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NEURON NETWORK TECHNOLOGIES APPLICATION IN LITHOLOGICAL-FACIAL DECOMPOSITION OF THE DEVONIAN AND CARBONIFEROUS SEDIMENTS ACCORDING TO GEOLOGICAL-GEOPHYSICAL DATA (NORTHWESTERN PART OF THE DNIEPER-DONETS DEPRESSION)

(Представлено членом редакційної колегії д-ром геол. наук, доц. О.В. Шабатурою)

Background. ***The growth of hydrocarbon reserves in the old oil and gas producing regions can be realized to a large extent due to the reinterpretation of geological and geophysical data on the old fund of wells (both within existing deposits and on areas that, under certain circumstances, were at one time assessed as unpromising). At this stage of geological exploration work, considerable work is being done to reinterprete the data of geophysical studies in the missed intervals of wells of the old fund, including exploratory wells. Similar works are carried out on deep horizons (Devonian), as well as on Mesozoic deposits, which in the last century were not of primary importance in terms of prospects in many areas. The available geological and geophysical material indicates significant difficulties in the correct identification of layers within the specified strata.***

Methods. ***The results of geophysical, petrographic and petrophysical studies on the deposits are analyzed. The methods of statistical analysis were applied in order to establish the possibility of using pattern recognition methods for lithological-facies dissection of well sections based on well-logging data.***

Results. ***Thanks to the use of neural network technology, the reliability of the traditional geological interpretation of the well-logging data was verified. The reliability of establishing the lithological-facies affiliation of individual layers in Upper Devonian, Lower, and Middle Carboniferous well sections has been increased by using an ensemble of calculated neural networks. An original approach to the implementation of neural network technology in the interpretation of geological and geophysical data is proposed.***

Conclusions. ***The article examines the geophysical characteristics of potentially promising horizons that were previously overlooked. The problems to be solved are indicated, as well as ways to increase the reliability of the geological interpretation of well-logging data in layers of different ages. In particular, the possibility and expediency of using machine learning based on neural network technologies is considered.***

Keywords: ***horizon, reservoir, lithology, Devonian, neural networks, well logging.***

Background

Many years of communication with specialists in the area of well-logging data interpretation, as well as own experience, lead to the understanding that the geological conclusions based on the materials of well logging are always probabilistic and quite subjective in nature. These well-known and obvious things, which are described in textbooks, and taught in universities to students, are realized only over the years. Even the calculated parameters, which are determined from the well logging data and are the basis for various methods of estimating oil and gas reserves, are the result of modeling the geological environment (reservoir rocks) based on our experiments (in a laboratory environment) with rocks in conditions that have never been identical to the natural occurrence of rock layers. We have to come to terms with this and adapt the geological interpretation of well-logging materials to the results of industrial development of oil and gas fields, formations, or deposits. That is, it is trivial to the maximum possible coincidence of estimates of productive (or non-productive) objects by geologists, geophysicists and developers. The same applies to the most simple (not at first glance) task, such as lithological decomposition of the formations by the well-logging data. The difficulties here are as follows:

- when the number of lithological types of rocks increases, the efficiency of their separation according to various geophysical parameters decreases (significant overlap of distributions of parameter values for lithotypes close in terms of lithological characteristics);
- lack of representative core collections for individual lithological types for every stratigraphic unit;
- a limited set of well-logging methods regarding the number of informative parameters that are measured in wells;
- difficulties (including the presence of subjectivism) of tying individual core samples to well sections and geophysical curves;
- atypical behavior of the logging curves opposite the layers that are uniquely identified by core data in terms of their lithological affiliation.

The listed difficulties are typical when studying the deposits of the Kinashivska structure (the extreme northwestern part of the northern border zone of the Dnieper-Donets depression), which was chosen to perform the reinterpretation of the well-logging data material in old exploration wells. It was precisely on this geophysical material

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from a specific area that promising approaches to increase the effectiveness of geological interpretation were tested.

Analysis of recent research and publications. Previous years, increased attention had been paid to deposits, which for certain reasons were considered secondary in relation to their prospects for the discovery of new deposits. Undoubtedly, for tens of years, the main production of hydrocarbons and the growth of oil and gas reserves in the Dnieper-Donets basin (DDB) took place at the expense of productive carbon horizons. Devonian deposits, due to their local distribution in the DDB, and in many areas even at great depths, were a rather difficult target for exploratory drilling. Thus, in the articles (Bagrii et al., 2023; Lukin, 1997, 2006, 2008; Stryzhak, Polishchuk, & Korzhnev, 2013), the variety of litholo-facies types of rocks capable of retaining hydrocarbons in Devonian formations is described in sufficient detail. At the same time, in the wells of the old fund, which revealed Devonian deposits during exploratory drilling, quite often negative conclusions were obtained regarding the presence of productive deposits with conditional hydrocarbon rates. There are quite a lot of reasons for such results both at the stages of conclusions based on the results of geophysical investigations in wells and during well tests. Moreover, in addition to the objective factors of the geological nature, there are also complications related to the low efficiency of interpretation of well-logging data in the study of Devonian deposits. Features of the opening of Devonian sediments during well drilling, testing technologies in the past also led to the omission of productive layers/objects in well sections. The review of geological materials, industrial tests and geophysical data obtained in different years in exploratory wells is one of the directions of work of production and research institutions aimed at identifying new promising oil and gas objects in Devon. Recommendations for similar works can be found in publications (Bagrii et al., 2023; Karpenko, Mykhailov, & Karpenko, 2015; Lukin, 1997, 2008; Stryzhak, Polishchuk, & Korzhnev, 2013; Vakarchuk, 2016).

Isolation of previously unsolved parts of the general problem. This article deals with issues related to increasing the efficiency of geological and geophysical research in wells. Moreover, due to the limited volume of the publication, only one of the aspects of solving such a problem is considered. Namely, increasing the efficiency of lithologic-facies decomposition of Devonian sediments and other younger sediments that are promising for oil and gas. The problematic issues related to this task are discussed below.

Geological and geophysical features of research objects. Oil and gas-bearing deposits of the sub-salt Devonian complex are described in detail in the work of (Lukin, 1997, 2006, 2008) in terms of their lithological-genetic origin and features of spatial distribution. On the example of a separate structure within the boundaries of the Kinashivska structure (DDB) in the section of the Upper Devonian (Famennian stage, depth interval 1962–2834 m), lithological types of rocks are found, inherent in significantly different conditions of sedimentation. Their diversity creates significant difficulties (as will be shown below) in the identification of lithotypes based on the data of geophysical studies (well logging) in well sections. We will present the individual characteristics of the main lithotypes of the Famennian layer from the wells of Kinashivska structure based on the results of well logging taking into account the macro descriptions of the core.

The powerful chemogenic stratum of the Upper Devonian age is represented by quite frequent alternation of salt layers with carbonate, carbonate-clay rocks and effusives. Limestone layers have high resistivity up to 2000 Ω·m and porosity of 4–5 %. Reservoirs are not distinguished among these deposits, according to the well-logging results.

The sediments of the Famennian stage of the Devonian are represented mainly by intersalt terrigenous formations. According to geophysical materials, they are divided into three strata: clay-carbonate, sandy and sandy-clay. According to geophysical data, there are no reservoir rocks in the lower layer.

Powerful terrigenous reservoirs with a porosity of up to 21 % and a resistivity of 0.5–0.7 Ω·m are found in the interval of the sandy stratum. According to all materials and test data, the considered reservoirs are saturated with water.

In the interval of the upper, sandy-clay stratum, the section is represented by a thin layering of sandy-clay reservoirs with argillites. There are also separate thin layers composed of probably tight sandstones and limestones.

All reservoirs have very low resistivity; their resistivity here ranges from 5 to 1.6 Ω·m. The rocks of this part of the section are poorly cemented and form caverns during drilling. The reservoirs here are selected according to the neutron gamma-ray (NGR) data, the increased readings of which, together with the decrease in natural gamma radiation (GR) according to the GHK, indicate a decrease in the clay content of the rocks. When tested by the equipment on the pipes from the reservoirs of the specified intervals, small inflows of oil were obtained. Careful analysis of the geophysical material made it possible to identify reservoir rocks with a total thickness of 39.2 m in the well interval, the weighted average porosity of which is about 15.4 %. It should also be noted that the stratigraphic breakdowns of the section were taken from the conclusions based on the results of the interpretation of the well-logging data performed by specialists of the Nizhyn Expedition of Well Logging (EWL), without author's corrections (authors of the article).

Since the reservoir rocks in this section of the well are quite atypical (low-resistivity and rich), the estimation of their oil saturation coefficient poses certain difficulties. Calculations using the usual techniques (Vyzhva et al., 2019, 2021; Rybalka et al., 2016) show that individual reservoirs have an oil and gas saturation ratio of 50 to 64 %. These numbers should be considered indicative.

The layer encountered in the roof of the Devonian terrigenous stratum (4 m thick) should be noted separately. It has a geophysical characteristic of carbonaceous rocks: very large resistivity values (up to 8000 Ω·m) and interval time ΔT; at low (at the level of clays) NGR readings. This layer and the layers lying above it (according to the data of the core study – breccia) obviously belong to Devonian supersalt deposits; they do not have reservoir properties.

According to geophysical materials, all selected terrigenous and carbonate reservoirs are water-saturated in carbonate deposits.

Methods

Decomposition of the entire section of the well on Kinashivska structure was carried out taking into account all geological and geophysical information. Logging materials were taken as a basis, as well as a macro description of the core, petrographic descriptions of cuts and test results. In addition, the assignment of specific lithological types to individual strata was based on own experience and the results of the interpretation of data from the well logging, performed at the time by geophysicists-interpreters of the geological department of the Nizhyn EWL. In contrast to the conclusions made earlier, we carried out lithological decomposition continuously along the entire wellbore (without focusing on promising layers and intervals). To visualize the petrophysical features of individual lithological types, parameter histograms were constructed for individual lithotypes of rocks, taking into account the stratigraphic affiliation. Separately performed for rocks of the Devonian (Famennian stage D_3fm), rocks of the Visean-Tournaisian (C_1v-t) of the Lower Carboniferous and rocks of the Moscovian and Bashkirian stages of the Middle Carboniferous (C_2m-b). As an example, the distribution of the average values of the exposure dose power of gamma radiation (GR) by lithotypes and stratigraphic affiliation of strata is shown in (fig. 1). A wide range of sedimentary rocks is found in the studied section – from terrigenous (argillites, siltstones, sandstones, sand breccia), coal layers, salt-bearing rocks – to carbonates (limestones, marl). Many transitional forms of lithotypes, which are almost impossible to uniquely identify on the log charts, are described during petrographic laboratory studies of the core. For the convenience and simplification of the construction of the lithological column based on the well-logging data, the individual lithological types of rocks named above, which certainly have individual characteristics in different layers, have been selected.

Fig. 1 clearly demonstrates the obvious difficulties in differentiating rocks by natural gamma-activity in the wells of Kinashivska structure: a) small differences in the average values of natural GR radioactivity between the main terrigenous rocks (except breccia) in the deposits of the Famennian stage of the Devonian; b) similarly, very similar GR characteristics between limestone and marl layers in D_3fm deposits; c) also close average values of GR between lithotypes of terrigenous rocks of the Lower Carboniferous, especially between argillites and siltstones; d) the differentiation of all observed lithological types significantly improves in the deposits of the Moscovian and Bashkirian tiers of the Middle Carboniferous. High values of natural gamma activity of sandstones, siltstones, especially Devonian and Lower Carboniferous, testify to the polymineral composition of the skeleton with a significant content of potassium feldspars and other minerals with an increased relative to the background content of radioactive elements. This composition of terrigenous rocks significantly affects the reduction of the differentiation of terrigenous rocks by the value of GR. High values of gamma activity in the interval of occurrence of probably salt-bearing rocks in the lower parts of the rocks indicate an increased content of potassium salt. At the same time, the increased values of the interval time of the longitudinal wave ΔT in relation to salt-bearing rocks are significantly higher than in pure salts, and the electrical resistivity according to lateral logging data (LL) is also not characteristic of pure evaporites (significantly lower). Increased values of NGR readings indicate the effect of chlorine on secondary gamma activity. The above features characterize the interval with isolated salt-bearing (probably) rocks as a layer in which there are sedimentary rocks with an increased content of evaporites. Such rocks are named "salt" in the lithological column and in the drawings in the article (fig. 1).

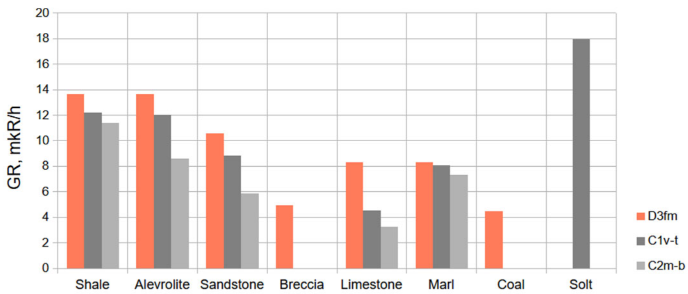

Fig. 1. Distribution of the average values of the natural radioactivity (GR) by lithotypes and stratigraphic affiliation of deposits in the well sections of Kinashivska structure

The above features of the average values distribution of natural radioactivity in the rocks of the Kinashivska structure from the Lower Devonian to the Middle Carboniferous clearly require the involvement of petrographic/geophysical parameters of a different nature in order to improve the efficiency of lithological decomposition of well sections. Fig. 2, 3 show the average values distributions of the intensity of the neutron gamma-log radioactivity NGR and the interval time of the longitudinal wave ΔT in the rocks of the structure. As can be seen, each method separately also has significant limitations regarding the effectiveness of such decomposition of the section into individual lithotypes.

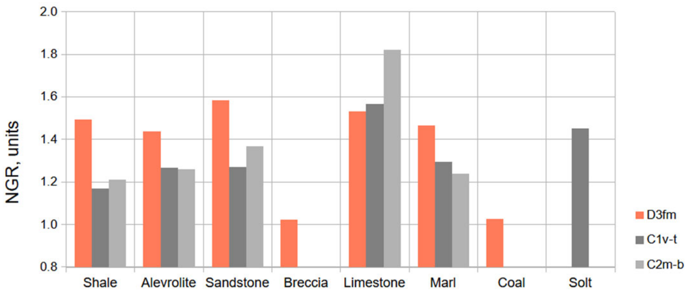

Fig. 2. Distribution of the average values of the intensity of the neutron gamma-log radioactivity NGR by lithotypes and stratigraphic affiliation of deposits in the well sections of Kinashivska structure

It should be noted that there is a regular decrease in the average values of NGR in the same lithological types of terrigenous rocks in the direction from old to younger deposits. Two factors are manifested here: an increase in the content of the clay component in the Carboniferous sandstones on the one hand (leads to a decrease in NGR readings), and an increase in the porosity of the sandstones of the Moscovian and Bashkirian layers (as it should be – increased readings of ΔT on the acoustic logging curves).

Coal layers stand out in contrast: minimal readings on GR curves (fig. 1), NGR curves (influence of density effect – low density) (fig. 2), increased values of ΔT.

In general, it should be noted that only certain types of rocks stand out quite contrastingly according to the complex of geophysical features. These are coal layers, salt-bearing rocks, pure compacted limestones. Other rocks have close values, which creates significant problems in the lithological decomposition of complex section. On the Kinashivska structure, special difficulties arise during the decomposition of well sections according to the data of well logging in the intervals represented by rocks of Devonian age (fig. 4, 5).

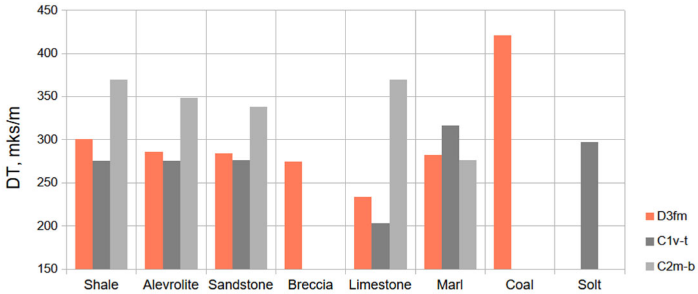

Fig. 3. Distribution of the average values of the interval time of the longitudinal wave ΔT by lithotypes and stratigraphic affiliation of deposits in the well sections of Kinashivska structure

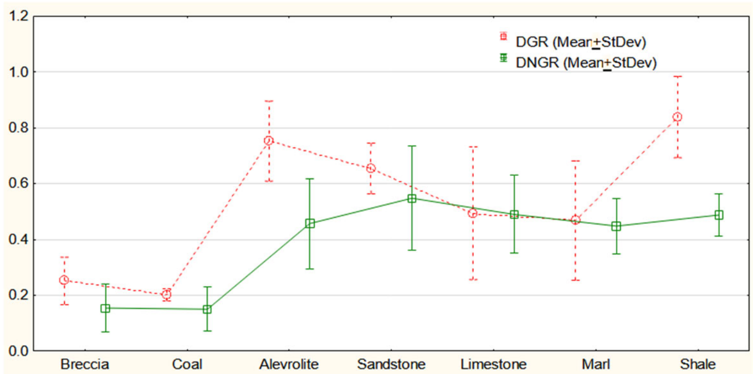

Fig. 4. Distributions of the characteristic values of the double difference parameters GR and NGR (DGR, DNGR) within ± their standard deviations (+ StDev) relative to the mean values by lithological types of rocks of the Famennian stage of the Kinashivska structure

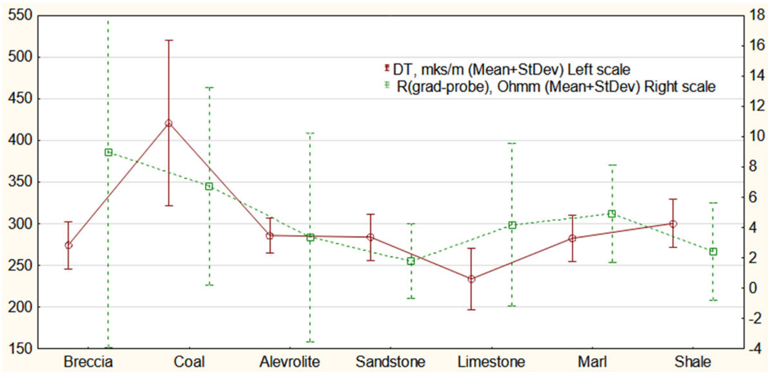

Fig. 5. Distributions of the characteristic values of the interval time of the longitudinal wave ΔT (DT) and the electrical resistivity of the gradient-probe (L= 4 m) within ± their standard deviations (+ StDev) relative to the mean values by lithological types of rocks of the Famennian stage of the Kinashivska structure

Fig. 4, 5 show the main statistical characteristics of the distributions of four geophysical parameters for all selected lithological types of rocks. It should be noted that these parameters are the main parameters used in the lithological decomposition of formations. Their peculiarity is that the factor of lithology significantly affects the readings of their logging methods, GR, NGR, sonic log, resistivity. All the parameters, presented here, have a different physical nature, which helps to conduct lithological diagnostics of rocks as efficiently as possible, taking into account different physical properties of deposits. It is clearly visible that the crossing of distributions within even ± one standard deviation (StDev) of the values is quite significant for most of the main lithological groups. This primarily concerns argillites, siltstones, sandstones and marls. According to the data of petrographic and petrophysical studies of the core material, the reservoir properties are characteristic of sandstones, siltstones and limestones in the well sections of the Kinashivska structure. Layers of limestones in well sections have a wide range of variability of porosity, which is due to different facies conditions of carbonate formation. However, the main reservoirs of the oil-saturated part of the section (according to the test data) are sandstones and siltstones.

Results

Actually, all the above-mentioned aspects of the use of these logging methods were lauded as a basis for the lithological decomposition of the section. In fig. 6, 7 there are tablets of logging diagrams from sections of one of the wells of Kinashivska structure with the interpretational results.

As noted, the construction of the lithological column was initially performed in a classic way – manually, taking into account all geological, geophysical, and core information (the left lithological column Lithology (start) in fig. 6, 7) based on the well-known domestic system GeoPoisk. Different areas of the section with a mixed lithological composition – terrigenous, carbonate, coal and salt-bearing rocks – were chosen for the demonstration. Of course, subjective, sometimes erroneous (or ambiguous) decisions of the petrophysicist can take place in a well section that is very difficult to interpret. To check the results of the interpretation in order to reduce random errors in individual layers, the procedure of creating "images" or interpretive models "logging-lithology" using the technology of artificial neural networks (ANN) was used. In our case, the popular Statistica-12 program, which has the Automated Neural Networks module, was used as an auxiliary. This program was chosen because it uses proven, repeatedly tested algorithms for creating ANNs, the description of which is given in the reference information for this program. The architecture of MLP – multilayer perceptron neural network was chosen as the basis for training.

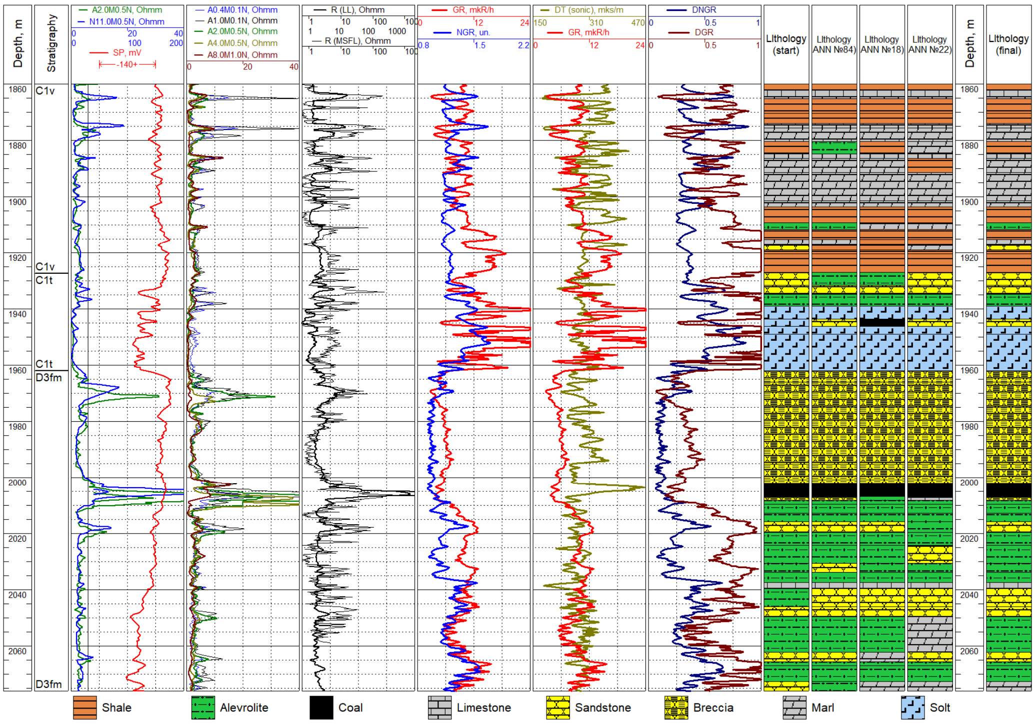

Fig. 6. Results of the refinement of the qualitative interpretation of the data of a typical well-logging complex for the purpose of lithological decomposition of the Kinashivska structure well section using neural network technology (D_3fm, C_1t, C_1v strata)

Multilayer perceptrons (MLP) is perhaps the most popular network architecture in use today, originally due to Rumelhart and McClelland (1986) and discussed at length in most neural network textbooks (Bishop, 1995). Each neuron performs a weighted sum of its inputs and passes it through a transfer function f to produce their output. For each neural layer in an MLP network, there is also a bias term. A bias is a neuron in which its activation function is permanently set to 1. Just as like other neurons, a bias connects to the neurons in the layer above via a weight, which is often called threshold. The neurons and biases are arranged in a layered feedforward topology. The network thus has a simple interpretation as a form of input-output model, with the weights and thresholds as the free (adjustable) parameters of the model. Such networks can model functions of almost arbitrary complexity with the number of layers and the number of units in each layer determining the function complexity. Important issues in Multilayer Perceptrons design include specification of the number of hidden layers and the number of units in these layers (Bishop, 1995). Other aspects include the choice of activation functions and training methods (Statistica. Electronic manual).

More detailed information about neural network modeling algorithms, in particular MLP, can be found in special literature. We used this technology precisely because it allows creating complex model relationships between quantitative and qualitative parameters, and dependencies can have discontinuous-nonlinear multivariate relationships. The following parameters were used as input continuous numerical data: electrical resistivity (LL method), GR data, values of the double difference parameters GR and NGR (DGR, DNGR), interval time of the longitudinal wave of the sonic method – ΔT (DT). The stratigraphic affiliation of the rocks was also used as input data. The initial information was the result of the previous manual lithological dissection of the section. After multiple repetitions of modeling neural networks in the Statistica program, an ensemble of 3 ANNs of the MLP type (12–10–8 architecture) was selected with a verification efficiency of at least 81 % (ANN №18 – 87 %; ANN №22 – 81 %; ANN №84 – 87 %). Fig. 6, 7 show lithological columns synthesized by corresponding ANNs. The effectiveness of the segmentation, i.e. the comparison of the simulated lithological types of rocks of the ANN with the initial ones performed by us, is clearly demonstrated in the tab. 1 (one network, No.84, is chosen as an example).

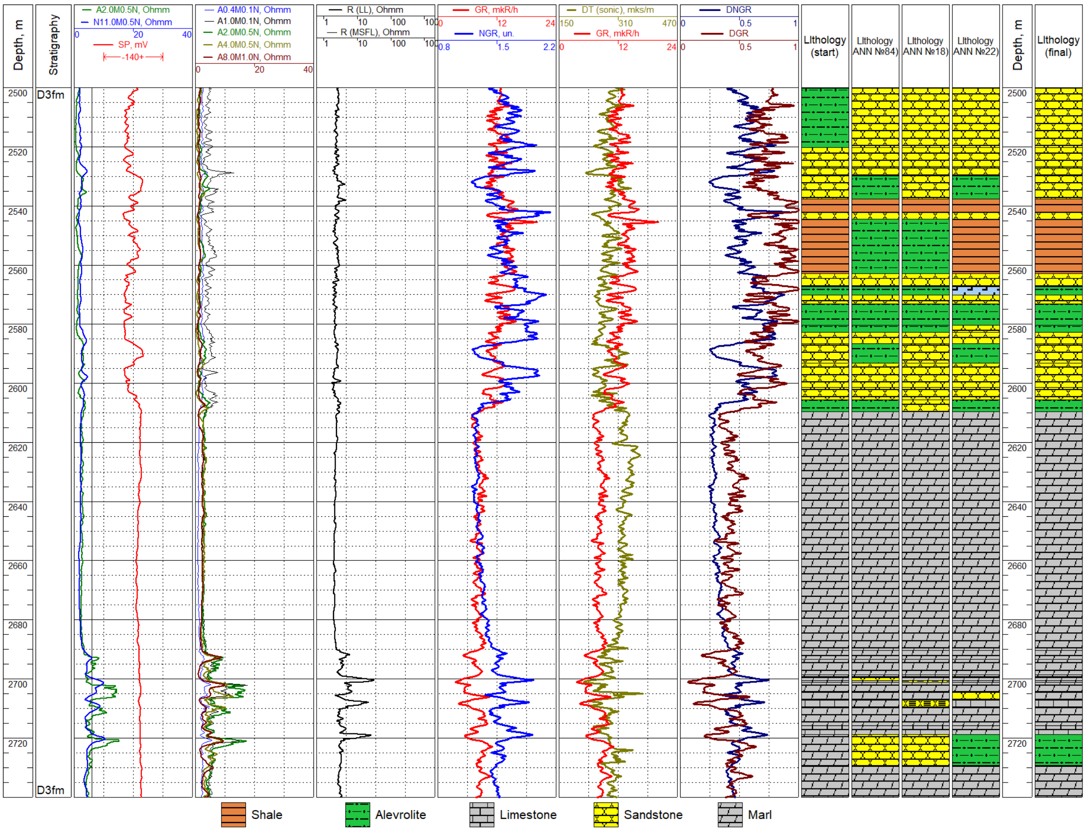

Fig. 7. Results of the refinement of the qualitative interpretation of the data of a typical well-logging complex for the purpose of lithological decomposition of the Kinashivska structure well section using neural network technology (famennian stage D_3fm)

Table 1

Table of the efficiency of lithological dissection, implemented by ANN No.84 in comparison with the initial (manual) dissection of the strata (efficiency 87%)

Predicted (ANN)	Shale	Alevrolite	Sandstone	Breccia	Limestone	Marl	Coal	Solt
84.MLP 12-10-8-Alevrolite	4	41	10	0	0	1	0	0
84.MLP 12-10-8-Breccia	0	0	0	7	0	0	0	0
84.MLP 12-10-8-Coal	0	0	1	0	0	0	3	0
84.MLP 12-10-8-Limestone	0	0	0	0	24	1	0	0
84.MLP 12-10-8-Marl	1	0	1	0	3	20	0	0
84.MLP 12-10-8-Sandstone	0	6	43	0	2	5	0	1
84.MLP 12-10-8-Shale	36	1	1	0	0	0	0	0
84.MLP 12-10-8-Solt	0	0	0	0	0	0	0	3

All implementations of lithological segmentation with the help of ANN testify to the high efficiency of the technology. Moreover, in many cases of discrepant results in individual layers with the initial (manual) dissection performed by a person, neural networks showed more correct results. That is, subjective errors in interpretation were eliminated as much as possible. After analyzing the modeling results, comparing the initial data regarding the assignment of lithological affiliation to individual layers (a total of 218 layers were selected in the section), the final column of the results of the lithological segmentation of the strata was formed. The results of ANN modeling were taken into account as much as possible. Assignment of a specific layer lithotype is based on the results of the maximum correspondence to the same results in 4 columns.

Discussion and conclusions

The specific example of lithological dissection of a very complex (and difficult) strata by geophysical characteristics (Upper Devonian, Lower and Middle Carboniferous deposits) shows that the use of neural network technologies allows solving several problems. Firstly, the number of errors of the interpreter when assigning a specific lithological type to individual layers is significantly reduced – by comparing the results of one's own manual interpretation with the results simulated by an ensemble of artificial neural networks in a specific well. Secondly, there is an opportunity to perform the task of lithological dissection in other wells of this area as objectively as possible by using ready-made models of artificial neural networks (ANN). At the same time, the main function of the interpreter is the "creative" analysis of the results of the dissection of the well strata based on ANN. The approach presented in the article to increase the reliability of the qualitative interpretation of logging data on the example of a rather problematic section of Upper Devonian, Lower and Middle Carboniferous rocks can be enhanced by the improvement of the ANN model by further training it on an array of neural model dissection with an efficiency higher than the given specific verification threshold.

Authors' contribution: Ivan Karpenko – general concept of research, geological basis of the research conducted, writing the initial version (draft) of the article, conclusion; Serhii Levoniuk – geological data interpretation, formation analysis, making significant changes and additions to the article; Oleksiy Karpenko – statistical processing and data filtering, neural network modeling, making significant changes and additions to the article; Andrii Loktiev – data validation.

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ЗАСТОСУВАННЯ НЕЙРОНОМЕРЕЖЕВИХ ТЕХНОЛОГІЙ ПРИ ЛІТОЛОГО-ФАЦІАЛЬНОМУ РОЗЧЛЕНУВАННІ ВІДКЛАДІВ ДЕВОНУ І КАРБОНУ ЗА ГЕОЛОГО-ГЕОФІЗИЧНИМИ ДАНИМИ (ПІВНІЧНО-ЗАХІДНА ЧАСТИНА ДНІПРОВСЬКО-ДОНЕЦЬКОЇ ЗАПАДИНИ)

Вступ. ***Приріст запасів вуглеводнів у старих нафтогазовидобувних регіонах значною мірою може бути реалізований за рахунок переінтерпретації геолого-геофізичних даних на старому фонді свердловин. Як у межах існуючих родовищ, так і на площах, які за певними обставинами були у свій час оцінені як неперспективні. На даному етапі геологорозвідувальних робіт виконується значна робота з переінтерпретації даних геофізичних досліджень у пропущених інтервалах свердловин старого фонду, у тому числі – пошукових і розвідувальних свердловин. Подібні роботи виконуються на глибокі горизонти (девон), а також на відклади мезозою, які в минулому столітті не були першочерговими в плані перспективності на багатьох площах. Наявний геолого-геофізичний матеріал свідчить про значні труднощі щодо правильної ідентифікації пластів у межах указаних стратонів.***

Методи. ***Проаналізовано результати геофізичних, петрографічних і петрофізичних досліджень по відкладах, що вивчалися. Застосовано методи статистичного аналізу з метою встановлення можливості використання методів розпізнавання образів для літолого-фаціального розчленування розрізів свердловин за даними геофізичних досліджень.***

Результати. ***Завдяки використанню технології нейронних мереж перевірено надійність традиційної геологічної інтерпретації даних геофізичних досліджень свердловин. Підвищено достовірність встановлення літолого-фаціальної належності окремих пластів у розрізах свердловин верхнього девону, нижнього і середнього карбону – шляхом застосування ансамблю розрахованих нейронних мереж. Запропоновано оригінальний підхід щодо реалізації технології нейронних мереж при інтерпретації геолого-геофізичних даних.***

Висновки. ***Розглянуто геофізичні характеристики потенційно перспективних горизонтів, які раніше пропускались. Вказано завдання, які слід вирішувати, а також шляхи підвищення достовірності геологічної інтерпретації даних промислової геофізики в різновікових товщах. Зокрема розглянуто можливість і доцільність використання машинного навчання на основі нейрономережевих технологій.***

Ключові слова: ***горизонт, колектор, літологія, девон, нейронні мережі, геофізичні дослідження свердловин.***

Автори заявляють про відсутність конфлікту інтересів. Спонсори не брали участі в розробленні дослідження; у зборі, аналізі чи інтерпретації даних; у написанні рукопису; в рішенні про публікацію результатів.

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