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Complex Exploration of Hydrocarbon Deposits on Arctic Shelf with Seismic, Electric Prospection and Electrochemical Methods

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ABSTRACT

Article describes basic principles of seismic, electric prospection and electrochemical data complexation, received on the same research objects. The goal of our exploration works is complex exploration of hydrocarbon deposits on arctic shelf. Complex is based on ion-selective electrodes for detection of heavy metal complex anomalies in sea water – indicators, which lies in sedimentary cover, oil deposits, in gas and gas condensate. Measurements are completed by sea bottom stations in profiling mode. Provided descriptions of new method of seismic, electric prospection and electrochemical data complexation while interpreting results of seismic research with reflected waves method and electric prospecting by electrical resistance and / or induced polarization method and an electrochemical method. Theoretical and methodological basics of geophysics data interpretation in the implementation of hydrocarbon prospecting are presented. Complex field works features that increases reliability of deposit availability forecast are described.

KEYWORDS
Hydrocarbon deposits, seismic, electric prospection and electrochemical methods, ion-selective electrodes, profiling, Kara sea

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Introduction

Basic principles of complex interpretation are based on relation of elements of geological structure and anomalies of geophysics fields on the one side and on relations between physical properties of rock, oil and gas on the other side, and with qualitative connection with corresponding anomalies. This relation is different for different methods, and the higher this difference, the better interpretation will be. According to the information theory it provides more information from combination of methods, rather than from using methods separately. The final goal of exploration works is certain object discovery, i.e. based on the (anomaly) signal detection theory with the interference on the background, this task leads to revelation of anomaly with a set shape

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(theoretically computed, from experience, measured on the standard objects, etc.) with the interference on the background, to which all known in this theory exploration efficiency criteria can be applied. Notice, as it is common in geophysics, anomalies with a set shape and intensities are calculated based on physical properties of rocks and ores, including water, oil and gas.

Materials and Methods

Development of theoretical and methodical basic of interpretation

Availability of functional or/and correlational link between speed (or/and density) and electric properties of rock , oil and gas, including their electrochemical properties allows us to make correlational methods of interpretation based on comparison of experimental data (speed, structural horizons – surfaces, conductivity, polarizability, electrochemical anomalies and other properties) or/and based on the results of preliminary interpretation of two and more geophysics methods with the usage of one method's results in interpreting another method or vice versa – methods of synchronous or/and asynchronous mutual statistical interpretation, including iterative.

In physical complex interpretation two main methods are mainly used. The first one is usage of pattern recognition algorithms and theory, which used if standard object (hydrocarbon deposits) is available, in which "tested" object are compared to "standard", the second one uses different correlational methods in different modifications.

Because seismic exploration, which used for exploration and research of potentially containing oil and gas structures of shelf, is the main method of geophysics, it is not always possible to identify promising deposits in deposit area and make conclusion about hydrocarbon raw type. In this case it will be expedient to use additional geophysics methods, which can in one way or another make a conclusion. This additional methods include electrochemical profiling, performed in movement of ship or at sea bottom stations stops in continuous recording mode.

Over the years VNIIOkeangeologia in partnership with Murmansk Arctic Geological Expedition (MAGE) and St. Petersburg Center for Innovative Technologies (CIT) puts into practice electrochemical modification of electrical research for regional and exploration works, oriented on search on oil and gas deposits.

Perspectives of this works substantiated theoretically (Berezkin, 1978). It is well-known theory occurrence of jet dispersion halos over the sources of heavy metals microelements revenue to the overlying medium. Electrochemical observation of the ship movements over the profiles have number of advantages comparing to the other methods.

This advantages includes: indication of seismic (structural) and electrical research anomalies, technical simplicity of measurements, relatively low expenses, simplicity of acquired data interpretation, spatial and temporal compatibility with other geophysics observations, performed on the same expedition ship.

In the dry land conditions rather massive amount of electrochemical works of that type ware performed. The results of this works allowed to determine oil

and gas and "empty" structures, to clarify the genesis, morphology and type of deposits among the structures, identified by seismic exploration.

Based on drilling, geotechnical, seismic and gravimetric works, performed in the Baltic Sea and Arctic seas, it was proofed, that in sediments, which overlying gas and gas condensate fields, basic fractured weakened zones are located over the central part of the deposit. The oil fields are characterized by connection of such zones to peripheral parts of the fields. In turn it determines the location of electrochemical anomaly. Applied technology allows dividing of deposits in the types of gas and gas hydrate, gas condensate and oil (Snopova, Anohin &Holmyanskii, 2016).

A result of the works on a number of hydrocarbon deposits of Barents-Kara region confirms effectiveness of the method and expediency of its use in exploration. Result of electrochemical profiling of Shtokman, Medyn, Polar, Rusanivsky depostits are on the pictures below.

The Shtokman gas condensate deposit is located in the central part of Barents Sea. Discovered in 1988. Sea depth in deposit area varies from 279 to 380 meters. Seven wells drilled on the deposit. In terrigenous deposit of the Middle Jurassic identified three gas-condensate deposits.

On the fig. 1 well-marked electrochemical anomalies over the Shtokman deposit are clearly visible by Cu, Pb and Cd ions.

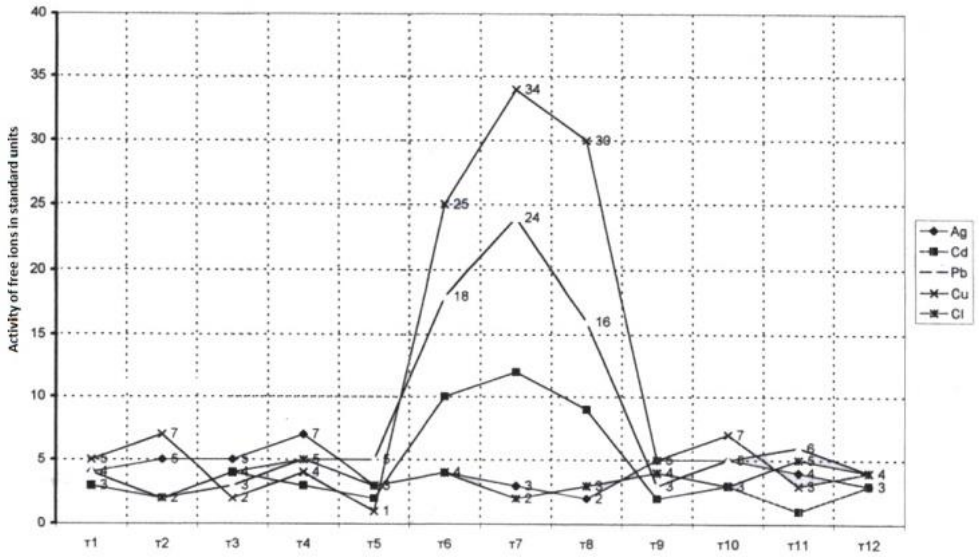

Figure 1. Electrochemical anomalies over The Shtokman gas condensate deposit (Holmyanskii & Vladimirov, 2002)

In the figures it can be seen well defined electrochemical anomalies - by Cu (Figure 2) ions, Pb and S (Figures 3 and 4).

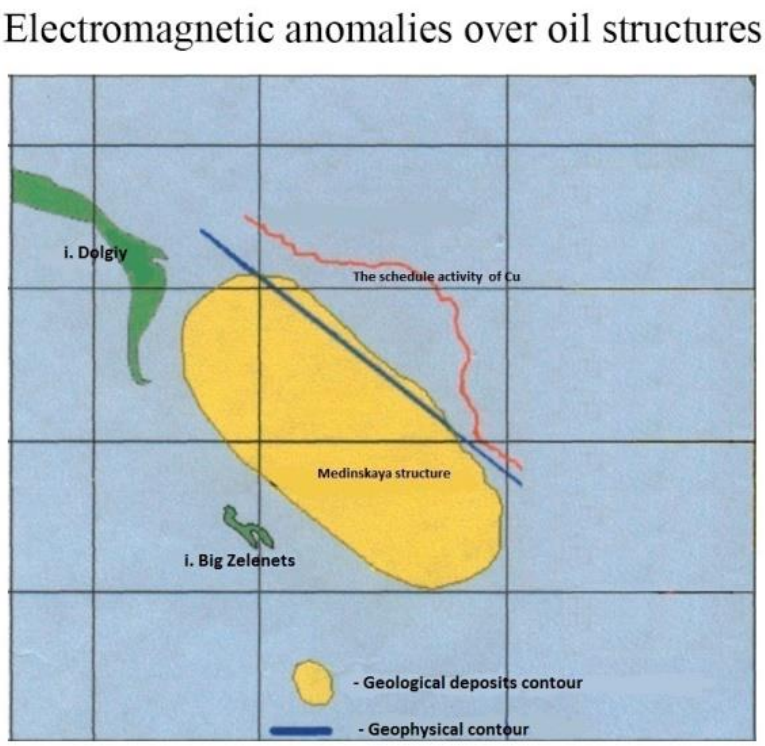

Figure 2. Electrochemical copper anomaly over the Medyn oil structure

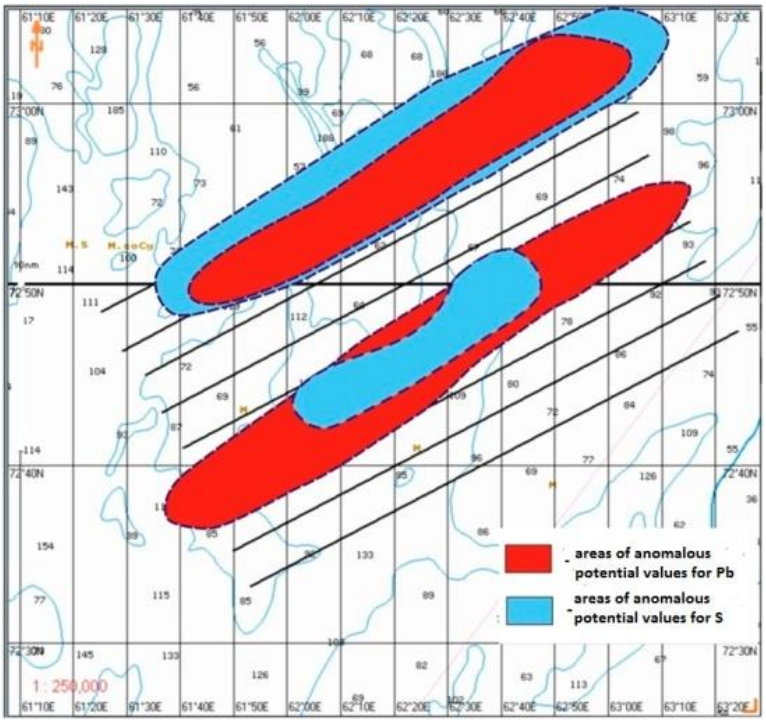

Figure 3. Detailed anomalous zones on landfill 1, Voroninskaya structure (Holmyanskii & Vladimirov, 2002)

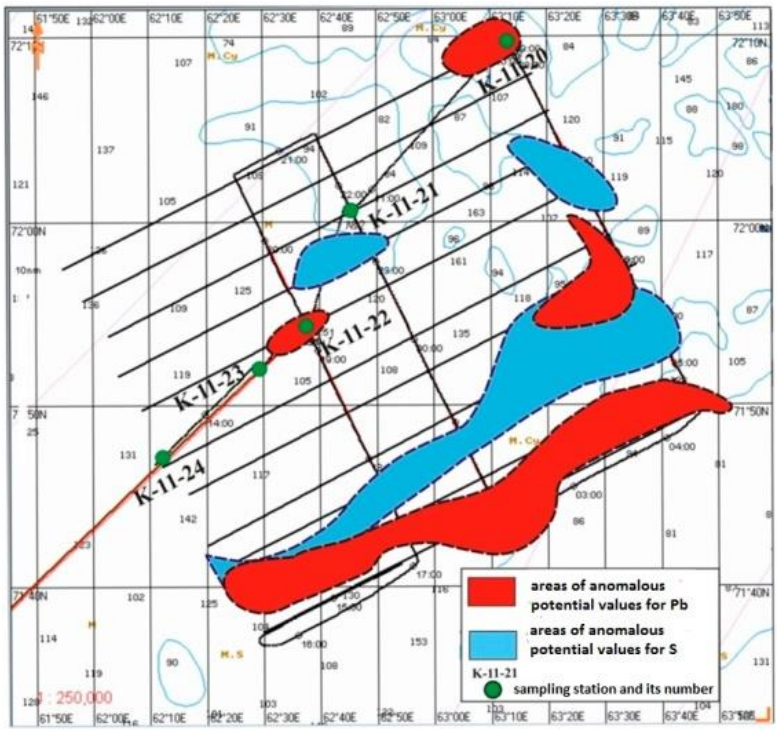

Figure 4. Detailed anomalous zones on landfill 2, Obruckevskaya structure (Holmyanskii & Vladimirov, 2002)

Deep-seated deposits on the shelf are often accompanied with accumulation of gas hydrates in the bottom layers of marine sediments. Gas hydrates and gas accumulations in these layers are clearly visible on seismic acoustic recording by gas bubbles.

Method of seismic, electric prospecting and electrochemistry complexification (interpretation)

Method of seismic prospecting complexification by reflected waves and electrical prospecting by resistance and caused polarization while exploring hydrocarbons on shelf, equipped with seismic sensors (see bottom stations) by $\Delta x \Delta y$ network (where $\Delta x1$=50m, $\Delta y1$ – distance between profiles) and by, for example, $\Delta x2$=500m, $\Delta y1 = \Delta y2$ network, electric prospecting sources of actuation, located on profile and/or in the area in a single filing system: seismic (airgun) and electric prospecting (dipole), working consistently for a given cycle time characterized by deposits detection of hydrocarbons on the results of seismic observations structural constructions are produced.

On seismic structures possible deposit location places are explored, and by geological and/or theoretical (sated) variability of deposit cuts variants are build, which will work as basis for the theoretical fields calculation (resistivity anomalies and polarizability, and others.), from which those anomalies are selected, that which have a maximum similarity with those obtained by the electrical prospecting experimental anomalies, and the most relevant cut of this

similarity is considered as the most reliable. According to this cut possible deposit contour and ambiguity of deposit position contour are built on changes in seismic cut options.

Electrochemical exploration of marine oil and gas deposits method

In this method over the profile of assumed deposit or perspective area in the water continuous measurement of heavy metals concentration with of ion-selective electrodes, which are selectively responsive to heavy metal ions of copper (Cu), lead (Pb) and cadmium (Cd), is conducted. This methods distinctive feature is additional measurements of Ag and Hg concentration, anomalies in concentrations of heavy metals at concentrations exceeding the oscillation amplitude of the background are isolated, if anomalies silver (Ag) and mercury (Hg) are missing, then by the shape and location of anomalies Cu, Pb, и Cd deposit contour is made, otherwise introducing amendments to the concentration of Cu, Pb, and Cd (excluding the effect of Ag and / or Hg from experimental dependences), isolating anomaly is corrected by Cu, Pb, и Cd values and by the form and location of the anomaly contour of deposit is made.

Complex field works specifics

Based on the results of exploration works, it was considered to be expedient to move to industrial works on Arctic shelf: from searching (seismic prospecting, electrical prospecting and electrochemistry on network 1/5(20)) to exploration (seismic prospecting, electrical prospecting/electrochemistry, seismic acoustic on exploration network). Seismic and electrical prospecting network can remain from searching stage.

Marine hardware complex IOL-HC used to for works. This complex was developed by VNIIOkeangeologia and CIT. It set for conducting seismic-acoustic, sonar direction and electro (electro) profiling simultaneously. During the profiling process exploration, geotechnical and ecological task could be solved.

Complex includes onboard and outboard parts.

Outboard part of Marine exploration complex IOL-HC towed behind the ship in 200-400 m. with burring up to the middle part of the water cut. Ion-selective electrodes set for measuring the activity of ions of the following elements: Cu, Pb, Cd, S, Ag is provided for the usage in complex. Based on the works experience, concentration of those elements ions consists anomalies in aqueous layer, which is associated with the proximity of the mass of hydrocarbons.

Features of the marine exploration complex:

— Number of channels of ion-selective sensors – 5

— Sensors Type - Cu, Pb, Cd, S, Ag (set of sensors can be adjusted for specific tasks).

Explorations works are carried by setting sea bottom seismic and electric prospecting satiations. Ion selective electrodes are connected to the electric prospecting stations (next nearest). Also towing underwater unit complex behind the ship is provided. Towing speed - 4-6 knots. The length of the measuring line is 400 m. The accuracy of the parameters evaluation is 0.02 mV.

In connection with field geophysics works with the purpose of exploration for oil and gas deposits appears the question of choosing a rational set of

geophysical, geochemical and other methods, which will solve the task most effectively and with lover expenses.

Rational complex choice is based on method effectiveness in determined area, the peculiarities of the geological structure, the physical parameters of oil and gas deposits, geological and geophysical knowledge and economic reasons. To choose rational complex and observation time special explorations (e.g. daily monitoring) on the known oil and gas fields, as well as on empty structures of area are completed. All kinds of geophysical, geochemical and other investigations carried out on the same profiles (Holmyanskii & Vladimirov, 2002).

Results and Discussions

Anomalies

Rising fluid flows forms complex geochemical anomalies in the bottom sediments – areas of local changes of informative geochemical indicators. Thus over the deposits of hydrocarbons they are formed from the overbackground concentrations of hydrocarbon gases, including methane with a high content of heavy carbon isotope, areas inflated number hydrocarbon-oxidizing microorganisms, and in number of cases, high concentration of oil fractions in the composition of bitumen, high concentration of iron and copper sulphides, etc. The peripheral part of the anomaly characterized by increased concentrations of carbon dioxide and hydrogen. Various combinations of helium, methane and other gases - typical signs of discontinuous disturbance appearance in the gas fields of bottom sediments of fluid-conducting zones.

Fluid-conducting zones

Discovered by seismic prospection structures are active geodynamic systems, which are in tense under the influence of natural geological processes due to continuous accumulation of energy of elastic recoil. When this energy level rises up to critical state, system becomes unstable and constantly and/or periodically discharges part of the accumulated elastic recoil energy. Micro earthquake with rupture of the continuity of the medium occurs.

If geodynamics system is in stable state, than any external impact (such as tidal power) leave no visible traces. For example, on the fig. 5 there is the result of monitoring exploration of the upper part of the landslide cut, where landslide reaction to the tidal powers can be seen. After tidal powers disappearing, the cut returns back to initial position, where two crossed disturbance can be seen (fig. 5). However, for some time during the day faults, which are fluid-conducting channels, opens and closes.

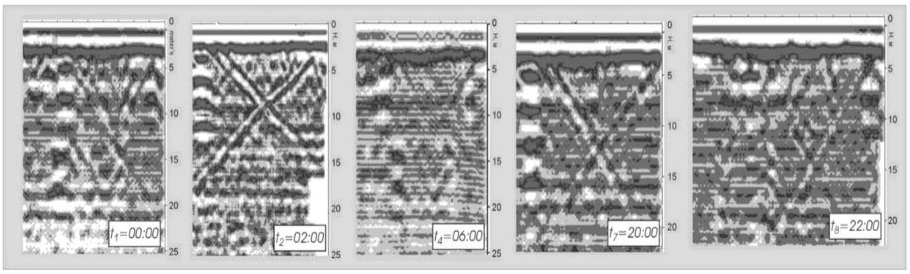

Figure 5. Example of cut daily monitoring according to radiolocation probing data

If the system is unstable, then the same tidal powers would leave "traces", which could be accumulated as elastic recoil energy and over the time tidal powers can become a trigger for elastic recoil energy discharge in form of earthquake or landslide, e.t.c.

Depending on geodynamics system state – accumulated energy level, degree of inhomogeneity in a space and structure, exogenous and endogenous processes, seasonal, daily and other changes, history of development, nature and condition of the last activation - geodynamic structures response to external natural and / or man-made impact is evaluated.

To evaluate the reaction of closed geodynamic system on external impact tidal powers, which impacts on this system structures and activates it on the regular basis, are needed to be examined.

Man-made impact on geodynamic system could be: vibrations and powerful stray currents fields; artificial and seasonal flooding; nature impact, gravitational influence on the steep slopes of the rock structure, temperature variations of structure; impairment of the integrity of the structure, e.t.c.

Example of tidal powers influence on landslide, acquired as the result of Ground Penetrating Radar survey is on the fig. 5.

For exploration of the features of the structure of the sedimentary cover on the area of the South and North Soleninskoye deposits high-precision aeromagnetic survey was completed.

One of the purposes of the high-precision aeromagnetic survey was an identification of weak manifestation of disjunctive impairments of sedimentary cover. Weakly manifested disjunctive impairments were fixed in magnetic field by positive linear anomalies with intensity 1.5-5.0 NTV, stipulated by execution of the fault zone formations with hydrothermal or magmatic origin, as well as by negative linear residual anomalies, connected with a decrease of the magnetic susceptibility due to the fragmentation of rocks in the fault zone.

At offset axes of linear correlation of anomalies other directions impairments are manifested.

According to fig. 6, local anomalies axis in the southern part of the area rounds the South Soleninskoye raising, changing their spread from north-eastern on the east to latitudinal on the south and to north-western on the west. Axis spreading impair lines of local anomalies correlation have north-west spread, crosses South Soleninskoye rising area and continued in the northern part of the area, passing by North Soleninskoye rising from the west.

Figure 6. Map of magnetic field local anomalies axis on Soleninskoye raising (by V.A. Loshkina)

Note: 1 – positive anomalies axis, 2 – negative anomalies axis, 3 – anomaly correlation impairment lines, admittedly connected with tectonic impairments. 4- uncorrelated anomalies, 5 – deep drilling exploration wells, 6 - isohypses ofseismic horizon Pb, in meters, 7 - the outer contour of SD-USH deposits productivity, 8 - line of special geochemical profiles.

According to correlation axis spread impairment, latitudinal spreading tectonic spreading group comes through the whole are, which appeared later, that impairments of north-eastern spread.

The density of weakly manifested tectonic impairments of nirth-western spread far more higher on South Soleninskoye rising are, which is the cased more damaged state, than on North Soleninskoye rising.

Because of the asymmetric spreading nature of the density of faults on the arches of structures, it appears that over the South Soleninskoye deposit arch in the gas field of Quaternary deposits higher concentrations of migrating hydrocarbons can be expected, than on North Soleninskoye deposit. And in fact, according to probing data, it can be clearly seen, that HCG concentration in the surface sediments in the North-Soleninskoye deposit is lower, than South Soleninskoye deposit, which indicates a manifestation of a more intense migration of HCG from deposits of South Soleninskoye rising.

Thus a comprehensive analysis of the nature and intensity of tectonic (weakly manifested) impairments, that creating main ways for effusive-diffusion leakage of hydrocarbons, while migrating from deposit to surface, allow to acquire additional criteria for exploration significance of hydrocarbon anomalies evaluation, and with it – heavy metals ions – indicators of the deposit.

With application of hardware complex there is a possibility to discover such gas anomalies, connected to fluids, by abnormally high concentration of metal ions in water associated with hydrocarbons.

Physical and geological basis of seismic prospecting usage for solving wide variety of prospecting tasks and for gas and oil exploration is the differentiation of geological cut on the set of physical properties (density, speed, absorption coefficient), affecting on propagation of elastic waves features, and / or receipt of structures, with which can hydrocarbon deposits can be connected, which are used for the calculation of the effect from the deposits in the resistance and polarizability. This system (operations order) can be used as a new method.

Seismic recordings, along the information about mutual spatial arrangement of the thickness and layers in the depths, contain information about such characteristic of the explored cut, as reservoir density, formation speed of elastic waves, formation absorption coefficients, information about sustainability (length) of reflectors, about stability of their properties. Meanwhile, the only sign of a possible detection of deposits on the seismic data is availability of anticlinal closed structure and only when complex it with electro prospecting it's role is increasing (Putikov, 2008).

While exploring non-anticlinal type deposits seismic prospecting facilities are used to evaluate seismic geological cut irregularities, mapping of tectonic disturbances and zones of weak impairment.

In the deposit are increased pyritization of cut, mineralization and calcareous of cover. Accordingly undergo certain changes in seismic properties in rocks, surrounding the depost.

Abnormal effects, related to hydrocarbon deposits, manifests in electromagnetic fields differently. The resolution of the various modifications varies. This predetermined the need of studying promising oil and gas anomalies features based on solution of direct and indirect tasks of electro prospecting for different modifications, development of ways of effectively allocating the required abnormalities, formulation experimental parametric studies on the known deposits. Electrical anomalies can come from deposits, or from regular variation of the geoelectric cut on the deposit, based on deposit influence and tidal powers (Berezkin, 1978).

Results of electric prospecting on a number of deposits of different types shows, that the main factor, that forming anomalies, especially in case of small deposits, is general changes geoelectric cut of zone type, caused by secondary changes in rocks under the influence of deposits. Complex interpretation task is establishing quantitative and qualitative links between observed electrical abnormalities and types of oil and gas fields (Berezkin, 1978).

The nature and intensity of the anomalies, caused by polarization on oil and gas fields determined by surveillance in wells and on the surface. The nature of the anomalies, caused by polarization on oil and gas fields connected to presence of electronically conductive minerals clusters in the area of deposits such as sulfides. Elevated concentration of sulfides is explained by reduction of sulfate dissolved in the stratal water, hydrocarbons of the deposit and it's halo or on a migration way to the trap. Recovery of hydrocarbons sulfates (sulfate process) leads to accumulation of hydrogen sulfide. Thus pyritization process of oil and gas containing thicknesses and overlying sediments occurs. During this process

in the upper part of the cut, which is available for reaching sufficient amount of oxygen, hydrogen sulphide is oxidized to sulfur, so the formation of sulfur is often associated with oil and gas fields (Berezkin, 1978).

Similarity of work results by caused polarization method in different areas, nowadays allows to explain anomalies, caused by polarization on oil and gas fields, by the presence in the upper cut of the deposit sulphide accumulations (mainly pyrite) with epigenetic origin, associated with the presence of hydrocarbons at the depth.

Caused polarization method used to find sulphide mineralization zones associated under certain conditions with oil and gas deposits.

Background values of sedimentary rocks polarizability are typically 1-1.5%, rarely reaching 2-3%. Exceeding polarizability over this background is the main sign of anomalies, caused by polarization (Berezkin, 1978).

Conclusion

Suggested new method allows to reduce prospecting expenses due to application of the technique of selection of the probability anomalies by specified a priori physical parameters of rocks and with already known structure of geological cut, received as the result of reflection seismic prospecting.

Based on the article, electrochemical profiling can be suggested as additional informative feature allows identification of complex seismic electrical anomalies.

Modern seismic and electric prospecting and electrochemical probing data interpretation, which was completed on explored area, and seismic acoustic profiling allows to isolate anomalies and recommend to conduct exploration drilling within them.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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