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GEOPHYSICS

Specific Features of the Deep Structure of the Novo-Elkhov and Romashkin Hydrocarbon Fields Based on Geoelectric Data

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In recent decades, problems of the active role of fluid factor in the structural transformations of lithosphere matter and its influence on the genesis of oil and ore deposits have been discussed in several publications [1–3]. In our work, we present experimental results of electromagnetic studies, which allow us to analyze the structural–tectonic links between the location of large (Romashkin and Novo-Elkhov) oil fields with trends in the distribution of electrical conductivity σ of rocks at depths from 10 m to 100–120 km. Along with the mineral composition of rocks, conductivity σ is an important physical parameter that characterizes the rheological properties of the medium, such as convective heat and mass transport, filtration of melts in the asthenosphere, viscous and brittle deformations in the crust, hydrothermal circulation, and others. This new information about the composition and state of the Earth's interior significantly complements the data on seismometry, deep seismic profiling, gravimetry, and other geophysical methods.

Choice of the study region was not accidental. Both oil fields are located in the sedimentary cover of the South Tatarstan Dome (STD) in the East European Platform, where crystalline rocks of the basement are located comparatively not very deep (1750–1850 m) below the surface. This territory has been studied well in the geological and geophysical aspects. Numerous wells drilled in this region include two superdeep ones (Fig. 1, wells 20000 and 20009). Borehole 20000 recovered soft and fissured basement rocks in the depth interval 4700–5099 m, characterized by the circulation of highly mineralized solutions saturated with gases and hydrocarbons [2]. High level of low-temperature hydrothermal processing of the basement with the indications of hydrocarbon-containing fluids was found in Borehole 20009 at great depths [1]. Thus, geostructural factors of the STD indicate that geoelectric prospecting can be successfully used for solving the problem formulated in our work. Before the beginning of the work, we had some data concerning the electrical resistivity (ρ) of the sedimentary cover based on the borehole logging data [2] and the transient field sounding method [4]. However, they do not allow us to find the relation between the fluid saturation of the medium with specific features of the geotectonic structure in the consolidated part of the section. Such problems can be solved by applying the methods of deep geoelectric prospecting, including magnetotelluric methods.

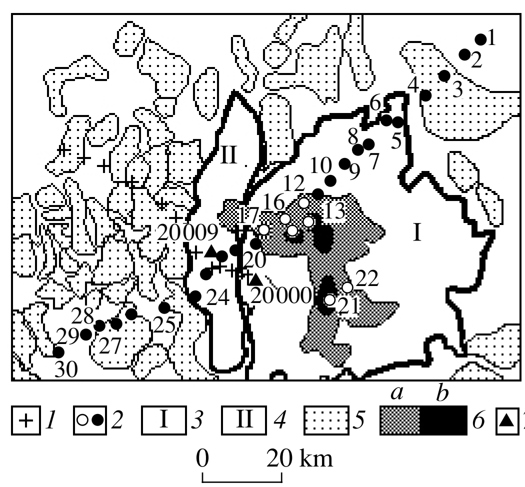

Fig. 1. Schematic location of points of electromagnetic soundings of the South Tatarstan Dome. Profiles: (*1*) Al'metievsk, (*2*) Granit; contour lines of oil and gas pools: (*3*) Romashkin, (*4*) Novo-Elkhov, (*5*) others; (*6*) contour lines of the anomalous magnetic field: (*a*) 400–2000 nT, (*b*) >2000 nT; (*7*) superdeep wells: (20000) Minnibaev, (20009) Novo-Elkhov.

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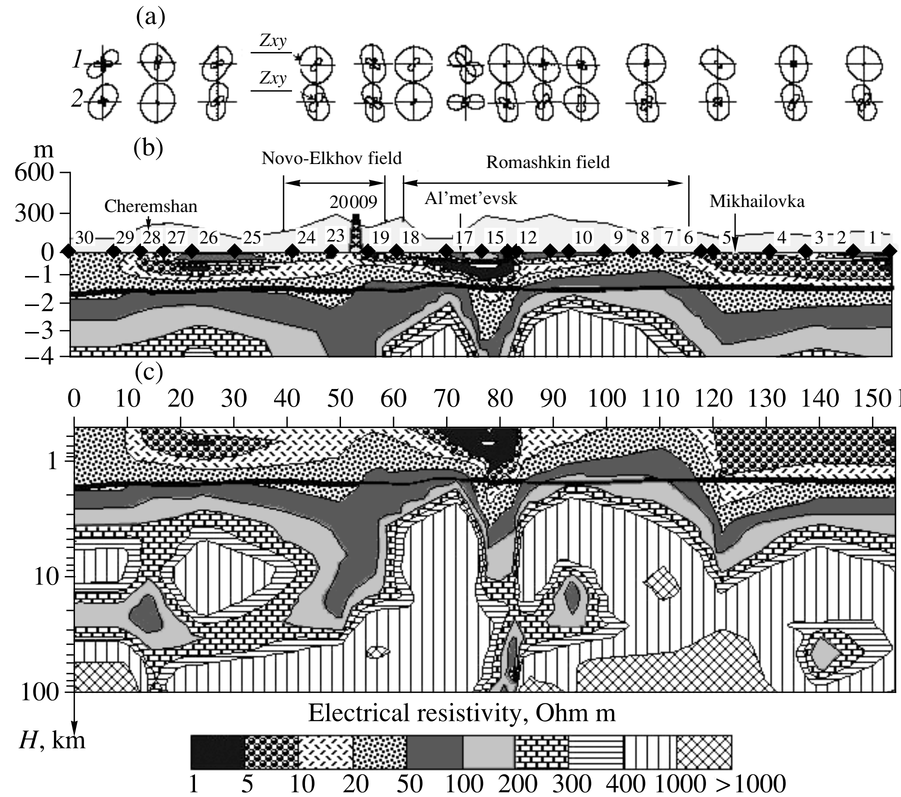

Fig. 2. Results of electromagnetic soundings along the Granit profile. (a) Polar diagrams of the principal (Z_{xy}) and additional (Z_{xx}) impedance for (*1*) high-frequency and (*2*) low-frequency ranges; (b) geoelectric section of the upper part of the crust (linear scale); (c) full geoelectric section (logarithmic scale).

Electromagnetic investigations were carried out in two stages. At the first stage (Fig. 1, *1*), we tested the method of measurements of the field with different sets of digital equipment and refined the data processing techniques with account of the specific conditions in Tatarstan: the presence of industrial noise caused by electric power lines, oil and gas pipelines, oil pumping stations, a well-developed network of roads with intensive traffic, and so on. At the second stage, we carried out regional investigation along the Granit profile (Fig. 1, *2*) with the application of methods of induction electric prospecting at frequencies ranging from 160 kHz to 10^{-4} Hz, such as induction electromagnetic sounding (IEMS) with a local source (magnetic dipole) and magnetotelluric sounding with a natural field source. This became possible due to the development of special equipment and methods (MChS-1, MTC-01, and Groza) at the Institute of Geophysics (Yekaterinburg) and the application of a GMS-06 wide-range measuring–calculating system (METRONICS Co.). The programming code for processing the MTS data along with the standard procedure of determining the amplitude and apparent-resistivity phase relations allowed us to control the number of points for Fast Fourier Transform and the duration of signal accumulation, to suppress pulse noises, to apply robust schemes for estimating the quality of the record, and so on. At each point of sounding, we plotted synthesized amplitude and apparent-resistivity phase curves for meridional (*X*) and latitudinal (*Y*) polarization of the field, as well as impedance polar diagrams at different frequencies (Fig. 2a), which characterize the geoelectric medium along the observation profile as a 2D inhomogeneous medium with the dominating submeridional direction of telluric fluxes and as a horizontally layered medium only over some regions of the Earth's surface.

During the quantitative interpretation of the obtained data, we took into account the results of film modeling [5], according to which curves *X* are the least distorted ones in Tatarstan. Such curves were used to plot the section. We also considered alternative versions based on numerical modeling of electromagnetic fields in 1D and 2D media using different service programs. In the final version of the section (Figs. 2b, 2c), we used the automated inverse program developed by L.N. Prokhorova that makes it possible to determine the structure of a geoelectric section based on an assumption about the gradient type of electrical resistivity variation with depth, without using any a priori information about the medium. The deviation in the values of ρ between the practical and theoretical curves did not generally exceed 1% (5% in some cases and 10% at points 10, 13, 17, 25, and 26).

Results of the investigations suggest the following conclusions:

(1) Estimates of electrical resistivity of the sedimentary cover within the northern STD reflect the mineral composition of rocks and modern fluid situation in the Romashkin and Novo-Elkhov areas (Fig. 2b).

(2) The geoelectric section of the so-called consolidated part of the lithosphere is generally distinguished by anomalously low values of ρ as compared with the normal value typical of the platform in other sections [6], indicating a significant transformation of the section within the known oil and gas fields. Fragments of the crustal conducting layer are found in the depth range of 10–30 km. At Point 19 (Novo-Elkhov deposit, Borehole 20009), the layer correlates with a tectonic distortion (the Altunino–Shunak fault). Geothermic data in [7] also present a version about the spatial relation between the formation of oil fields and high-temperature gas–fluid mixtures. Khristoforova et al. monitored the accessible Well 20009 and other boreholes drilled in the STD, showing that "…specific beds of the basement are characterized by constant functioning of processes of convective heat-and-mass transport, namely, the motion of fluid in inundated zones and the existence of constant gas inflow from great depths." Calculations of temperature variation with depth [8] indicate that isotherms of critical temperatures for water solutions (450°C) would be observed in the STD region at a depth of 20–30 km. Hence, the behavior of the crustal conductor can be compared with phase transitions between vapor and fluid. According to [9], supracritical solutions (374–450°C) are highly permeable and they can migrate along tiny cracks.

(3) The main structural feature of the geoelectric model is related to the Romashkin field. In the upper part of the section, this field is outlined as a high-Ohm dome limited from both sides by graben-shaped zones with ρ = 50–200 Ohm m (the lower values are related to edges). The central part of the field incorporates a large deep subvertical fracture with anomalously high conductivity (>1000 S). Roots of the fracture are traced down to a depth of ~10 km (Fig. 2c), where thermodynamic conditions permit the existence of partly melted matter. The significant reworking of the lithospheric section, existence of the deep fracture, results of superdeep borehole drilling, and increased heat flux suggest the following conclusion. During tectonic activation in the geological past, the STD region with the Al'met'evsk magnetic anomaly [10] could be permeable for high-temperature geothermal solutions that facilitate the formation of magnetite as a result of diaphthoresis of metabasic rocks and subsequent hydrothermal metasomatism. It is possible that this process is continuing at present.

Thus, the geoelectric data have yielded new information that can be considered an alternative to other data based on seismic gravity and other geophysical methods. The new information suggests the influence of primary abiogenic high-temperature gas–fluid mixtures from deep levels of the lithosphere on the formation of large deposits of hydrocarbon raw material.

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