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ON THE CONNECTION OF THE HYDROCARBONS PRESENCE AND EPIGENETIC SULFIDES IN THE SOUTH OF YAKUTIA

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Currently the prospecting and exploration for hydrocarbons continues to be one of the most promising directions in geological exploration. The use of pulsed electrical exploration technique for prospecting of hydrocarbon reservoirs in combination with seismic prospecting makes it possible to significantly increase the probability of discovering the deposit, thereby lowering the likelihood of drilling an exploratory well that will not give an inflow. Also with the help of seismic exploration it is quite difficult to identify non-structural deposits. One of the reasons for the occurrence of anomalies caused by induced polarization (IP) is the epigenetic pyrite formed above the deposit as a result of the formation of a geochemical barrier at the boundary of the penetration of atmospheric oxygen.

The presence of abnormally high values of induced polarization in the upper part of the section that differed from the background value within one of the deposits located at the southern part of Yakutia was manifested in the results of a one-dimensional inversion of the data from the electromagnetic sounding and induced polarization (EMS-IP) technology, performed within the polarizing horizontally layered model of the medium, in which the frequency dependence of the resistivity is described by the Cole-Cole formula. The idea of EMS-IP is to maximize the full use of information from transient processes induced by rectangular polarity pulses that are used in traditional DC methods. For the EMS-IP method, a high resolution and depth of study were obtained using the mean gradient setup.

The investigated anomaly of the induced polarization is present at a depth of about 150 m and is confined to the pyritized interval of intensely fractured rocks of the Jurassic deposits, which is confirmed by a core sample data selected from the exploration hydrogeological wells. The one-dimensional mass inversion of the data showed sensitivity to the layer with an abnormally high value of the IP. The discrepancy in the model containing the pyrite layer is much higher than in the model not containing the pyrite layer.

Key words: hydrocarbons, epigenetic pyrite, pulse electric exploration, Cole-Cole model, EMS-IP, induced polarization, grounded electric circuit

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Introduction. According to modern ideas, the migration of hydrocarbons above the oil deposit in the upper parts of the section influence the occurrence of significant physical and chemical changes. Secondary changes in mineralogical and physical properties of rocks are mostly quite contrasting in comparison with background values and appear at shallow depths of soil [5, 11]. The main purpose of the work is to justify the use of pulsed electrical prospecting with a grounded source and receiver for exploration of hydrocarbon deposits at the anomalous values of the induced polarization (IP) in the upper part of the section, due to the presence of epigenetic pyrite. In order to fulfill this task, there have been used different technologies such as the differential-normalized method of electrical exploration (DNEP) [4] and the method of electromagnetic sounding and induced polarization (EMS-IP) [2, 8], which allow to identify and single out these anomalies as a result of solving the inverse problem using horizontal stratified model with frequency-dependent electrical resistivity (ER). The reservoir itself, located at great depths, does not necessarily have a significant contrast in conductivity [9]. In combination with seismic prospecting and other non-seismic methods, this approach enhances the likelihood of having a reliable prediction for the presence of hydrocarbon deposits up to 80 %.

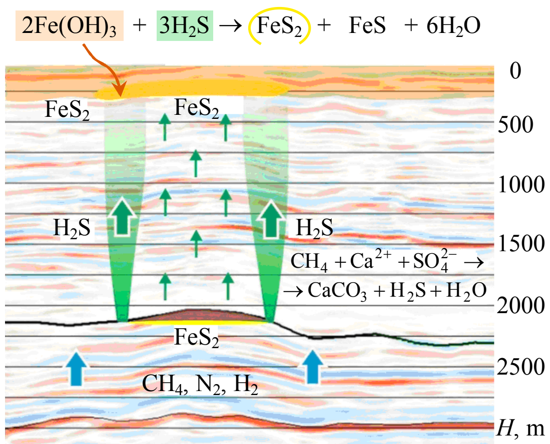

Fig.1. The scheme of advanced polarizability zones formation process above the hydrocarbon deposits

Justification of the existence of zones with advanced polarizability. The formation of zones with advanced polarizability located above hydrocarbon deposits is described by the following mechanism (Fig.1):

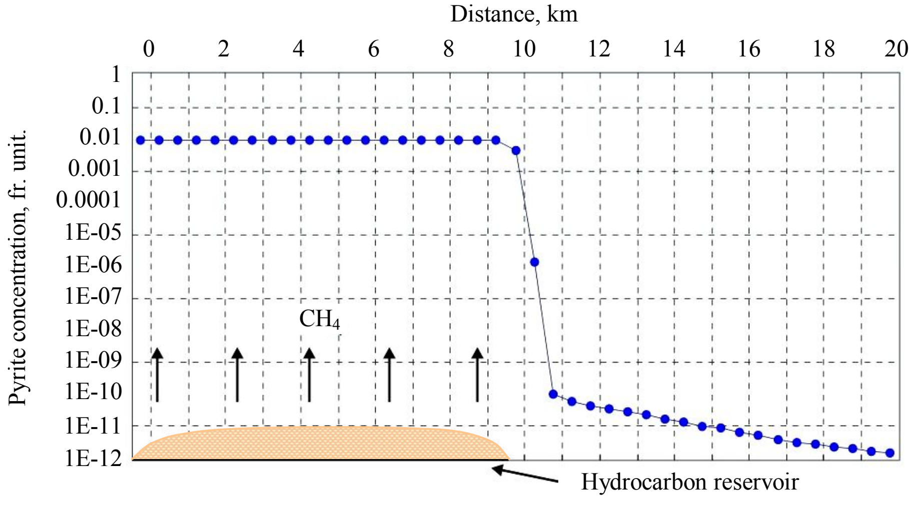

Fig.2. Theoretically calculated pyrite concentration for a simplified model of hydrocarbon reservoir [13]

1. The regional flow of insoluble gasses (*methane*, *nitrogen*, *hydrogen*), which is controlled by tectonically weakened zones, raises from the earth.

2. This flow captures ***hydrogen sulfide*** near the hydrocarbon reservoirs and raises up together with it.

3. At the level of the two main geochemical barriers – oil-water contact (OWC) and the upper regional confining bed – the epigenetic pyrite is formed due to the interaction of hydrogen sulphide, which is released in the course of chemical reactions caused by the presence of hydrocarbons and ferric oxide. In case of reservoir deforming process, the reductive conditions are replaced by oxidizing ones, which may lead to limonitization of pyrite over the previously existing deposit (Taranenko et al., 2001; Kudryavtseva, 2010; Nedolivko, 2010; etc.).

4. The pyrite-bearing rocks are distinguished by advanced polarizability in comparison to the background response of IP of enclosing sediment rock (Komarov, 1980).

Epigenetic (secondary) pyrite is formed due to the interaction of hydrogen sulfide migrating from the oil and gas deposit together with oxides, hydroxides and iron ions present in the upper part of the section [14].

The paper describes the results of calculating the pyrite concentration for an idealized oil reservoir model (Fig.2). It is shown that a column of altered rocks is formed over the deposit, which is characterized by the presence of pyritization in the region of the upper geochemical barrier. The increased concentration of pyrite, in turn, leads to the formation of anomalies of IP, which is considered as one of the prospecting indicators [10]. This approach explains the presence of an anomaly over the North-Gulyaevskoye field, taken as a standard during the test works of the DNEP in the Barents Sea. The seismic survey was conducted at this field and an exploration well was drilled, in which the pyrite concentration is known. The concentration was determined at 11 points, two maxima were observed – within the deposit and in the region of the upper geochemical barrier, at the boundary of the penetration of atmospheric oxygen. As a result of the inversion, there were created maps of the polarizability distribution at depth intervals of 350-450 m and of the resistivity in the layer from 2000 to 3000 m. The region of increased values of the ER corresponds to the position of the deposit in depth and in plan, and the anomaly of the IP values is related to the seal of carbonate complex, its contours correspond to the position of the OWC [7].

It has been empirically proved that the exploration conducted using the DNEP technology is efficient in different mining-geological conditions within the range of depth intervals from 100 to 5 km for prospecting the hydrocarbons in-shore and off-shore. That is why the application of similar technology of EMS-IP for exploration of hydrocarbons by abnormal IP values has good prospects.

The results of EMS-IP works at the southern part of Yakutia. In the course of work of exploration and assessment of groundwater within the boundaries of one of the hydrocarbon (HC) deposits in the south of Yakutia, there have been collected and summarized the data on hydrogeological wells, many of which had marks of pyrite intervals. In the general complex of geological, geophysical and hydrogeological methods, the EMS-IP technology was used for detailed area work for investigation of three drilling sites. A total of 544 sounding locations were recorded at 14 profiles with a total volume of 27.3 lineal kilometers with a step of 50 m (Fig.3).

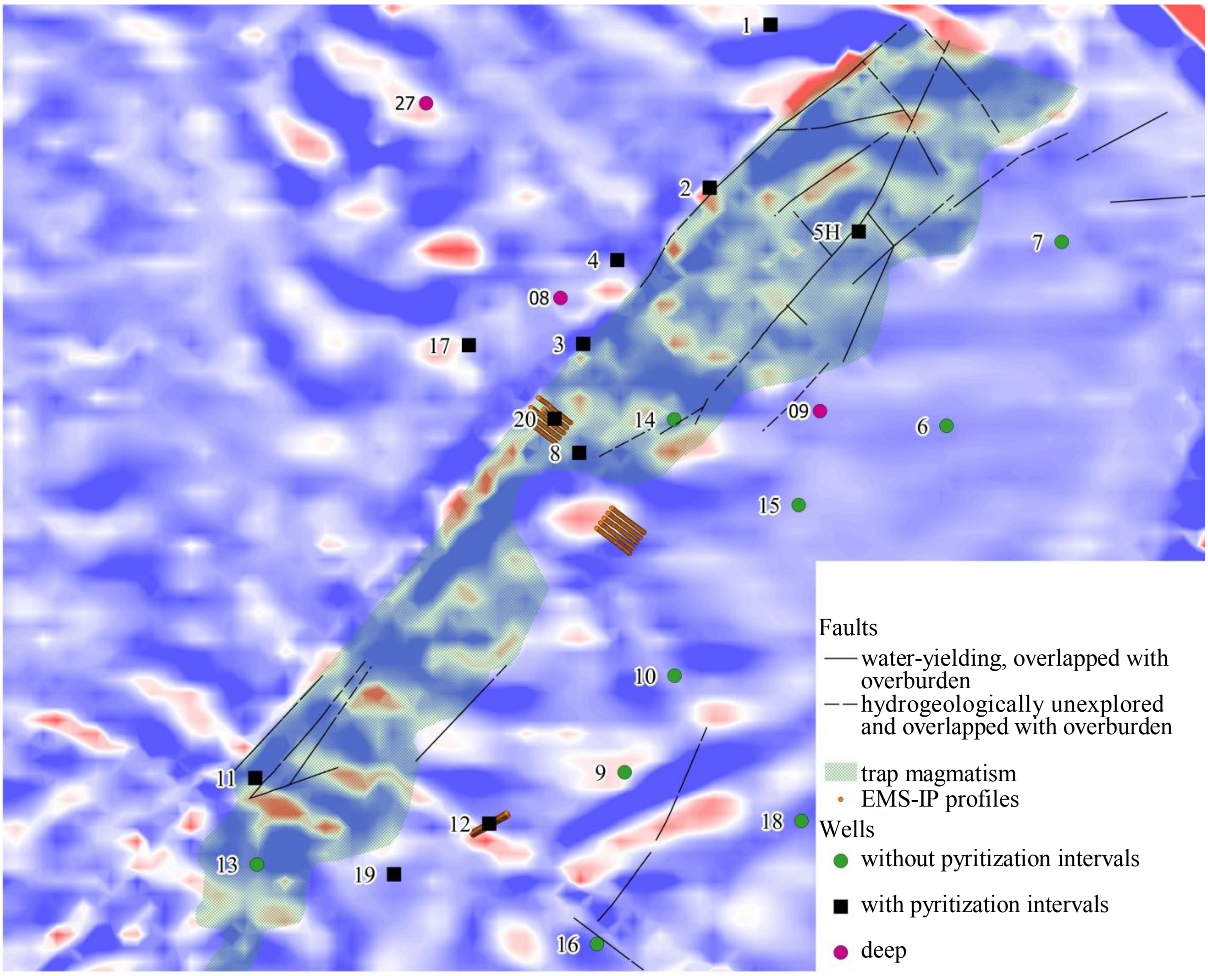

Fig.3. Scheme showing pyrite distribution intervals laid over the magnetic component map (*Mz*) at the depth of 990-1900 m

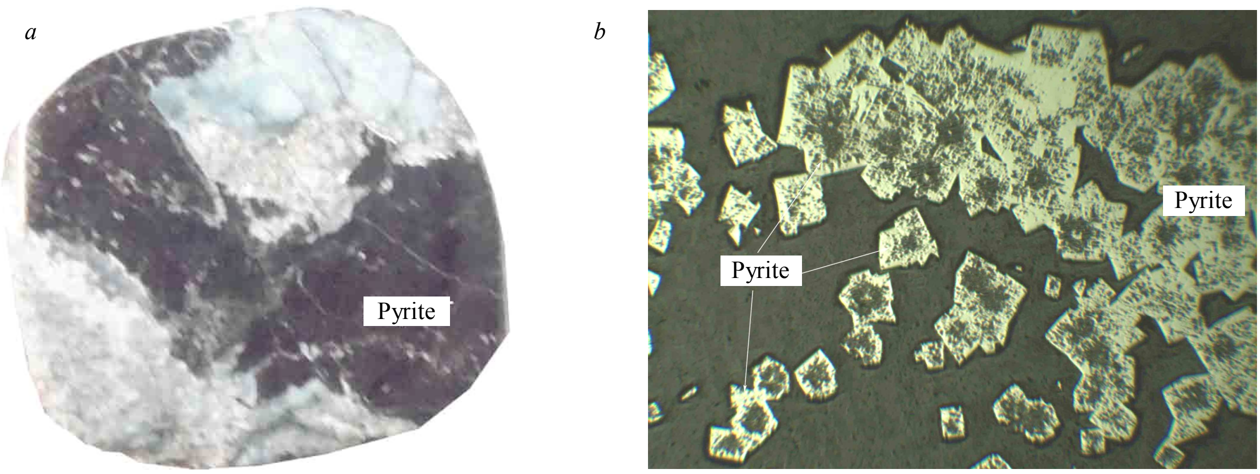

Fig.4. Polished hand specimen from core sample (*a*), that was taken at Tympuchikansky licensed field (Yakutia) at depth of 150 m near the deep-hole well, which produced oil at the depth of 1600 m, and a microscope (nicole II) picture (*b*) with the field of 2.6 mm. The edge zone of the concentric zonal structure is made of a stripe of spotted aggregates of spheroidized pyrite with thickness of 1-2 mm, which is transformed into scattered impregnation at the central part

The explored section 1 lies within the boundaries of trap magmatism development zone, which was identified by intense local magnetic field anomalies. Due to a combination of indicators a tectonically weakened, probably water-cut zone was identified, within which a borehole 20 was drilled [6].

A total of 20 exploration wells were drilled on the site, 11 of which include pyrite intervals, according to aeromagnetic survey data, ground-based electrical prospecting, hydrogeological, geochemical data. According to the data provided by deep drilling, hydrocarbons are widespread in the area of work widely, to a greater or lesser extent in terrigenous reservoirs, at a depth of about 1600 m, the presence of which, according to our assumptions, explains such a significant degree of pyritization. Twenty samples from the well were taken and sent to the Institute of Geochemistry n.a. A.P.Vinogradov of the SB RAS for analysis to determine the origin of pyrite (Fig.4).

Based on the results of the chemical analysis performed by the senior research fellow A.E.Budyak, the following conclusions are drawn. The analyzed samples are characterized by sulfide mineralization – from low sulfide to high degree. The only ore minerals are pyrite-marcasite and pyrite, with the predominance of the latter. In occasional particles sphene, rutile, anatase and magnetite were registered. The rocks are slightly crumpled and fractured. Pyrite precipitates are characterized by banded-vein-like, massive, interspersed, and mesh textures. The characteristic structures of the seggregations are fine- and micro-grained, lamellar, cryptocrystalline, spherolitic, filiform, and limy; for pyrite-marcasite – helium, colloform, concentric-zonal, and microstrip. The characteristic feature is the presence of spheroidized pyrite, most likely, having a metasomatic origin.

The second stage of the research consisted in performing a one-dimensional inversion of data in order to estimate the contribution of the layer containing pyrite to the convergence of the theoretical and practical curves. To verify this assumption, an inversion of the transition characteristics is performed on the basis of the model of a horizontally layered polarizable medium. The inversion of the EMS-IP curves was performed within the framework of a one-dimensional polarizing model. The calculations were carried out by using the frequency-dependent ER complex value. To describe the frequency dependence of the ER value, the Cole-Cole formula was used, the application of which makes it possible to describe the majority of experimental dispersion dependencies in rocks. For a complex resistivity, it has the following form

$$\rho(\omega) = \rho_0 \left\{ 1 - \eta \left[1 - \frac{1}{1 + (i\omega\tau)^c} \right] \right\},$$

where ρ_0 – electric resistivity, Ohm·m; η – polarizability, $0 \le \eta \le 1$; i – «unit imaginary number»; τ – relaxation time, s; c – power index, $0 < c \le 1$ [3, 9].

Geoelectric models were selected using the «Mars1D» software [5]. To do this, a layer was added to the geoelectrical model already selected for its electrical properties corresponding to pyrite.

Based on the results of the simulation process, the sections for ER ρ and polarizability η were built up to a depth of 1 km (Fig.5). A red triangle shows a well 20, for which a pyritization interval was described using the core sample and which was used as a reference for specifying a polarizable layer. The depth of the roof of this layer according to the survey data varies from 50 to 250 m. In addition to the anomalously high values of polarizability and relaxation time, against a background of enclosing sedimentary rocks, this layer is distinguished by lower values of the ER. The tectonically weakened low-resistivity zone can be traced down the section in the dense high-resistivity rocks of the Litvintsevskaya bed series, while the southeastern block is shifted upwards by about 30 m from the north-west part of the deposit. In the relatively permeable rocks, it is necessary to take into account the influence of the fault, since if the fault is in the immediate vicinity of the deposit, hydrogen sulfide migrates along it, expanding the anomaly of the IP [4, 10, 13].

Thus, it should be concluded that in the investigated area, the anomalous polarizability of the upper part of the section, represented by intensely fractured rocks of the Jurassic deposits, is associated with impregnated sulfide mineralization. This assumption agrees with the results presented in paper [12], where it was shown that the values of τ from 0.02 to 0.15 s and $c = 0.5$ are observed at pyrite concentrations in sedimentary rocks of about 2-5 %.

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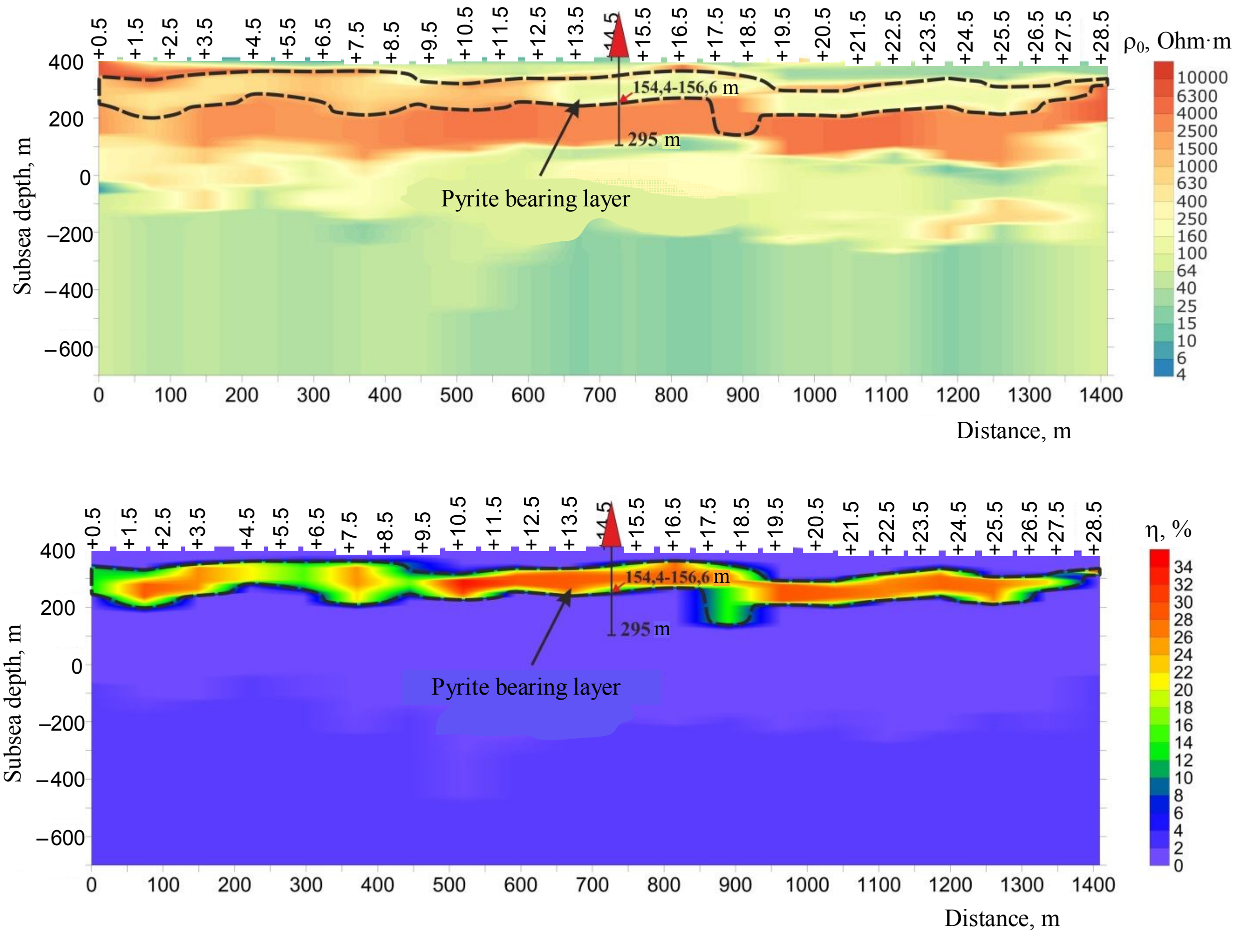

Fig.5. Geoelectric section of ER and polarizability along the profile 4

In order to make sure that the presence of a layer of h thickness with anomalously high indicators of the IP affects the convergence of theoretical and practical curves, a one-dimensional selection of the model with and without this layer was made (see the table). The results of the simulation are shown in Figs.6 and 7.

Geoelectric parameters of a model with and without pyrite layer

Layer nr.	A model with pyrite layer					A model without pyrite layer				
	ρ, Ohm·m	η, %	τ, s	*c*	*h*, m	ρ, Ohm·m	η, %	τ, s	*c*	*h*, m
1	14.5	0.01	0.00001	0.9	16.4	14.5	0.01	0.00001	0.9	16.4
2	201.3	0.01	0.00001	0.9	9.6	201.3	0.01	0.00001	0.9	9.6
3	2556	0.01	0.00001	0.9	15.1	2556	0.01	0.00001	0.9	15.1
4	2501.3	0.01	0.00001	0.9	20.3	2501.3	0.01	0.00001	0.9	20.3
5	100.5	24.9	50.15	0.49	148.1	100.5	0.01	0.1	0.5	148.1
6	4015	0.01	0.1	0.5	102	4015	0.01	0.1	0.5	102
7	86.5	0.01	0.1	0.5	53	86.5	0.01	0.1	0.5	63
8	61.6	0	0.1	0.5	147.2	61.6	0	0.1	0.5	147.2
9	33.8	0	0.1	0.5	102.2	33.8	0	0.1	0.5	102.2
10	20.5	1	0.01	0.5	–	20.5	1	0.01	0.5	–

Figure 6 shows an example of grading at one point. At this station, the decrease in convergence occurs at 9.3 %. As a result of one-dimensional modeling, a certain dependence was established. The decrease of convergence is observed on the whole profile, if we exclude from the model the

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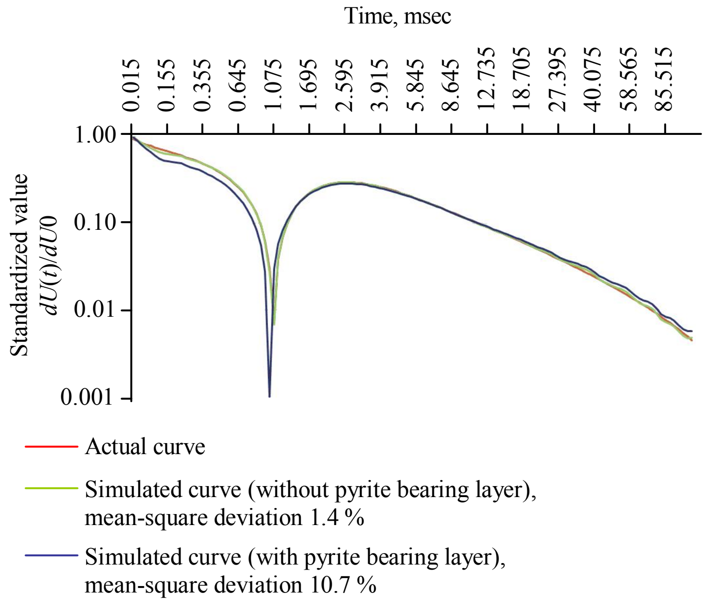

Fig.6. Convergence curves

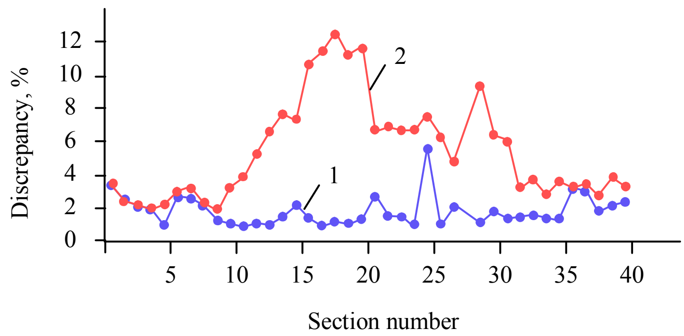

Fig.7. Simulated curves convergence graph in a model with (1) and without (2) pyrite bearing layer

layer including pyrite. For clear visual illustration of the selection results, a graph showing the value of the discrepancy between the theoretical and practical curves at each station profile for both models is presented (Fig.7).

As it is seen from the diagram that the value of the discrepancy is different for the two models. The convergence of the curves in the model including the layer containing pyrite is relatively higher than in the model without pyrite. The difference of the discrepancy varies from the first percent to the first ten percent.

Conclusions. The material for wells containing intervals of pyritization was collected and analyzed. As a result of the analysis of the core sample, it is established that impregnated pyrite is of heterogeneous type, and it could be probably related to the presence of a hydrocarbon deposit. To justify this relationship, it is required to perform additional laboratory studies using core samples and oil from the target horizon.

By using mass inversion performed within the framework of a one-dimensional polarizing model, it has been shown a sensitivity to a presence of a layer with an abnormally high IP containing epigenetic pyrite. The discrepancy in the model including the polarizable layer is substantially higher, which makes it possible to use this feature as an exploration technique for identifying the position of the hydrocarbon reservoir in the plan.

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