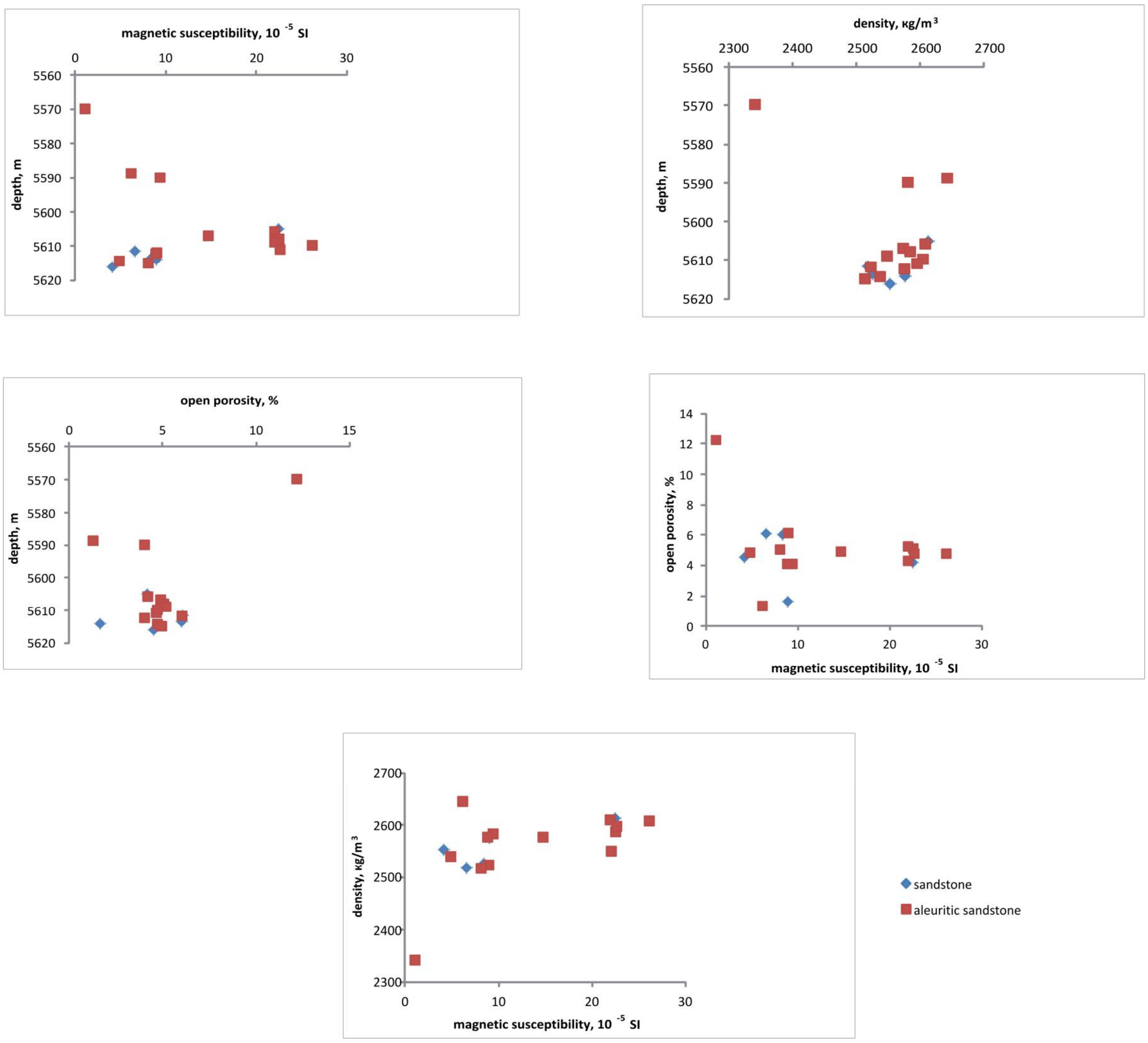

**Fig. 9.** Diagram of distribution of magnetic susceptibility, density, and open porosity of the rocks from bore-hole 18

*Well 21* (5577–5588 m). Within the boundaries of the V-19 horizon, there is a small layer of sandstones and aleuritic sandstones (5582-5586 m) with elevated values of $\chi$ – (4.25–19.7)*$10^{-5}$ SI. At other depths, the magnetic susceptibility is very slight (0.5–6.2)*$10^{-5}$ SI (Fig. 10). In the depth range of 5584–5586 m, the density of sandstones decreases, while aleuritic sandstones are increasing. Magnetic susceptibility of rocks decreases, and density increases within the limits of interval 5581–5581.8 m. There is a slight association of magnetic susceptibility and density (r = 0,47) and the reverse one with open porosity (r = -0,37) for all types of rocks. A close relationship was observed between porosity and density (r = -0.97).

In *the well 64* core was taken from depths of 5248–5386 m. The V-17 and V-18 horizons, which are represented by aleuritic sandstones, were allocated. In horizon V-17, the values of magnetic susceptibility are in the range of (0.6–5.3)*$10^{-5}$ SI. In the horizon V-18 there are two intervals: at a depth of 5344-5357 m, $\chi$ values are within (-0.3–4.9)*$10^{-5}$ SI, there are 2 samples with elevated values of this parameter: 15.2*$10^{-5}$ SI and 23.8*$10^{-5}$ SI. At a depth of 5381–5386 m – the values are (3.1–24)*$10^{-5}$ SI (Fig. 11). The correlation coefficient between open porosity and density is -0.97, and the correlation dependences between other parameters are very small. If the values of $\chi$ of these three parameters are averaged over the intervals of 5240–5300 m, 5340–5360 m and 5380–5390 m, then it can be concluded that the magnetic susceptibility increases with depth (r = 0.3): $\chi_{av.}$ = 3.39*$10^{-5}$ SI, $\chi_{av.}$ = 4.42*$10^{-5}$ SI and $\chi_{av.}$ = = 9.62*$10^{-5}$ SI respectively. Rocks in the range of 5340-5360 m with $\sigma_{av.}$ = 2462 kg/m$^3$ are characterized by the lowest density values and the highest porosity of 7.04%, the lowest - in the range of 5380-5390 m with $\sigma_{av.}$ = 2491 kg / m$^3$ and open porosity of 6.38%. In the range of 5240–5300m, the average density of rocks is 2484 kg / m$^3$, with an open porosity of– 6.19%.

*Well 67* (5482–5515 m). Rocks of horizon V-19 in the range of 5490–5500 m are characterized by elevated values of magnetic susceptibility (5–28.2)*$10^{-5}$ SI) and density (2620 kg/m$^3$) of sandstones and aleuritic sandstones against the background of their insignificant values ($\chi$ = (-0.06–2.2)*$10^{-5}$ SI, $\sigma$ = 2270–2460 kg/m$^3$) (Fig. 12). Let us note the presence of 3 samples with increased values of $\chi$ at a depth of 5509–5513m – ($\chi$ = 11,5-17.8)*$10^{-5}$ SI). Density increases slightly with depth (r = 0.35). The correlation dependences of the studied parameters are very insignificant, with the exception of porosity and density – (r = -0.98).

### *The discussion of the results*

In most wells, no clear patterns in the distribution of the studied characteristics could be detected. This is due, primarily, to the unevenness of sampling in wells, their insignificant number, as well as low-power or different sampling intervals. The experimental data on the magnitudes of the magnetic susceptibility, density, and porosity of rocks allows us to analyze their average values for individual horizons of the sedimentary cover. Horizon V-16 is found in wells 16 (5080–5088 m), 5 (5150–5159 m), 9 (5065–5075 m) and 1 (5065–5070 m) and is represented by several samples in each of the wells. The highest values of magnetic susceptibility have sandstones from the well 1 – (8.9–14.9)*$10^{-5}$ SI, the lowest ones - sandstones from well 9 – (0.8–3.4)*$10^{-5}$ SI. This is an interesting pattern, since the depth of sampling in these wells is the same.

Horizons V-17 and V-18 are found in wells 16, 4, 2 and 64. In well 64 at depths of 5248–5295, the magnetic susceptibility of the aleuritic sandstones of horizon V-17 is slightly lower (0.6–5.3) * $10^{-5}$ SI than the sandstones of well 2 from a depth of 5200–5259 m (1.1–1.4)*$10^{-5}$ SI. In well 4 at a depth of 5180–5278 m, the value of magnetic susceptibility of sandstones (3.1––35)*$10^{-5}$ SI is close to $\chi$ values of aleuritic sandstones from well 16 at a depth of 5216-5236 m ((1.5-14.3)*$10^{-5}$ SI) and higher in value from wells 64 and 2. In the well 16, the V-18 horizon is open at a depth of 5300–5316 m with low magnetic susceptibility values of aleuritic sandstones ((1.9-8.8)*$10^{-5}$ SI). In well 64, this horizon is located at a depth of 5344–5386 m with more high $\chi$ values of aleuritic sandstones – (-0.3–24)*$10^{-5}$ SI. In well 4 - at a depth of 5381–5552 m (total 2 samples) with high $\chi$ values of sandstones (22–31)* $10^{-5}$ SI, close to the values from 64 wells.

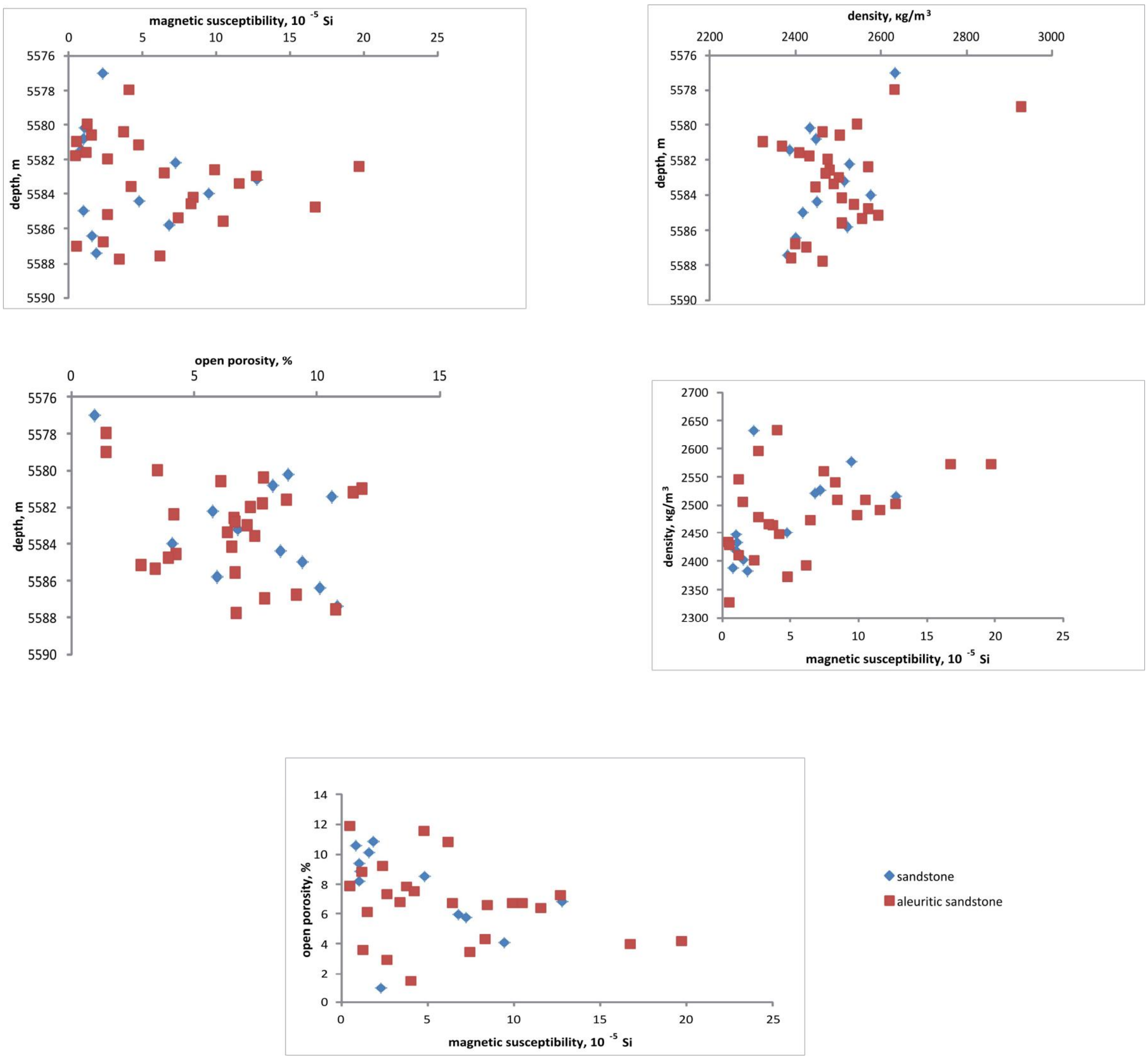

**Fig. 10.** Diagram of distribution of magnetic susceptibility, density, and open porosity of the rocks from bore-hole 21

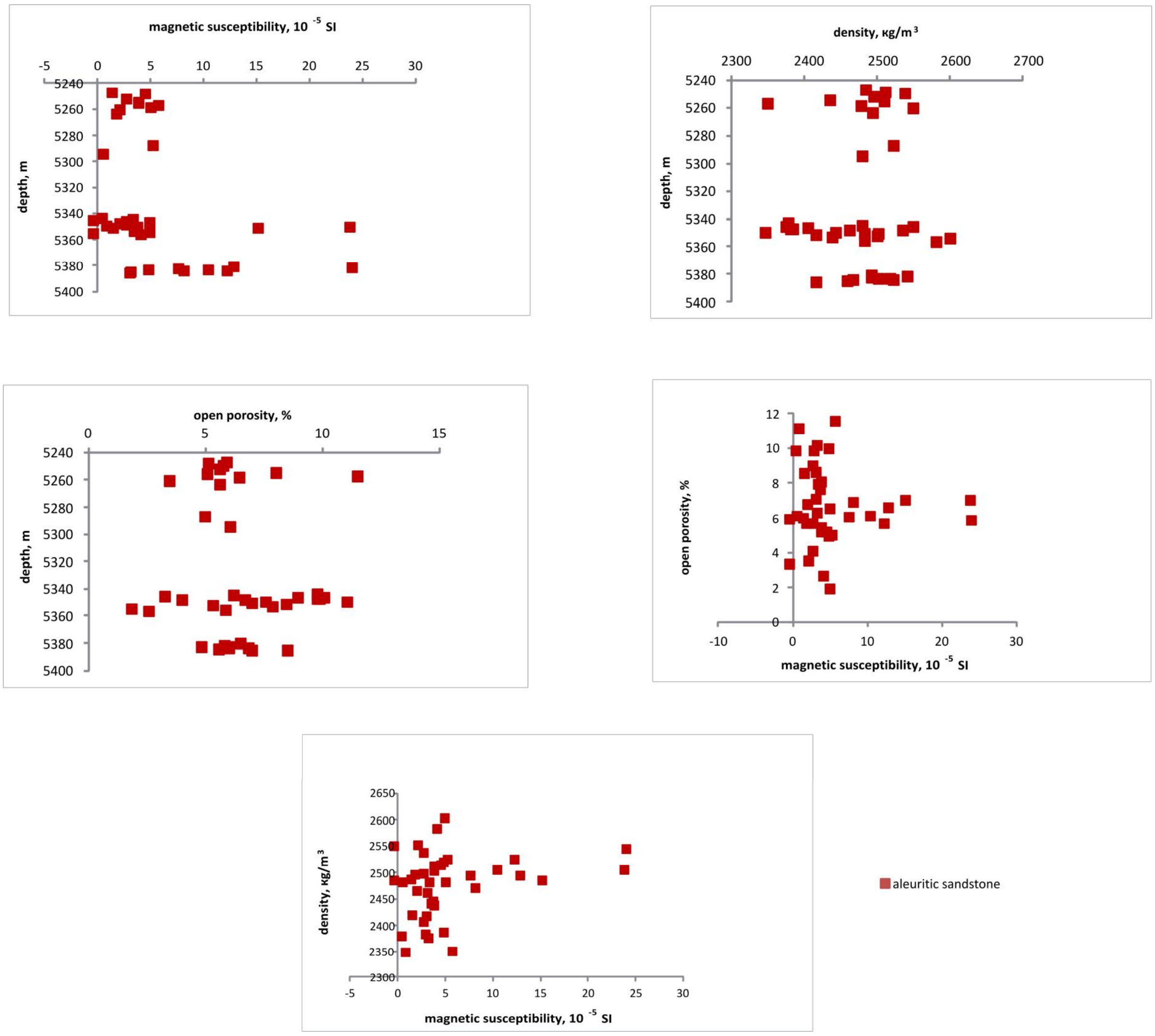

**Fig. 11.** Diagram of distribution of magnetic susceptibility, density, and open porosity of the rocks from bore-hole 64

Within the limits of horizon V-19 in wells 18, 21, 67 there are found layers of sandstones and aleuritic sandstones with increased magnetic susceptibility at different depths. In the well 18 - at a depth of 5605–5612 m ((22–26)* $10^{-5}$ SI), in the well 21 – 5582–5586 m ((4.25–19.7)*$10^{-5}$ SI), in the well 67 – 5490–5500 m ((5–28)*$10^{-5}$ SI) against the background of low indicators - (-0.06–2.2)*$10^{-5}$ SI. In the well 5, this horizon is represented by sandstones 5568-5700 m and is characterized by the lowest values of magnetic susceptibility of rocks in this well (1.6–3.2)*$10^{-5}$ SI.

The least magnetic susceptibility are found in the aleuritic sandstones from well 17, the F horizon ($\chi_{av}$ = = -0.05*$10^{-5}$ SI) and in limestones from well 17 of the V-24 horizons ($\chi_{av}$ = 0.07*$10^{-5}$ SI) and the V-26 horizon ( $\chi_{av.}$ = 0.38*$10^{-5}$ SI). They also have the highest density (2705 kg / $m^3$), and naturally, the lowest open porosity (0.71%). The most high magnetic susceptibility values are characterized by sandstones (horizons B-8-9, C-19-20, C-21, C-22-23 and V-16) and aleurolites (horizons B-12 and C-6) of well 1 – 16.2 and 22.5*$10^{-5}$ SI respectively, aleuritic sandstones and sandstones (horizon V-19) from well 18 with $\chi$ = 13.7*$10^{-5}$ SI and 10.08*$10^{-5}$ SI, respectively, as well as the sandstones of well 4 from horizon V-18 with $\chi_{av.}$ = 18.2*$10^{-5}$ SI (Tab. 1, 2). Note that most of the values of the magnetic susceptibility of rocks are characteristic of rocks from the deposits of hydrocarbons, but in general, the variation range of magnetic susceptibility values is quite wide - from (-0.042)*$10^{-5}$ SI (well 17, limestone, horizon V-24) to 60.6*$10^{-5}$ SI (sandstone, well 4, horizon V-18). There are samples with abnormally high $\chi$ values on the background of significantly lower levels: in well 21, the magnetic susceptibility of aleuritic sandstone from horizon V-19 is 126*$10^{-5}$ SI, sandstone from well 67 from horizon V-19 is 53.6*$10^{-5}$ SI, aleuritic sandstone with streaks of carbonaceous inclusions in horizon V-18 of well 64 – 82.2*$10^{-5}$ SI, and aleuritic sandstone of horizon V-16 from well 16 – 46.2*$10^{-5}$ SI. The limits of changes and average values of the physical parameters of core samples in the horizons are given in Table 3. Such a significant differentiation of the values of the magnetic susceptibility of rocks depends not only on their lithological composition and paleotectonic conditions of formation, but also on their oil and gas content [Maksymchuk, Kuderavets, 2009; Drukarenko, 2017]. By a number of theoretical models [Berezkin et al., 1982; Orlyuk, 1997], and as a result of experimental studies and observations of local magnetic anomalies over hydrocarbon deposits, the presence of zones in the environment with differentiated magnetic properties over deposits of oil and gas has been established. Local magnetic anomalies over deposits are explained by magnetic inhomogeneities of the epigenetic nature in near-surface layers, as well as, as already noted, by changes in the magnetization of rocks in the passage of hydrocarbons through deep faults and in confinement to magnetic sources in the lower parts of sedimentary cover and crystalline basement.

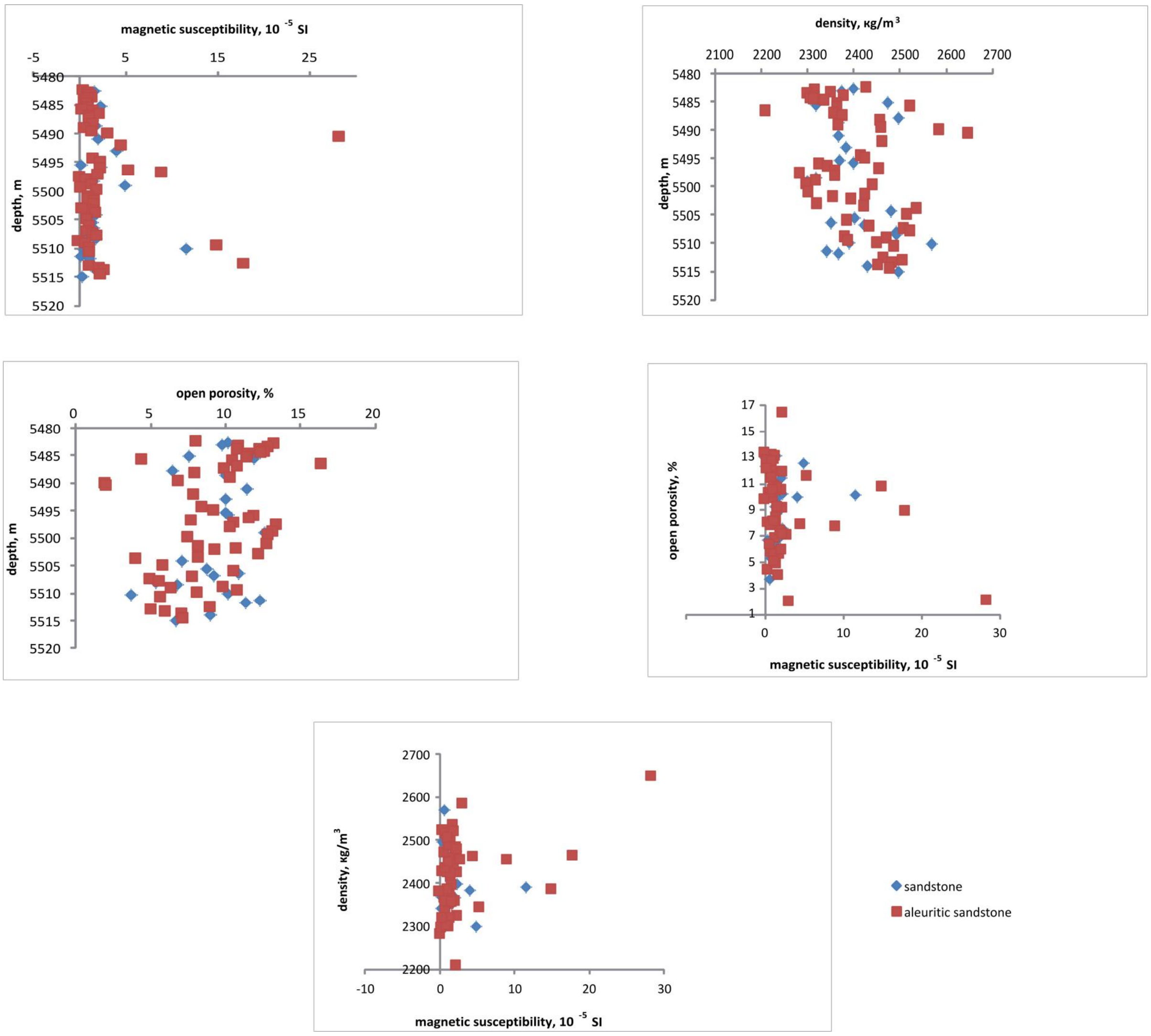

**Fig. 12.** Diagram of distribution of magnetic susceptibility, density, and open porosity of the rocks from bore-hole 67

In almost all wells, the behavior of the magnetic susceptibility and density of rocks is the same with depth. Only in wells 1 and 5 a decrease in the magnetic susceptibility of rocks was recorded against the background of an increase in their density. In well 21, a small layer of sandstones and aleuritic sandstones (5585–5588m) can be distinguished, in which the magnetic susceptibility rises slightly with depth against the background of rock softening. This can be a favorable condition for the passage and accumulation of hydrocarbons, since it is one of the regional criteria for oil and gas content [Starostenko, 2015]. In all wells, the inverse correlation between open porosity and density for all types of rocks is naturally observed, the highest (-0.99) - in well 5, the lowest - in well 1 (-0.84).

*Table 3*

**The limits and average values of physical parameters of samples from wells of Semyrenkivske gas condensate field**

| | Horizon | Type of rocks | Parameter value | $\chi$, $10^{-5}$ Si | Density кg/m$^3$ | | Open porosity % |
|---|---|---|---|---|---|---|---|
| | | | | | Dry | Mineralogical | |
| 1 | V-16 | sandstone | min | 0.79 | 2476 | 2673 | 1.87 |
| 2 | V-16 | sandstone | max | 14.91 | 2634 | 2703 | 7.96 |
| 3 | V-16 | sandstone | average | 5.33 | 2557 | 2668 | 4.9 |
| 4 | V-17 | aleuritic sandstones | min | 0.61 | 2317 | 2642 | 3.51 |
| 5 | V-17 | aleuritic sandstones | max | 24.1 | 2690 | 2817 | 11.5 |
| 6 | V-17 | aleuritic sandstones | average | 6.2 | 2500 | 2677 | 7.5 |
| 7 | V-17 | sandstone | min | 1.12 | 2317 | 2667 | 3.7 |
| 8 | V-17 | sandstone | max | 60.6 | 2690 | 2817 | 13.2 |
| 9 | V-17 | sandstone | average | 9.61 | 2486 | 2675 | 8.45 |
| 10 | V-18 | aleuritic sandstones | min | -0.33 | 2348 | 2637 | 1.88 |
| 11 | V-18 | aleuritic sandstones | max | 24.1 | 2715 | 2809 | 11.1 |
| 12 | V-18 | aleuritic sandstones | average | 5.56 | 2490 | 2665 | 6.49 |
| 13 | V-18 | sandstone | min | -0.047 | 2406 | 2669 | 2.45 |
| 14 | V-18 | sandstone | max | 30.9 | 2701 | 2769 | 10.5 |
| 15 | V-18 | sandstone | average | 9.48 | 2537 | 2699 | 6.47 |
| 16 | V-19 | aleuritic sandstones | min | -0.06 | 2209 | 2618 | 1.28 |
| 17 | V-19 | aleuritic sandstones | max | 26.2 | 2928 | 2970 | 16.4 |
| 18 | V-19 | aleuritic sandstones | average | 5.08 | 2455 | 2663 | 8.8 |
| 19 | V-19 | sandstone | min | 0.08 | 2300 | 2619 | 0.95 |
| 20 | V-19 | sandstone | max | 22.4 | 2612 | 2726 | 13.2 |
| 21 | V-19 | sandstone | average | 3.49 | 2455 | 2665 | 7.1 |
| 22 | V-24 | limestone | min | -0.042 | 2680 | 2691 | 0.23 |
| 23 | V-24 | limestone | max | 0.9 | 2725 | 2756 | 1.1 |
| 24 | V-24 | limestone | average | 0.07 | 2706 | 2722 | 0.66 |
| 25 | V-26 | limestone | min | -0.22 | 2677 | 2685 | 0.23 |
| 26 | V-26 | limestone | max | 2.8 | 2715 | 2729 | 0.76 |
| 27 | V-26 | limestone | average | 0.38 | 2702 | 2716 | 0.49 |
| 28 | S-1s | sandstone | min | | 2465 | 2652 | 1.7 |
| 29 | S-1s | sandstone | max | | 2627 | 2728 | 7.9 |
| 30 | S-1s | sandstone | average | | 2538 | 2690 | 5.6 |
| 31 | S-2b | sandstone | min | | 2436 | 2705 | 6.0 |
| 32 | S-2b | sandstone | average | | 2532 | 2737 | 7.5 |
| 33 | S-6 | aleurolite | min | 5.27 | 2555 | 2652 | 1.73 |
| 34 | S-6 | aleurolite | max | 6.89 | 2627 | 2673 | 3.64 |
| 35 | S-6 | aleurolite | average | 5.87 | 2581 | 2660 | 2.95 |
| 36 | S-19-20 | sandstone | min | 18.8 | 2551 | 2709 | 5.61 |
| 37 | S-19-20 | sandstone | max | 26.6 | 2574 | 2727 | 6.22 |
| 38 | S-19-20 | sandstone | average | 22.4 | 2557 | 2719 | 5.94 |
| 39 | S-21 | sandstone | min | 2.46 | 2465 | 2676 | 4.77 |
| 40 | S-21 | sandstone | max | 2.57 | 2577 | 2707 | 7.89 |
| 41 | S-21 | sandstone | average | 12.05 | 2505 | 2689 | 6.83 |
| 42 | S-22-23 | sandstone | min | 7.8 | 2482 | 2679 | 6.38 |
| 43 | S-22-23 | sandstone | max | 9.2 | 2513 | 2684 | 7.34 |
| 44 | S-22-23 | sandstone | average | 8.54 | 2493 | 2682 | 7 |
| 45 | B-8-9 | sandstone | min | 18.4 | 2435 | 2705 | 6.16 |
| 46 | B-8-9 | sandstone | max | 42 | 2605 | 2776 | 9.9 |
| 47 | B-8-9 | sandstone | average | 26.9 | 2498 | 2730 | 8.48 |
| 48 | B-12 | aleurolite | Min | 28.9 | 2539 | 2727 | 5.9 |
| 49 | B-12 | aleurolite | Max | 46.3 | 2603 | 2769 | 7.25 |
| 50 | B-12 | aleurolite | Average | 34.6 | 2656 | 2742 | 6.75 |
| 51 | F | aleuritic sandstones | Min | -0.59 | 2523 | 2637 | 0.72 |
| 52 | F | aleuritic sandstones | Max | 0.49 | 2688 | 2708 | 4.4 |
| 53 | F | aleuritic sandstones | Average | -0.05 | 2583 | 2662 | 2.56 |

With regard to the ratio of magnetic susceptibility and open porosity, the highest correlation coefficient between these parameters is observed in aleurolite (well 1), which is equal to 0.81. The weak backward correlation was found in the aleuritic sandstones of well 18 - (r = -0.28), well 21 - (r = -0.32), well 67 – (r = -0.27); and sandstones of well 5 – (-0.23) and well 21 – (-0.45).

The least density are found in sandstones and aleuritic sandstones in well 67 with $\sigma_{av.}$ = 2406 kg/m$^3$ and open porosity of 9.3%. The density of rocks varies within quite considerable limits from 2209 kg/m$^3$ to 2928 kg/m$^3$ (aleuritic sandstones, horizon V-19), with its average value being 2510 kg/m$^3$. The apparent mineralogical density of the studied rocks varies from 2619 kg/m$^3$ (aleuritic sandstones, horizon V-19) to 2970 kg/m$^3$ (aleuritic sandstones, horizon V-19), with its average value - 2680 kg/m$^3$. Wide limits of density fluctuations indicate the variability of the lithological composition of core samples and their porosity.

As a result of analyzing the laboratory studies of the porosity of rocks by the method of saturation with a model of the NaCl collector solution, it was found that this parameter varies from 0.23 % (limestones of horizons V-24, V-26) to 16.4 % (aleuritic sandstone, horizon V-19) with an average of 3.4%. In the general, the studied sandstones are characterized by elevated open porosity values (Table 3).

It should be noted that part of the sandstone samples from the described wells were used to study changes in the acoustic and capacitive properties of terrigenous rocks under high pressures and a qualitative assessment was given of changes in the structure of their void spaces under conditions of compression and relaxation [Vyzhva et al., 2017]. As a result, it was found that the elastic wave velocities are more sensitive to pressure changes than the porosity coefficient, and it was also possible to reduce collectors properties of reservoir rocks during their compaction (provided that the total porosity decreases and no new penetrating channels were found). The authors of the above article identified a group of 4 samples of aleuritic sandstones from well 67 of horizon V-19 with a similar structure of void space, which have a fairly high open porosity – from 7.1% to 13.13%.

In the above mentioned work [Lukin et al., 2011], as a result of analyzing the filtration-capacitive characteristics of sandy collectors-metasomatites at great depths, the authors made a decision about conditionality of reservoir rocks with a porosity of 6-6.5%. It also noted that the actual gas flow rates from wells over 5.5 km vary from weak gas emission to 270 thousand m$^3$/day and it is impossible to trace the pattern of flow rate's decrease with depth, according to the authors, even with a large amount of factual material, since collectors are highly productive with porosity of 6-8, and even 5.5-7%.

As an example, the authors bring data directly for several wells, one of which is well 2, from the Semyrenkivske field. In it, at a depth of 5505-5600 m, a gas flow rate of 268 thousand m$^3$/day was obtained from rocks with a porosity coefficient of 5.5–8.5%. Unfortunately, samples from these depths for the mentioned well are absent and it was not possible to investigate the magnetic susceptibility and density of rocks. The authors explain the high flow rates from low-porous layers caused by the presence of significant fracturing in them, which is confirmed by the actual research data of a large number of cores and by geophysical well-researching data [Lukin et al, 2011]. Taking into account that the Semyrenkivske field is located in the intersection zone of geodynamically active faults at the present stage of their development and above the magnetic source (predictably Devonian age) in the upper part of the crystalline basement and the bottoms of the sedimentary cover [Orlyuk, 1999; Pashkevich et al., 2014], it is possible to predict the development of this type of reservoir rocks at more significant depths. To the west of Verkhovtsevsko-Lgovskyi fault the main magnetic sources of the Earth's crust are located. Devonian magmatism is presented here most energetically, which indicates the intensity of the deep processes during rifting. To the west of Poltava, bodies with high magnetisation are located at different depths and at the top of the crust and are associated with stems of magmatic formations and effusives. The largest magnetic bodies here are correlated with areas with an abnormally high density, which may indicate the intensive basification of this part of aulacogene that spatially coincides with the area of the Central Depression [Orlyuk, 1999]. As a source of the Lokhvytska regional magnetic anomaly, where the Semyrenkivske field is located, the complex magmatic body of the Devonian stage of development with several stages of formation is considered. During the last stage there was the penetration of the stem-shaped bodies [Pashkevich et al., 2014]. According to [Bagdasarova, 2013], longitudinal, and near-subliminal faults remain geodynamically active up to the present. We can make an assumption about the geodynamical activity of this part of the crust while faults considered as hydrocarbon migration paths. It partially confirmed by Semyrenkivske and several other fieldlocations. These fields located in close proximity to the Kryvorizko-Krupetskyi, Central and sublatitudinal faults are related to stem-shaped body in the area of the Semyrenkivske deposit. These faults of consolidated crust apparently are linked to ruptures in sedimentary cover and can be the supply channels for deep fluids [Pashkevich et al., 2014].

### *Scientific novelty and practical value*

For the first time, magnetic, and filtration-capacitive characteristics of reservoir rocks samples were obtained in complex with magnetic field analysis and fault tectonics of the territory were performed for the Semyrenkivske field. The integrated approach made it possible to comprehensively analyze and explain the modern oil and gas content of the Hlynsko-Solokhivskyi OGR, to formulate criteria for the deep oil and gas content of the Earth's crust in the region under study, and to identify vertical hydrocarbon migration routes. Petrophysical characteristics obtained can be used for construction of geological and geophysical models, stratification of geological sections, and allocation of lithomagnetic marking horizons.

### *Conclusions and suggested futher research*

As a result, for the Semyrenkivske field, on the basis of the presence of a local magnetic anomaly and the node of the intersection of the Kryvorizko-Krupetskyi and sublatitudinal faults, it is possible to predict the presence of “layered” gas condensate deposits, including the bottoms of sedimentary cover and the crystalline basement. It can be assumed there is a presence of significantly fractured reservoir rocks with low porosity below 5600 m in the research area, considering the presence of geodynamically active faults and the magnetic source, probably of Devonian age and the stem-shaped in the lower parts of sedimentary cover and the upper part of the crystalline basement.

Carrying out additional mineralogical research and the use of already obtained petroacoustic electrometric data for a part of the samples of Lower Carboniferous terrigenous rocks from Semyrenkivske field will enable determination of the perspectivity of reservoir rocks at great depths. Lower Carboniferous secondary reservoirs of the central part of the DDA are of particular interest to study, since the productive horizons there are connected with quartzite-sandstones with completely reduced primary porosity. Therefore the secondary nature of the reservoir rocks appears quite sharply. It is necessary to investigate the physical parameters of the rocks from the outside of the productive horizons and compare them to the already obtained data. This determines the further direction of the research.

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# ЗВ'ЯЗОК ФІЗИЧНИХ ВЛАСТИВОСТЕЙ ГЛИБИННИХ ПОРІД-КОЛЕКТОРІВ ГЛИНСЬКО-СОЛОХІВСЬКОГО НАФТОГАЗОНОСНОГО РАЙОНУ З ГЕОМАГНІТНИМ ПОЛЕМ ТА РОЗЛОМНО-БЛОКОВОЮ ТЕКТОНІКОЮ

**Мета дослідження.** Дослідити фізичні властивості порід-колекторів Семиренківського родовища Глинсько-Солохівського нафтогазоносного району (НГР) Дніпровсько-Донецького авлакогену для оцінки їх фільтраційно-ємнісних властивостей, а також обгрунтування зв'язку нафтогазових родовищ з джерелами локальних магнітних аномалій, які виникають при проходженні вуглеводнів. **Методика досліджень** полягає в експериментальному вивченні зразків порід (циліндри), а саме у вимірюванні магнітної сприйнятливості на капометрі MFK1-B та у визначенні густини і відкритої пористості за стандартними методиками, у аналізі та зіставленні отриманих даних з геолого-тектонічними картами району досліджень. **Результати.** Отримані значення магнітної сприйнятливості, густини та відкритої пористості зразків порід-колекторів з 11 свердловин Семиренківського родовища, які представлені пісковиками, алевритистими пісковиками, вапняками та алевролітами. Досліджено розподіл даних параметрів із глибиною, а також розраховано їхні кореляційні залежності. У всіх свердловинах зафіксована обернена кореляція між відкритою пористістю та густиною для всіх типів порід. Чітких закономірностей щодо зв'язку магнітної сприйнятливості та густини не виявлено. Використаний комплексний підхід у проведенні експериментальних досліджень у сукупності з теоретичними даними, аналізом геомагнітного поля та розломно-блоковою тектонікою дає можливість всебічно проаналізувати та пояснити сучасну нафтогазоносність Глинсько-Солохівського НГР, сформулювати критерії глибинної нафтогазоносності земної кори досліджуваного регіону, виділити вертикальні шляхи міграції вуглеводнів. **Наукова новизна.** Вперше для Семиренківського родовища виконано петрофізичні дослідження порід у комплексі з аналізом магнітного поля та розломної тектоніки території, а саме отримано магнітометричні та фільтраційно-ємнісні характеристики зразків порід-колекторів, що дають змогу детальніше та комплексно вивчити вуглеводневий потенціал цього району. **Практична значущість.** Отримані результати доповнюють інформацію про петрофізичні властивості гірських порід досліджуваного регіону. Для Семиренківського родовища, на підставі наявності локальної магнітної аномалії та вузла перетину Криворізько-Крупецького та субширотного розломів, можна прогнозувати наявність "ешелонованого" газоконденсатного покладу, включно з низами осадового чохла та кристалічним фундаментом.

*Ключові слова:* фізичні властивості порід; магнітна сприйнятливість; локальні та регіональні аномалії магнітного поля; Семиренківське родовище; родовища вуглеводнів.

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# СВЯЗЬ ФИЗИЧЕСКИХ СВОЙСТВ ГЛУБИННЫХ ПОРОД-КОЛЛЕКТОРОВ ГЛИНСКО-СОЛОХОВСКОГО НЕФТОГАЗОНОСНОГО РАЙОНА С ГЕОМАГНИТНЫМ ПОЛЕМ И РАЗЛОМНО-БЛОКОВОЙ ТЕКТОНИКОЙ

**Цель исследования**. Исследовать физические свойства пород-коллекторов Семиренковского месторождения Глинско-Солоховского нефтегазоносного района (НГР) Днепровско-Донецкого авлакогена для оценки их фильтрационно-емкостных свойств, а также обоснование связи нефтегазовых месторождений с источниками локальных магнитных аномалий, возникающих при прохождении углеводородов. **Методика исследований** заключается в экспериментальном изучении образцов пород (цилиндры), а именно в измерении магнитной восприимчивости на каппометре MFK1-B и в определении плотности и открытой пористости по стандартным методикам, в анализе и сопоставлении полученных данных с геолого-тектоническими картами района исследований. **Результаты.** Полученные значения магнитной восприимчивости, плотности и открытой пористости образцов пород-коллекторов из 11 скважин Семиренковского месторождения, которые представлены песчаниками, алевритистыми песчаниками, известняками и алевролитами. Исследовано распределение данных параметров с глубиной, а также рассчитаны их корреляционные зависимости. Во всех скважинах зафиксирована обратная корреляция между открытой пористостью и плотностью для всех типов пород. Четких закономерностей связи магнитной восприимчивости и плотности не выявлено. Использован комплексный подход в проведении экспериментальных исследований в совокупности с теоретическими данными, анализом геомагнитного поля и разломно-блоковой тектоникой дает возможность всесторонне проанализировать и обосновать современную нефтегазоносность Глинско-Солоховского НГР, сформулировать критерии глубинной нефтегазоносности земной коры исследуемого региона, выделить вертикальные пути миграции углеводородов. **Научная новизна**. Впервые для Семиренковского месторождения выполнены петрофизические исследования пород в комплексе с анализом геомагнитного поля и разломной тектоники территории, а именно получено магнитометрические и фильтрационно-емкостные характеристики образцов пород-коллекторов, позволяющие более детально и комплексно изучить углеводородный потенциал данного района. **Практическая значимость.** Полученные результаты дополняют информацию о петрофизических свойствах горных пород исследуемого региона. Для Семиренковского месторождения, на основании наличия локальной магнитной аномалии и узла пересечения Криворожско-Крупецкого и субширотного разломов, можно прогнозировать наличие “эшелонированной” газоконденсатной залежи, включая низы осадочного чехла и кристаллический фундамент.

*Ключевые слова:* физические свойства пород; магнитная восприимчивость; локальные и региональные аномалии магнитного поля; Семиренковское месторождение; месторождения углеводородов.

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