УДК550.837:551.24(477) DOI: https://doi.org/10.24028/gj.v46i5.313534

Geoelectric heterogeneities of the Pre-Dobrudga Trough as a zone of hydrocarbon manifestations

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Received 30 December 2023

For the first time, a geological and geoelectrical interpretation of the three-dimensional model of the Earth's crust and upper mantle was carried out for the Pre-Dobrudga Trough and adjacent areas. It was based on observations of the Earth's low-frequency electromagnetic field conducted in 2009—2012 by the National Academy of Sciences of Ukraine. The material confidently indicates that hydrocarbon occurrences are confined to the detected anomalies of high electrical conductivity. These are characterized by subvertical channels (from the surface to 10 km deep) galvanically connected with sediments or sub-vertical contact zones of different resistivity observed not only in the Earth's crust (10—40 km) but also at crust-mantle depths (40—60 km) and in the upper mantle (110—160 km).The channels may determine the flow of ultra-deep fluids.

The geoelectric criteria included maximum thickness of the sedimentary stratum, subvertical rise of electrical conductivity anomalies from the crust-mantle depths or column to the entire thickness of the Earth's crust, subvertical boundaries of heterogeneities (contacts of different resistivity) in the consolidated Earth's crust and upper mantle,presence of a highly conductive asthenospheric layer. We identified a significant number of local areas that can be considered promising for hydrocarbon occurrence. The majority of them spatially coincided with the already well-known oil and gas fields — Skhidnosaratske and Zhovtoyarske, with the explored oil and gas prospective areas (Izmailska, Kyslytska, Prymorska, Shyrokivska), and with those that correspond to the areas of special permits for industrial exploration. However, the newly discovered areas that meet most of the geoelectric criteria, but for which no no information on oil and gas content is publicly available, clearly require additional geological and geophysical studies. It has been shown that zones of high electrical conductivity caused by the presence of deep fluids should be considered as deep centers of hydrocarbon generation and ways of their migration to the upper horizons of the Earth's crust.

Key words: geoelectromagnetic methods, interpretation of a three-dimensional model, conductivity anomalies, hydrocarbons.

Introduction. Ukraine's ever-growing demand for natural hydrocarbon raw materials, especially in wartime and after the war, has necessitated the search for new ways to increase commercial oil and gas reserves. A promising approach is to study the patterns of formation of oil and gas fields in the sedimentary cover associated with the deep structure of the Earth's crust and the processes occurring in it [Lukin, 2014].

Given the modern self-organizing, hierarchical block model of the Earth, the geological environment is an open, dissipative, spatially connected block structure [Shuman, 2017]. In this regard, attention to the deep fluids and processes of the Earth's de-

Citation: Burakhovych, T.K., Kushnir, A.M., & Stolpakov, A.Yu. (2024). Geoelectric heterogeneities of the Pre-Dobrudga Trough as a zone of hydrocarbon manifestations. *Geofizychnyi Zhurnal*, *46*(5), 32—51. https://doi.org/10.24028/gj.v46i5.313534.

gassing has sharply increased [Shestopalov et al., 2018]. Fluids coming from the mantle and crust are products of physicochemical interactions and phase transitions due to the redistribution of matter and heat in the overall geodynamic process. The accompanying increase in electrical conductivity allows predicting promising areas for mineral exploration.

The deep anomalies of high electrical conductivity were revealed by observations of the Earth's low-frequency natural electromagnetic field of external ionospheric-magnetospheric origin. They can be the result of fluid migration in the area of the southwest of the East European Platform (EEP) and its rim [Burakhovych et al., 2015, 2022; Sheremet et al., 2016; Kushnir, Burakhovych, 2021]. For example, Kulik [2009] supposes a chain of conductive structures in the crust of the Eurasian region, which correlates with the lateral discontinuous northern Dobrudga-Crimean-Caucasian branch of the known Alpine-Himalayan mobile belt.

Section «Subsoil use in Odesa Oblast» at [Kharina, 2007] notes that the extraction of minerals of national importance, such as oil and gas, in the subsoil of the Pre-Dobrudga Trough (PDT) is actually at the stage of pilot development. Based on the seismic surveys conducted about 70 years ago, drilling was carried out in the Bilhorod-Dnistrovskyi, Saratskyi and Tatarbunarskyi districts. The Middle Devonian sulfate-carbonate reservoirs, which lie at depths of 2630—3640 m, are considered to be productive. The Skhidnosaratske and Zhovtoyarske fields were discovered [Ivanyuta, 1998]. The explored oil reserves were not of commercial value at that time due to the high cost of production caused by significant depths, the oil having high wax content, high sulfur content, and complex reservoir structure of the fields.

Today, despite various geophysical methods have been used in the PDT [Starostenko et al., 2013b, 2015; Burakhovych et al., 2015; Sheremet et al., 2016; Amashukely et al., 2019] and wells (parametric, structural, prospecting and exploration) drilled in various tectonic structures, many issues of deep tectonics and oil and gas content of the region still need to be studied. This is due to the presence of geological prerequisites: a thick sedimentary stratum, a favorable combination of rocks of different lithological composition in the geological section as well as producing, accumulating and screening complexes, and the establishment of commercial oil content of Devonian sediments [Chepizhko et al., 2014].

The purposes of this study are:

– further interpretation of the three-dimensional model of electrical resistivity (ρ) in the Earth's crust and upper mantle in the PDT area [Burakhovych et al., 2015] in connection with the detailing of areas promising for hydrocarbon exploration;

– explaining the nature of high electrical conductivity anomalies based on a comprehensive analysis of geological and geoelectric data;

– determining the migration paths of deep fluids and the interaction of deep horizons as a factor in geodynamic processes to find promising mineral structures.

General characteristics of the 3D geoelectric model. One of the most comprehensive reviews of the deep structure of the North Dobrudga and the PDT area based on the results of previous experimental observations of magnetotelluric sounding (MTS) and magnetovariation profiling (MVP) is presented in [Sheremet et al., 2016, Section 4]. In 2009—2012, modern experimental geoelectric observations were made at the «Reni—Bilyayivka», «Kiliya», «Izmail», DOBRE regional profiles [Starostenko et al., 2013a] and in the vicinity of Zmiinyi Island [Kushnir, Shirkov, 2013], which significantly supplemented previous studies. Based on the generalized data from the MTS, deep MTS, audio-MTS, and MVP, a three-dimensional geoelectric model of the distribution of ρ in the Earth's crust and upper mantle was constructed. It highlights anomalies of high electrical conductivity at different depths from the surface of the Earth's crust to the upper mantle (Fig. 1). The 3D modeling technique was carried out using the Mtd3wd software [Mackie et al., 1994], and the calculations and general analysis of the geoelectric model are described in detail in [Burakhovych et al., 2015].

Conductors stretching for hundreds of kilometers are lined up along deep faults of various ranks and their intersections: Frunzenskyi, Saratskyi, Bolhradskyi, Kahulsko-Izmailivskyi, Chadyr-Lunhskyi, etc. A highly conductive layer of a complex spatial configuration is distinguished on the southern side of the PDT between the Frunzenskyi and Kahulsko-Izmailivskyi (in the west), Saratskyi (in the east) and Bolhradskyi (in the north) faults and lies at depths corresponding not only to the Earth's crust but also to the upper part of the upper mantle (from 10—40 to 40—60 km with ρ=10 Ohm·m). An almost isometric local area of high electrical conductivity (ρ=10 Ohm·m) at depths of 10 to 40 km was found on the northern side of the PDT, which is associated with a change in the orientation of the Chadyr-Lunhskyi fault.

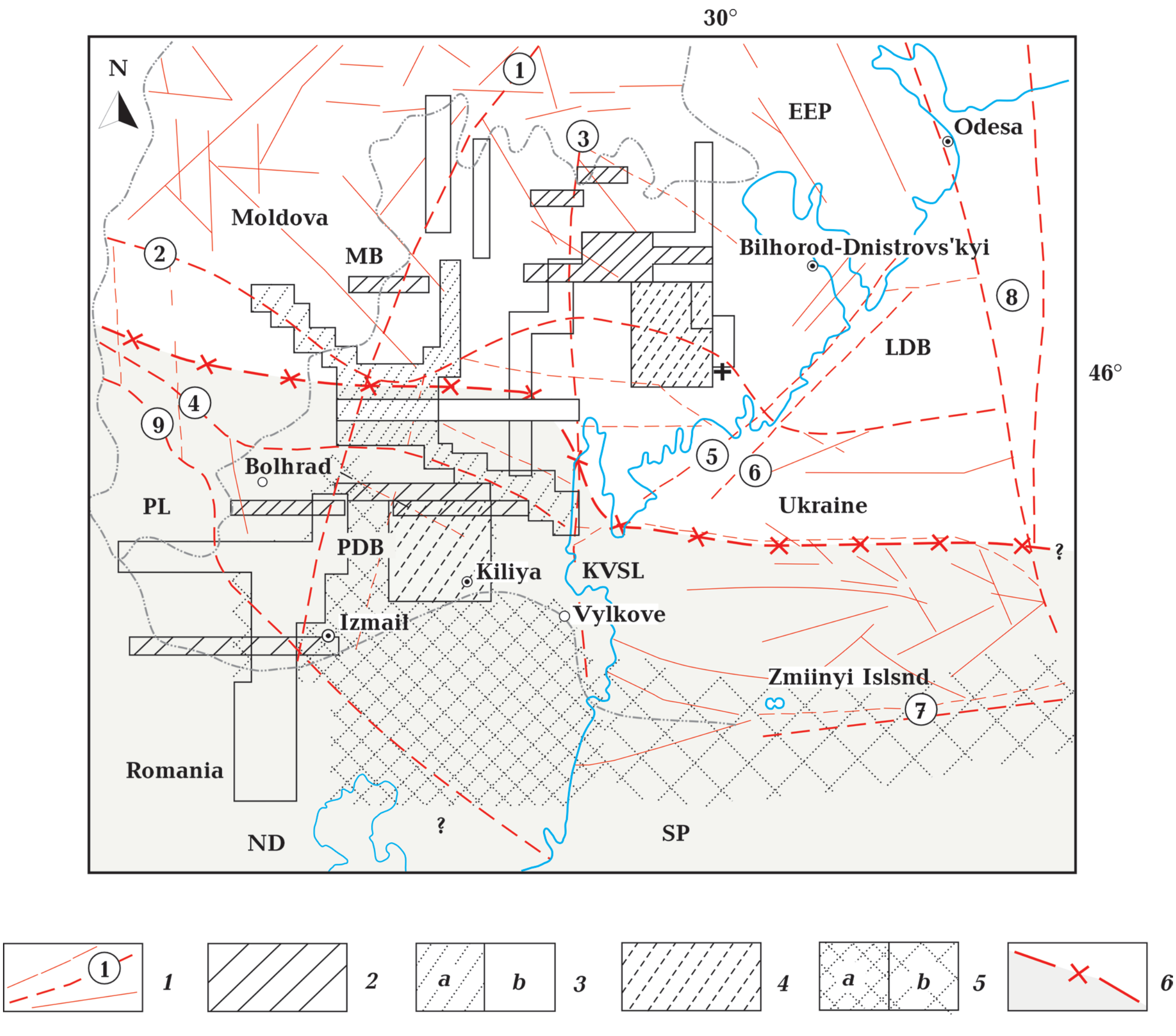

Fig. 1. Distribution of electrical resistivity based on the results of 3D modeling of the Pre-Dobrudga Trough and Northern Dobrudga according to data [Kushnir, Shirkov, 2013; Burakhovych et al., 2015] based on the [Krylov,1988]: *1* — deep fault zones of different ranks (1 — Frunzenskyi, 2 — Chadyr-Lunhskyi, 3 — Saratskyi, 4 — Bolhradskyi, 5 — Alibeiskyi, 6 — Chornomorskyi, 7 — Sulynskyi 8 — Odeskyi, 9 — Kahulsko-Izmayilskyi); *2*—*6* — parameters of geoelectric inhomogeneities (*2* — the depth of the top and the bottom (*h*) from the surface to 1 km, ρ=1,5 Ohm·m; *3* — *h*=1÷10 km (*a* — ρ=3 Ohm·m, *b* — ρ=10 Ohm·m); *4* — *h*=10÷40 km, ρ=10 Ohm·m; *5* — *h*=40÷60 km, ρ=10 Ohm·m (*a*), *h*=15÷30 km, ρ=100 Ohm·m and *h*=30÷60 km, ρ=10 Ohm·m (*b*) ; *6* — the northern border of the asthenospheric layer *h*=110÷160 km, ρ=70 Ohm·m). KVSL — lifting (Kiliyskyi, Vilkovskyi, Zmiinyi Island), MB — Moldavian Basin, LDB — Lower Dniester Basin, PL — Prut Ledge, ND — Northern Dobrudga, PDT — Pre-Dobrudga Trough, EEP — East European Platform, SP — Scythian Plate.

The northern edge of the PDT has a distribution of electrical conductivity in the upper mantle similar to that of the EEP, i.e., the parameters correspond to the generally accepted one-dimensional section: ρ_1=2000 Ohm·m, h_1=160 km; ρ_2=600 Ohm·m, h_2=40 km; ρ_3=250 Ohm·m, h_3=50 km; ρ_4=100 Ohm·m, h_4=70 km; ρ_5=50 Ohm·m, h_5=80 km; ρ_6=20 Ohm·m, h_6=100 km; ρ_7=10 Ohm·m, h_7=100 km; ρ_8=5 Ohm·m, h_8=160 km; ρ_9=1 Ohm·m, h_9=200 km; ρ_{10}=0.1 Ohm·m, $h_{10}=\infty$ km, where h_i та ρ_i power and resistivity of a layer. The southern edge has an electrically conductive layer at depths of 110 to 160 km with ρ=70 Ohm·m and is described by a «normal» section inherent in the Cimmerian Crimea.

According to the estimates of the one-dimensional inversion of the deep MTS data of the subsoil of Zmiinyi Island [Kushnir, Shirkov, 2013], a zone of high electrical conductivity with ρ=10 Ohm·m was obtained at depths from 20 to 100 km. Changes in electrical parameters in the Earth's crust and upper mantle are assumed to be caused by deep fluids. According to the 3D geoelectric model, in the northwestern shelf of the Black Sea between two deep faults: Kiliya and Pechenega-Kamena faults, a powerful sublatitudinal anomaly at the crust-upper mantle boundary was detected in the depth range of 30—60 km with ρ from 10 to 100 Ohm·m. Its axial part corresponds to the Sulynskyi fault.

Analysis of the structural and geological position. It is interesting to note that tectonically, the study area, namely the PDT, belongs to the western part of the Black Sea Trough. There, higher-order tectonic structures are joined: The EEP on the Archean-Middle Proterozoic crystalline basement and the Scythian Plate (SP) on the Hercynian-Early Cimmerian folded basement. The boundary between them runs along a structural fault zone, a tectonic marginal suture characterized in some areas by varying degrees of penetration of disjunctive faults into the sedimentary cover and the formation of flexures.

The PDT is a complex graben-like structure, asymmetrical in section. Three main zones are distinguished: the sloping north edge lies on the ancient Precambrian basement, the steep south edge on the young folded-metamorphosed Hercynian-Cimmerian basement of the EEP, and the axial part of the graben in the area of articulation of platforms of different ages. In the eastern part of the southwestern slope of the EEP, there is a syncline zone of the Lower Dniester Depression with a tendency to dip the basement towards the Black Sea.

According to a seismic survey, the surface of the Precambrian basement in the most submerged part of the trough lies at an average depth of 10 km [Seghedi, 2012]. The structure of the trough consists of sediments of the Riphean (arkose sandstones and conglomerates with mudstone interlayers) and Silurian-Permian ages (terrigenous clay and carbonate formations) with a total thickness of 4500 m, overlain by the Triassic terrigenous carbonate strata. The sedimentary cover has linearly extended zones formed by chains of small local positive structures of the northwestern strike, which manifested themselves as sub-vertical interspersed ρ on the vertical sections of the 3D geoelectric model along the «Reni—Bilyayivka» and «Kiliya» profiles (Fig. 2—4). Also, the northwest strike is preserved for the Dobrudga folded structure and the Jurassic Moldavian Depression superimposed on the PDT.

There are many options for the position of the southwestern border of the EEP in the area of the PDT and Dobrudga, which is supposed to be located in a strip about 500 km wide. The most comprehensive overview is given in [Mokriak, 2014]. In this publication, based on the geological reinterpretation of geophysical materials, satellite image interpretation, and morphometric analysis (in the Prut-Dniester interfluve), it spatially coincides with the Mechyn zone of Northern Dobrudga (Romania) and is much further south than the schemes of other authors. An example of the northern most location of the EEP boundary is the fault that separates the outer edge of the Precambrian platform and its submerged part in the south [Mokriak, 2014, see the list of references, in particular A.V. Drumya, 1959].

According to the deep geoelectric model, the boundary between the «normal» sections of the EEP and the inactivated Crimean cimmerides best corresponds to the position of the Precambrian platform boundary according to M.V. Vysotsky [Mokriak, 2014, see the list of references, in particular, Vysotsky M.V., 1959] and [Kruglov, Gurskyi, 2007]. According to A.V. Drumya, the boundary runs along the southern edge of the northern monoclinal slope of the Jurassic Basin, i.e., coincides with the axial part of this trough. According to S.S. Kruglov and D.S. Gurskyi [2007], it is along the axial part of the PDT, which is considered as an integral part of the Scythian epiorogenic zone. The latter tectonic line crosses all geological boundaries, the selection of which is based on a comprehensive interpretation of all available geological and geophysical information.

The publication [Amashukely et al., 2019] considers the deep structure of Dobrudga region and the PDT in terms of reflecting the development of the Trans-European Suture Zone (TESZ). The boundaries between the Paleozoic hercynids of Central Europe and the Tertiary Carpathians are known to have a significant contrast in the electrical conductivity of the crust. The northeastern contact of the hercynids and the Archean system, on the EEP known as the TESZ, is marked by the North German-Polish anomaly in bay-like geomagnetic variations [Stănică et al., 1999; Wybraniec et al., 1999; Semenov et al., 2003; Smirnov, Pederson, 2009]. The anomalous body of high electrical conductivity lies at a depth of about 50 km. Geoelectrically, this regional structure has a layer of high electrical conductivity in the middle mantle. There, in a fairly wide (approximately from 15° to 40° E) and long area, the electrical conductivity increases to 100 kS [Semenov, Jozwiak, 2006]. The depth of the roof of this layer varies from 600 to 800 km.

In 2001—2003, experimental studies were conducted under the CEMES project [Semenov et al., 2008]. Long-term magnetotelluric data were collected at eleven permanent geomagnetic observatories located several hundred kilometers along the southwestern margin of the EEP. A smoothed image of the integrated electrical conductivity (in kS) of the 200-kilometer thickness was obtained. The results indicate that the electrical structures of the upper mantle of the EEP and the Phanerozoic plate of Western Europe are different, and a transition zone is recorded between them, coinciding with the TESZ.

The European database on the depth of the lithosphere-asthenosphere interface is constantly updated. A new map showing lateral changes in its depth is presented in [Korja, 2007]:

1) the Phanerozoic European lithosphere with significant thickness fluctuations 45—150 km is much thinner than the Precambrian lithosphere;

2) the TESZ is the main geoelectric, as well as geological and geophysical boundary in Europe, separating two rather different regions;

3) the thinnest lithosphere is located under the Pannonian Basin (45—90 km);

4) there are no signs of high electrical conductivity of the upper mantle in most of the EEP.

As a result of numerous MTS and MVP studies, the western margin of the EEP (in particular, the PDT and North Dobrudga structures) is traced by anomalous objects of high electrical conductivity in the crust and upper mantle [Burakhovych et al., 2015, 2022; Kushnir, Burakhovych, 2019, 2021].

Based on modern geological and geophysical studies [Amashukely et al., 2019], with an emphasis on the deep seismic sounding (DSS) data from the DOBRE-4 and PANCAKE profiles, the TESZ is an inclined fault system. Its northeastern border passes near the surface under the PDT, and the southwestern border is adjacent to the Pechenega-Kamena fault which crosses the boundaries of the upper and middle crust. The entire crust within the TESZ has reduced velocity parameters and the largest deflection in the Mohorovichich discontinuity. The mantle structure of the

TESZ [Gintov et al., 2022] based on seismic tomographic studies using Taylor approximation reflects its complex structure. On the one hand, the TESZ goes deeper into the mantle to a level of about 700 km as a subvertical limitation of the EEP.On the other hand, inclined layers — slabs — are clearly visible. They sink to the southwest to a depth of 350—600 km and are interpreted as traces of subduction processes.

Analysis of geoelectrically heterogeneous zones. The last stage of building a geoelectric model can be considered interpretation in order to obtain its physical and geological paremeters for use in such important areas as studying the prospects of oil and gas in the region. Let us consider a 3D geoelectric model [Burakhovych et al., 2015] based on a series of five vertical sections along profiles of different orientations in space (Fig. 2). Most of them correspond to the profiles of experimental electromagnetic observations, e.g., «Reni—Bilyayivka», «Kiliya», DOBRE [Starostenko et al., 2013a], etc.

Almost all the profiles cross different

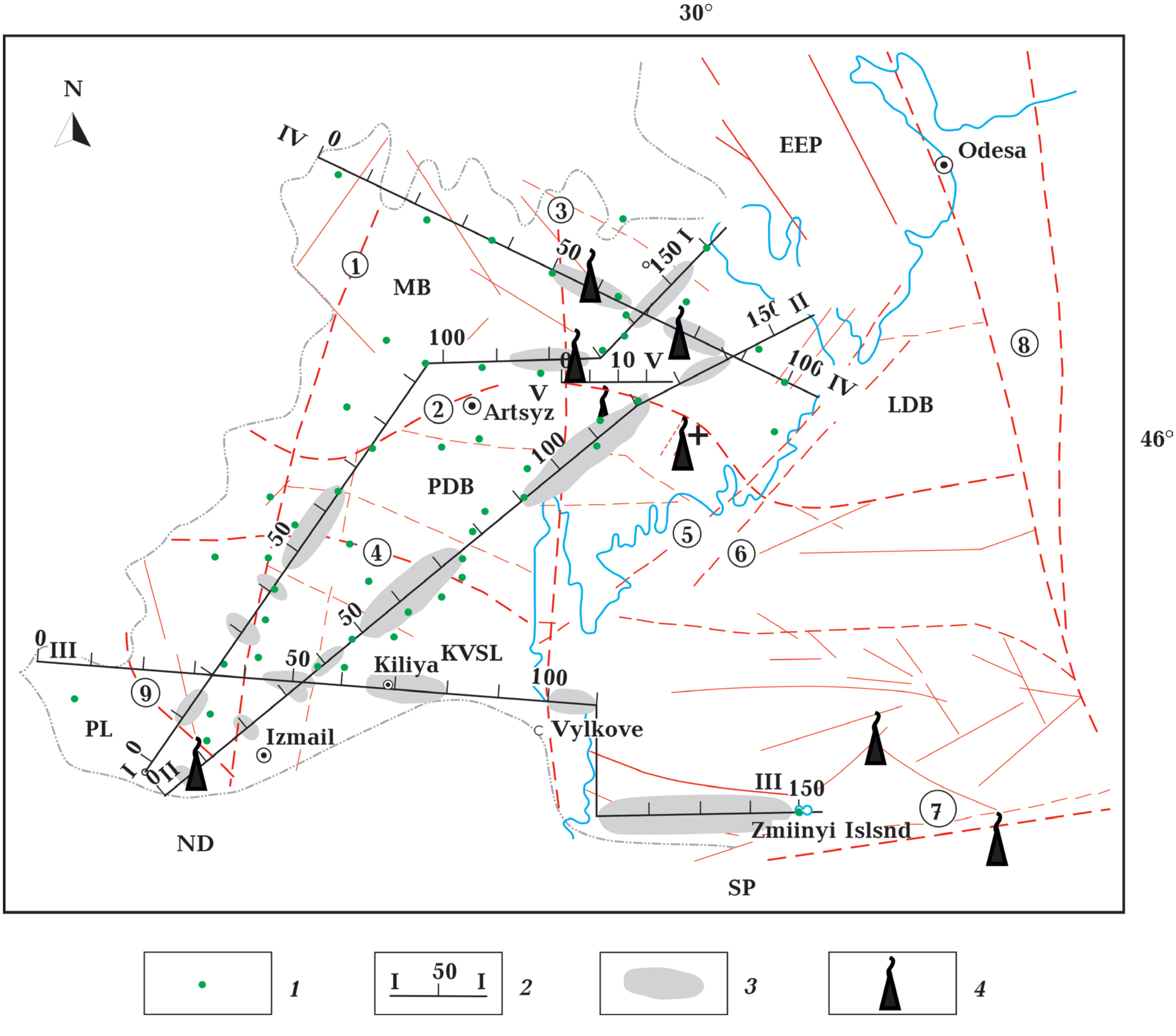

Fig. 2. Scheme of the interpreted profiles and prospective spaces of hydro-carbon manifestations: *1* — MTS, AMTS and MVP observation points according to [Starostenko et al., 2013a; Sheremet et al., 2016]; *2* — interpretive profiles based on which vertical sections of the 3D geoelectric model were constructed (pickets in km): I—I —«Reni—Bilyayivka», II—II — «Kiliya», III—III — «Reni—Zmiinyi Island», IV—IV — DOBRE, V—V — line across the Skhidnosaratske oil field; *3* — interpretedhydro-carbon prospective according to the data of the 3D geoelectric model; *4* — oil and gas fields.For other conventional notation, see in Fig. 1.

geological structures: The Prut Ledge of the Northern Dobrudga, the PDT with the Moldavian Depression superimposed on it, the Kiliya-Zmiinyi Island uplift and others, as well as deep faults of various ranks: Frunzenskyi, Chadyr-Lunhskyi, Saratskyi, Bolhradskyi, Kahulsko-Izmailskyi, etc. Each structural unit is characterized by the total longitudinal conductivity of the near-surface layers (from 100—200 S for uplifts to 1000 S for the axial parts of the faults) and the depth of the consolidated basement surface (from the surface to 1 km for the Prut Ledge, to 7—9 km for the PDT (within the Moldavian Basin 2—5 km)). According to these parameters, the distribution ρ of sediments ranges from 1.5 to 20 Ohm·m against the background of ρ=2000 Ohm·m of the consolidated crust. The geoelectric sections for all profiles have vertical cross-section in ρ at a depth of more than 1 km.

Consider the *vertical section of the model along the «Reni—Bilyayivka» profile* (Fig. 3). The 160-km-long profile has a general orientation from southwest to northeast, but at the 95—130 pickets, the direction changes from west to east (see Fig. 2). In the vertical section from the surface to 160 km, three heterogeneous low-resistivity layers (near-surface up to 10 km and deep 10—60 and 110—160 km) are distinguished against the background of a normal section with ρ=2000 Ohm·m.

1. The near-surface layer (heterogeneous in terms of ρ distribution and thickness) corresponds to sediments. The geological and tectonic structure is well reflected in the geoelectric data. The profile is divided into three parts:

– the Prut Ledge (pickets up to 10 km) with ρ=2000 Ohm·m from a depth of 1 km;

– the Paleozoic Depression (pickets 10—65 km) has a sub-vertical geoelectric structure in terms of ρ distribution. Thus, homogeneous (pickets 10—30 km, 50—70 km) and heterogeneous (pickets 30—50 km) columns with ρ of 1.5—20 Ohm·m are interspersed and can be traced from the surface to the consolidated foundation with ρ=2000 Ohm·m. Their thickness varies sharply from 2 to 9 km. The most conductive section (ρ=1.5÷3 Ohm·m) is the sedimentary stratum that have width between 17—25 km and stay around the Bolhradskyi fault;

– the Jurassic Basin (pickets 65—150 km) is characterized by a subhorizontal structure. From the surface to 4—5 km, there are conductive layers with a thickness of 1 to 3 km with ρ=5÷20 Ohm·m, complicated by narrow sub-vertical columns with a width of 5—10 km with ρ=3 Ohm·m, corresponding to deep faults. Deeper than 5 km, a consolidated basement with ρ=2000 Ohm·m is distinguished.

This variation of the depth of the consolidated basement in terms of ρ coincides with the position and geometry of the upper crustal velocity boundaries along the DOBRE-4 profile [Starostenko et al., 2013b]. Here, the basement under the Prut Ledge consists of a single layer with a velocity of ≈5.8 km/s, in contrast to the PDT, where there are two layers with velocities of ρ=5.10÷5.15 km/s and ρ≤6.0 km/s, respectively.

Deep faults: Kahulsko-Izmailskyi (picket 5—10 km), Frunzenskyi (30—35 km), Bolhradskyi (in the area of 50 km), Chadyr-Lunhskyi (picket 75 km), Saratskyi (pickets 115—130 km) faults manifested as zones of high and low resistance contacts or subvertical conductive columns throughout the entire thickness of sedimentary strata.

2. The depth interval in the Earth's crust and crust-upper part of the upper mantle (10—60 km) is characterized by local anomalies. For example, the transition zone from the Prut Thrust to the PDT (pickets 0—50 km) is accompanied by an inhomogeneity with ρ=10 Ohm·m at depths of 40—60 km, its upper edge corresponds to the depth of the Moho boundary [Starostenko et al., 2013b]. To the east of the Saratskyi fault (pickets 125—140 km), a local conductive (ρ=10 Ohm·m) zone is identified for the entire thickness of the consolidated crust and deeper (from 10 to 40 km). We emphasize that such a vertical rise of local heterogeneities corresponds well to the geometry of the Moho boundary position according to the DSS data along the DOBRE-4 profile.

3. The depth interval in the upper part of

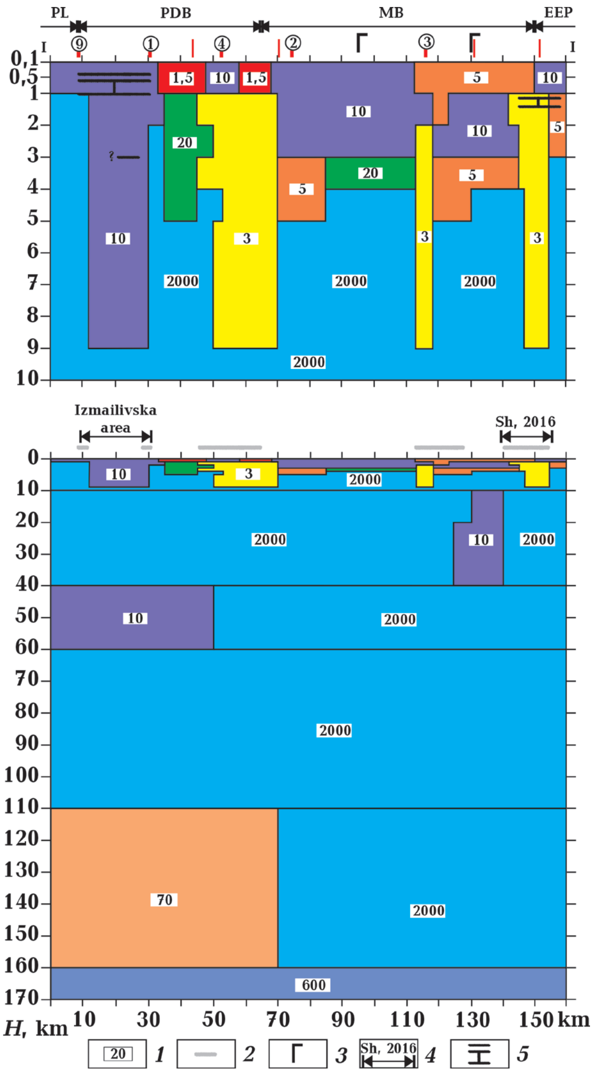

Fig. 3. A vertical section of the 3D resistivity distribution model in the depths of the Pre-Dobrudga Trough and North Dobrudga along the profile «Reni—Bilyayivka»: *1* — resistivity values, *2* — prospective hydrocarbon areas according to the 3D geoelectric model, *3* — change in spatial orientation of the profile, *4* — prospective oil and gas areas according to publicly available information: Sh, 2016 — [Sheremet et al., 2016, p. 132], differently named areas, for example, Izmailivska — according to the Ukrainian Geological Survey (https://www.geo.gov.ua), *5* — depth intervals of oil and gas bearing horizons of fields and prospective areas. For other conventional designations, see Fig. 1.

the upper mantle (110—160 km) beneath the Prut Rise and the PDT at pickets from 0 to 70 km is characterized by an asthenosphere with ρ=70 Ohm·m, which is typical for the normal distribution of ρ of the inactivated Cimmerian SP.

The interpretive profile «Kiliya» (160 km long) has a general southwest to northeast orientation and crosses the PDT at a distance of about 100 km (Figs. 2, 4). As in the previous profile, the geological and tectonic structure is well reflected in the geoelectric data and is represented by three heterogeneous low ρ layers in the vertical section.

1. The near-surface layer corresponds to electrically conductive sedimentary rocks and is divided into four parts by geoelectric parameters:

– the Prut Ledge generally has a high ρ=2000 Ohm·m. However, from the surface to 1 km, ρ=10 Ohm·m is observed. Whereas in the narrow zone of sub latitudinal extension, which corresponds to the Kahulsko-Izmailskyi marginal suture, a significant local decrease in ρ to 1.5 Ohm·m is recorded;

– the geoelectric structure of the Paleozoic PDT (10—95 km pickets) is characterized by a number of homogeneous (10—20, 38—45, 58—75, 75—95 km pickets) and heterogeneous (20—38, 45—58 km pickets) columns in terms of ρ (from 1.5 to 20 Ohm·m) with a width of 2.5 to 20 km, the thickness of which varies sharply from 2 to 9 km. Usually, the contacts of zones with different ρ (not necessarily from the surface, sometimes their projections to the surface) spatially correspond to the deep faults, for example, Frunzenskyi (near the 20 km picket), Vladychensko-Muravlivskyi (38 km picket), Bolhradsko-Suvorivskyi (54 km picket), Dmitrievskyi (60 km picket), Nerushayskyi and Spaskyi (75—80 km pickets), and Hlybochytskyi (90 km picket). A column up to 20 km wide with the highest conductivity (ρ=3 Ohm·m) from the surface and throughout the sedimentary strata was found around the deep Bolhradskyi fault;

– the third part is a transitional part between the PDT and the Moldavian Basin (pickets at 95—130 km). The depth interval of 3—5 km is heterogeneous with ρ=5 Ohm·m and a destructive consolidated basement at a depth of 5—6 km in the center of the fan-shaped convergence of geological faults: Hlybochytskyi, Novooleksiyivskyi, Saratskyi and Chadyr-Lunhskyi faults [Sheremet et al., 2016, p. 140, Fig. 4.5];

– the Moldavian Jurassic Basin (130—160 km pickets) is an inclined structure (from northeast to southwest) according to geoelectric data. Thus, the surface homogeneous layer (ρ=10 Ohm·m) has a thickness of 1 to 3 km. Beneath it lies an electrical conductivity anomaly (ρ=3 Ohm·m) with an upper edge at depths of 1 to 4 km between the Lebedovskii and the inclined Dniestrovskyi faults. The latter converge at a depth of 4—5 km into a sub-vertical zone that separates the southern and northern parts of the crystalline basement of the Jurassic Basin.

2. The depth interval in the Earth's crust and crust-upper part of the upper mantle (10—60 km) has local anomalies. For example, the transition zone from the Prut Ledge to the PDT (0—50 km pickets) is accompanied by heterogeneity of a complex configuration with ρ=10 Ohm·m at depths of 40—60 km. It is complicated by a local subvertical uplift of a narrow region at the 40—50 km pickets to a depth of 10 km. The latter spatially corresponds to the central part of the PDT, where the Vladychensko-Muravlivskyi and Bolhradsko-Suvorivskyi faults are located and can be traced to a depth of 16 km [Sheremet et al., 2016, p. 140, Fig. 4.5]. In the subsoil (depth interval 10—40 km) of the southern part of the Moldavian Basin (105—130 km pickets), around the intersection of the Saratskyi and Chadyr-Lunhskyi deep and other faults (see Fig. 1), a local conductive (ρ=10 Ohm·m) zone was identified.

3. The depth interval in the upper part of the upper mantle (110—160 km) beneath the Prut Ledge and the southern side of the PDT at pickets from 0 to 70 km has an asthenosphere with ρ=70 Ohm·m, typical for the normal distribution of ρ of the inactivated Cimmerian CP.

The «Reni—Zmiinyi Island» profile (150 km long) has a general sublatitudinal orientation and is parallel to the south by 30 km at pickets over 110 km (Figs. 2, 5). Thus, it crosses the southern side of the PDT and extends in the northwestern part of the Black Sea shelf to Zmiinyi Island. The latter, as well as the Kiliyskyi, Vilkovskyi, and Zmiinyi Island uplifts, and all of theseare composed of semi-metamorphosed Lower Paleozoic rocks with high resistivity (ρ=2000 Ohm·m was assumed in the model).

Let's consider the deep structure according to the geoelectric model, focusing on the heterogeneous layers of low resistivity. The geoelectric section from the surface to 2 km characterizes the sedimentary layer

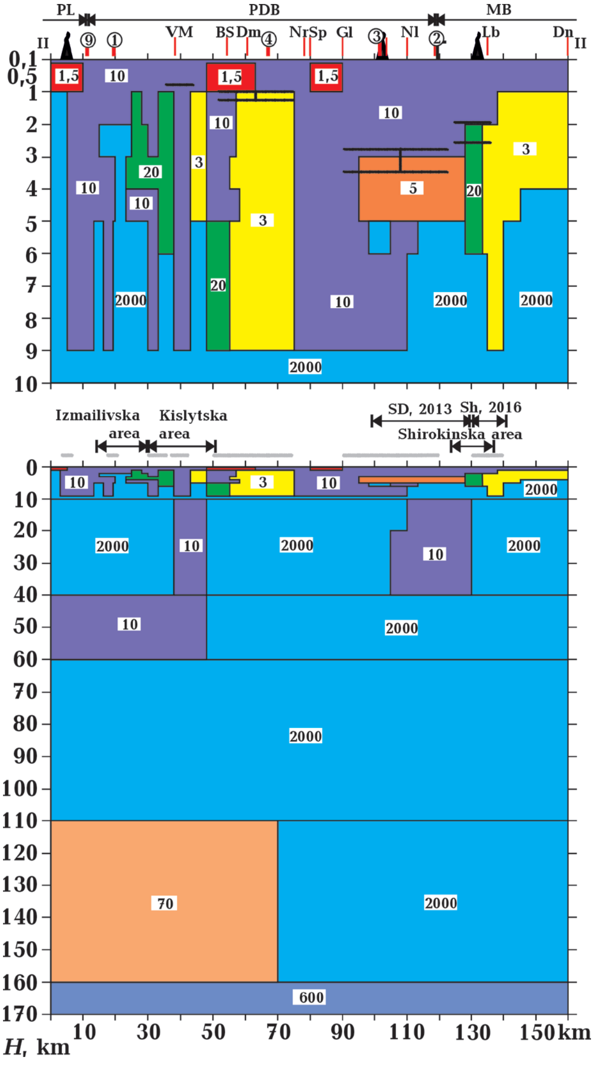

Fig. 4. A vertical section of the 3D resistivity distribution model in the depths of the Pre-Dobrudga Trough and Northern Dobrudga along the «Kiliya» profile. SD, 2013 — special permit areas of «Maps of oil and gas bearing regions of Ukraine with elements of subsoil use» [Yevdoshchuk et al., 2013]. Abbreviation of the names of tectonic faults: VM — Vladychensko-Muravlivskyi, BS — Bolhradsko-Suvorivskyi, Dm — Dmytrievskyi, Nr — Nerushaiskyi, Sp — Spaskyi, Gl — Hlybochytskyi, Nl — Novooleksiivskyi, Lb — Lebedovskyi, Dn — Dnistrovskyi. For other conventional notation, see Fig. 1—3.

with a homogeneous ρ = 10 Ohm·m, as in the previous cases. In accordance with the geological and tectonic structures, the southern side of the PDT (10—110 km pickets) is subdivided subvertically from a depth of 2 km by the relief of the consolidated crust and the distribution of ρ into three zones:

– 17—43 km pickets; from the surface to 9 km it is homogeneous with ρ=10 Ohm·m and is limited by the Kahgulsko-Izmailskyi and Frunzenskyi deep faults;

– 45—80 km pickets, from 2 to 5 km heterogeneous, represented by a series of narrow (5 to 20 km wide) columns with ρ from 3 to 40 Ohm·m. Deeper, there is a foundation ledge with ρ=2000 Ohm·m, which geologically corresponds to the Kiliyskyi uplift;

– 80—105 km pickets; sub-vertical columns with ρ of 10 and 20 Ohm·m are traced for the entire thickness of the sedimentary stratum.

The transition from the subvertical alternation of the sedimentary formations of the PDT to the layered conductive structure of the Vilkovskyi and Zmiinyi Island uplifts (pickets over 110 km, ρ from 10 to 20 Ohm·m) takes place to the east of the Saratskyi deep fault. In geoelectric terms, the uplifts are manifested in the rise of the consolidated basement up to 5 km with an assumed ρ=2000 Ohm·m. This part of the profile is traced along the Sulynskyi deep fault.

The deep heterogeneity in the crust-upper mantle (10—60 km) has a complex configuration with ρ=10 Ohm·m and is manifested within the western part of the southern side of the PDT (20—80 km pickets). In general, its upper edge lies at a depth of 40 km, but under the Kiliyskyi uplift, the subhorizontal anomaly abruptly changes its position to subvertical and rises to a depth of 10 km (60—80 km pickets). The Vilkovskyi and Zmiinyi Island uplifts (105—150 km) are characterized by a layered conductive structure at crust-mantle depths: 16—30 km, ρ=100 Ohm·m and 30—60 km, ρ=10 Ohm·m. Deeper along the entire profile, the distribution of ρ corresponds to the normal one for an inactivated Cimmerian SP.

In accordance with the structure of the crust, the velocity model along the sublatitude seismic profile DOBRE-5 [Starostenko et al., 2015] identified characteristic structures in the area of the PDT and the offshore part of the Karkinitskyi Trough to Zmiinyi Island. The high-speed section of the PDT has a thick (10—12 km) sedimentary cover, where the 8—10 km thicker section has longitudinal wave values of V_P~5.7÷5.8 km/s (as noted in the reference, no difference between Devonian rocks and the Rift basement can be detected). On the other hand,

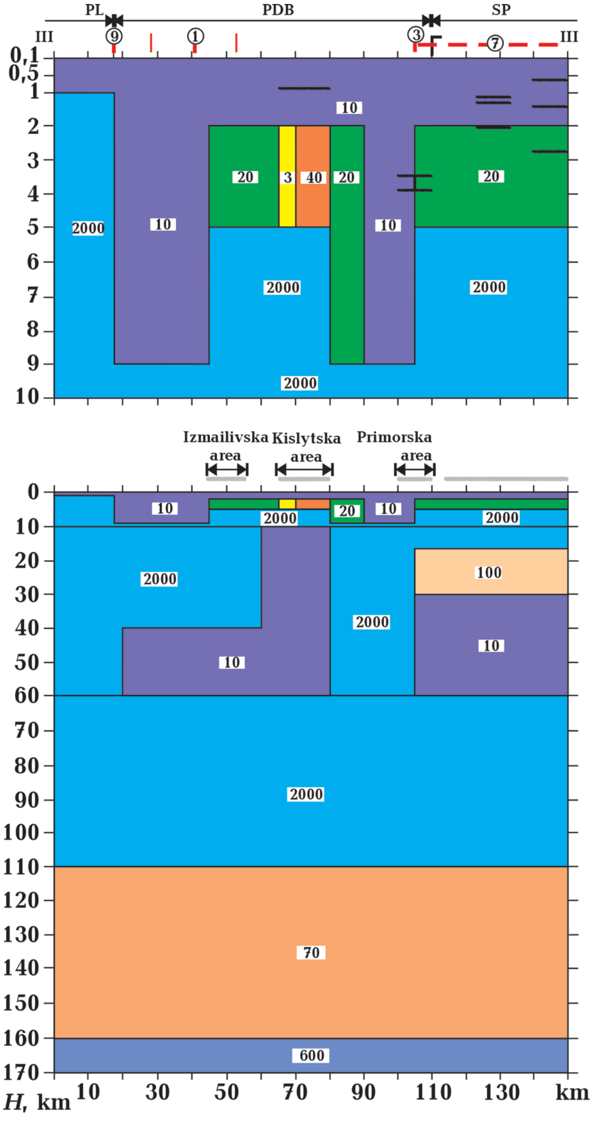

Fig. 5. A vertical section of the 3D resistivity distribution model in the depths of the southern side of the Pre-Dobrudga Trugh along the profile «Reni—Zmiinyi Island». For other conventional designations, see Fig. 1—3.

under the Vilkovskyi and Zmiinyi Island uplifts a sharp rise of the basement to a depth of 2.5—3.5 km is observed. The crystalline crust of this structural element is two-layered (the lower part is missing), unlike the crust characteristic of the EEP and similarity to the typical crust of the TESZ and Variscan Western Europe. However, its thickness is somewhat greater, with a depth to the Moho surface of 38—40 km.

It can be emphasized that, according to the interpretation of electromagnetic and seismic methods, the structure of the upper part (up to 10 km) of the Earth's crust is similar in general. However, the three-dimensional geoelectric model gives a more detailed picture of the distribution of electrical conductivity inhomogeneities at depths above 10 km not only in the Earth's crust but also in the crust-mantle interval. The uplifts (Kiliyskyi, Vilkovskyi, Zmiinyi Island) were manifested in the uplifts of both the basement of the sedimentary column and the upper edge of the crust-mantle heterogeneities. It should be noted that the depth structure along the «Reni—Zmiinyi Island» geoelectric profile may be similar to that of the TESZ due to the presence of local heterogeneities at different depths, but the distribution of ρ everywhere in the depth interval of 110—160 km corresponds to the normal one for the inactivated Cimmerian CP.

The northern side of the PDT, overlapped by the Jurassic Moldavian Depression, is crossed from northwest to southeast by the 100-km-long DOBRE profile [Starostenko et al., 2013a] (Figs. 2, 6, *a*). The geoelectric model along the profile reflects not only an increase in the thickness of sediments from 2 to 5 km, but also a decrease in ρ from 10 to 1.5—3 Ohm·m. Almost all major discontinuities are manifested by sub-vertical low-resistivity structures throughout the entire thickness of the sedimentary column and deeper: Halats-Tyraspolskyi and Frunzenskyi — ρ=10 Ohm·m, Saratskyi and Lebedovskyi — ρ=3 Ohm·m, Alibeyskyi — ρ=5 Ohm·m. In the crust, in the depth range of 10—40 km to the east of the Saratskyi fault, a local sub-vertical structure 10 km wide with ρ=10 Ohm·m can be traced. The northern side of the PDT is characterized by the distribution of electrical conductivity in the upper mantle similar to that of the EEP.

Hydrocarbon occurrences in geoelectrically heterogeneous zones. Based on the geological and lithological-stratigraphic analysis of potential structures and strata within the Southern oil and gas region of Ukraine, promising stratigraphic complexes and territories were identified [Mykhailov et al., 2014, pp. 201, 202, 204]: strata of the Lower Devonian, upper part of the Visean and Lower Serpukhivian Carboniferous, middle and upper part of the Middle Jurassic, as well as the territory of the Lower Devonian, Lower Carboniferous complexes of the northeastern part of the PDT and the Middle Jurassic complex of the PDT.

Studies using electromagnetic methods have shown that the most favorable areas for hydrocarbon deposits are those composed of a sufficiently thick (up to 10 km) sedimentary layer of Paleogene to Silurian sediments, characterized by low ρ of 10—100 Ohm·m. Differences between sediments in terms of ρ are determined by both their composition and the degree of metamorphism. The main area favorable for hydrocarbon prospecting is located in the PDT — on the Bessarabian-North Black Sea Plate (Lower Danube and Horokhiv blocks) according to the scheme of the main structural and tectonic elements of the Jurassic section [Sheremet et al., 2016, p. 132]. Some favorable areas are found on the Moldavian Plate, but here the thickness of Jurassic sediments does not exceed 2.0—2.5 km.

Typically, oil deposits are located along deep faults and their intersections. Where there is an extensive system of regional faults of different orders, and geotectonic processes have led to the formation of zones of compression in the Earth's crust, through which hydrocarbons penetrated into the near-surface sedimentary rocks, secondary trapped fields are formed [Gryn, 2021].

Local heterogeneities in the Earth's crust and upper mantle create not only vertical intermixing of high and low ρ, but also chan-

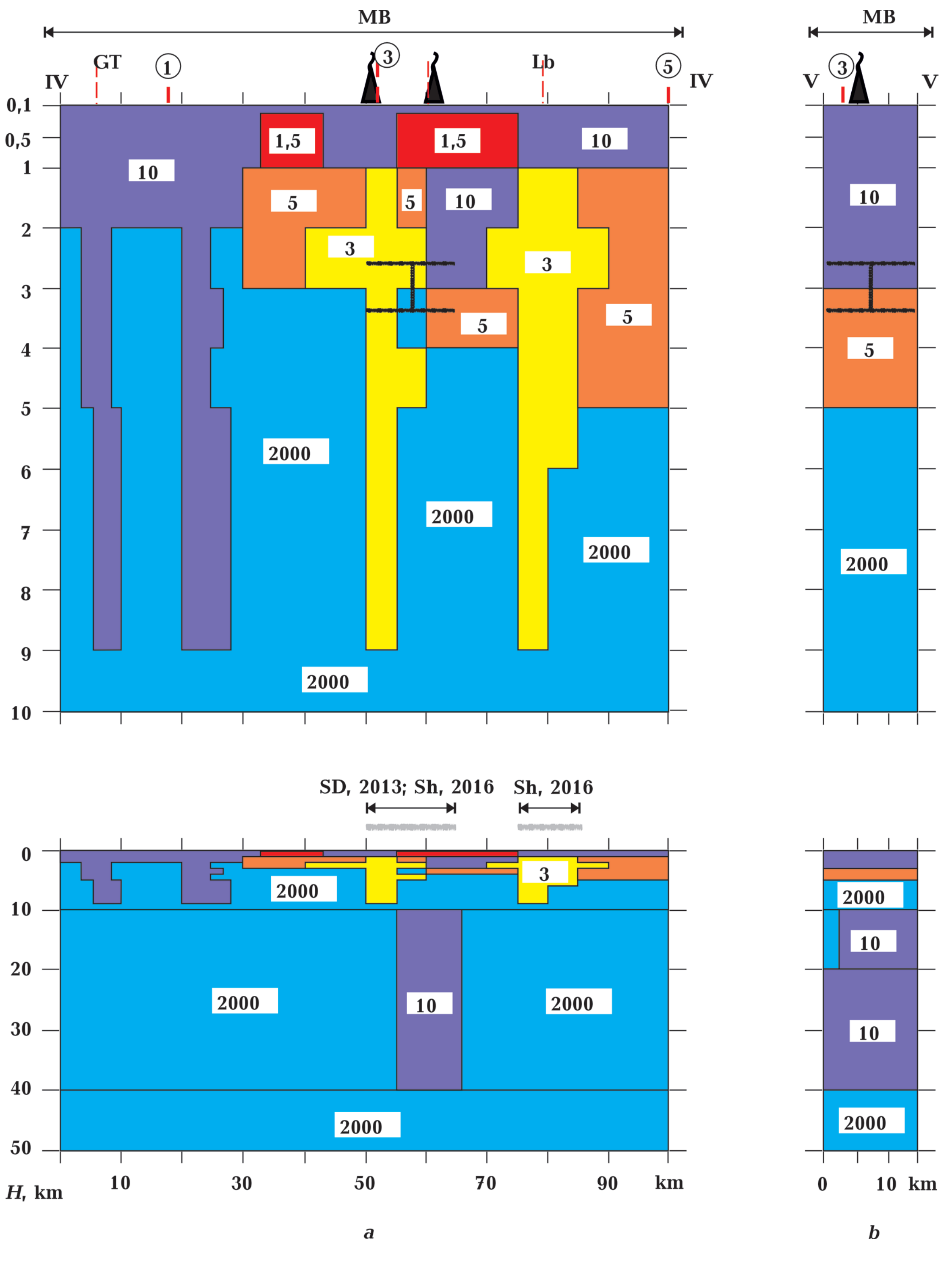

Fig. 6. A vertical section of the 3D resistivity distribution model in the depths of the northern side of the Pre-Dobrudga Trough along the DOBRE profile [Starostenko et al., 2013a; Sheremet et al., 2016] (*a*) and the profile that crosses the area of the Skhidnosaratske oil field (*b*). Abbreviation of the names of tectonic faults: GT — Halats-Tiraspilskyi. For other conventional notation, see Fig. 1—3.

nels that are galvanically connected to sedimentary formations and can be considered as pathways for the flow of deep hydrocarbon matter. Interpretation of the three-dimensional model of the distribution of ρ of the Earth's crust and upper mantle in the

PDT area made it possible to detail the predicted areas of hydrocarbon occurrence. The vertical sections of the ρ distribution highlighted promising areas (see Fig. 2—6): «Reni—Bilyayivka» (in the vicinity of pickets at 10 and 30 km, between pickets 45—65, 113—126 and 140—155 km), «Kiliya» (in the vicinity of pickets at 5 and 20 km, between pickets 30—35, 38—43, 50—75, 90—120 and 130—140 km), «Reni—Zmiinyi Island» (between pickets 45—55 and 65—80 km, in the vicinity of at picket at 105 km and over 115 km), DOBRE (between pickets at 50—65 km, with uncertain prospects at pickets 75—85 km), as the most favorable for hydrocarbon exploration according to the above.

The projected areas of the profile «Reni—Bilyayivka» in the vicinity of the 10 and 30 km pickets correspond to the Izmailska area according to the Ukrainian Geological Survey (https://www.geo.gov.ua/) (see Figs. 2, 3). The prospectivity of Jurassic deposits is evidenced by oil shows recorded during well drilling: 28 wells (304—305 m) recovered an oil-rich core; 300 wells (685—1050 m) showed gas and oil in the sandstone core. It is preliminarily recommended to drill a parametric well in the Izmail structure at a depth of 3100 m to assess the oil and gas prospects of Jurassic deposits.

The data suggests the possibility of hydrocarbon occurrences in high electrical conductivity anomalies identified by geoelectromagnetic data in the interval of 45—65 km pickets. The latter are characterized by subvertical channels around the Bolhradskyi deep fault and are galvanically connected with sediments. In addition, subvertical contact zones of different resistivities are observed not only in the Earth's crust, but also in layers in the upper mantle (40—60 km, 110—160 km), which may cause the inflow of ultra-deep fluids.

Classifying the area between pickets at 113—126 km as a prospect remains controversial. From the surface, it corresponds to the above features and is spatially related to the deep Saratskyi fault, but at the depths of the upper mantle there are no heterogeneities. A similar geoelectric structure, traced along lower-ranked faults, is observed for pickets at 140—155 km. Between them (125—140 km pickets), an almost sub-vertical column of high conductivity is seen for the entire thickness of the consolidated crust. According to [Mykhailov et al., 2014; Sheremet et al., 2016], the area of the villages of Stara Tsarychanka and Kryva Balka (145—158 km pickets) is considered to be the most indicative, where oil content is associated with Silurian rift formations at a depth of 1200—1400 m, as well as with possible deposits in the Lower Devonian.

The predicted areas of the profile «Kiliya» in the vicinity of the 5 km pickets (oil and gas field according to [Sheremet et al., 2016, Fig. 4.37, p. 182] and 20 km spatially correspond to the Izmail area described above, between pickets 30—35 and 38—43 km Kyslytska structure (https://www.geo.gov.ua/) (see Figs. 2, 4). These areas are also identified by geoelectric data along the profile «Reni—Zmiinyi Island» between pickets 45—55 and 65—80 km (see Figs. 2, 5). Three pre-Cretaceous complexes are of prospecting interest here, which are characterized by a favorable combination of reservoirs and tires: Silurian-Lower Carboniferous, Permian-Triassic, and Jurassic. In the Upper Jurassic rocks, the reservoirs are limestone, sandstone and siltstone, confined to different stratigraphic levels. One of the most extensive reservoir formations can be traced in the lower part of the Kelovey stage (oil-rich sandstones were recovered from well 137 (Baymakliyska)). The website (https://www.geo.gov.ua/) recommends drilling a 900 m deep exploration well in the Kyslytska structure to assess the oil and gas content of Jurassic formations.

Between the pickets of 50—75 km of the «Kiliya» profile, hydrocarbons are expected to occur along the high-electrical conductivity anomaly represented by a sub-vertical channel in sediments with an axis in the Bolhradska deep fault zone and a sub-vertical contact of different resistivity observed in the upper mantle (110—160 km). The geologic section [Sheremet et al., 2016, Fig. 4.5, p. 140] clearly shows the block structure and dip of the Bolhradskyi fault up to 16 km. It is the southwestern part of the Lower Dunaiskyi and Bashtanskyi blocks that is of the greatest interest due to its thick Jurassic, Triassic, and Devonian sediments, which occur as monoclinic and weakly syncline-like strata. When searching for structural oil and gas traps, Jurassic deposits with a thickness of 1700 to 5100 meters are considered promising.

Between the picket sections 90—120 and 130—140 km of the «Kiliya» profile, there is an almost isometric heterogeneity of high electrical conductivity in the crust against the background of a homogeneous-layered normal section of the EEP.

The southern section (pickets at 90—120 km) in the sedimentary stratum has a geoelectrically complex structure inherent in the area of intersection of the Saratskyi, Chadyr-Lunhskyi deep and lower-ranked faults. According to the geological and geophysical section along the profile of the Limanske—Petrivka village in the south of Odesa oblast, the oil fields are confined to the deep Chadyr-Lunhskyi fault — the border between the PDT and the Lower Dniester Depression [Sheremet et al., 2016, p. 130]. Oil deposits in the Upper and Middle Devonian sediments at a depth of 2600—3300 m are associated with local uplifts of the PDT. Carbonate sediments of the Middle and Upper Devonian are cavernous, fractured, and porous, making them potential reservoirs. Their oil content has been confirmed by the discovery of two fields — Zhovtoyarske and Skhidnosaratske. In addition to the Middle and Upper Devonian sediments, Lower Devonian terrigenous formations have favorable reservoir properties for gas exploration [Radkovets, Koshil, 2017].

It should be noted that the vertical section of the model along the latitudinal profile that crosses the area of the Skhidnosaratske oil field is characterized by a thickness of up to 5 km of conductive sedimentary strata (ρ=5÷10 Ohm·m) and a vertical column for the entire thickness of the consolidated crust with ρ=10 Ohm·m to the east of the Saratskyi fault (see Figs. 2, 6, *b*). The deposit itself is confined to the eastern border of the deep anomaly.

In the northern section of the «Kiliya» profile (pickets 130—140 km), the Shyrokivska structure is considered to be promising [Chepizhko et al., 2014], which is included in the fund of newly discovered oil and gas prospects in the Odesa oblast (State Service of Geology and Mineral Resources of Ukraine, 2012). A subject of special attention is the Lower Devonian terrigenous complex, considered favorable for the formation of hydrocarbon deposits in traps of lithologic-stratigraphic and tectonically shielded type within the Lower Dniester Depression. Usually, tectonically shielded deposits are formed along faults, which complicates the geological structure of local structures. In this case, the northern part of the «Kiliya» profile is saturated not only with deep faults (Saratskyi, Chadyr-Lunhskyi, Lebedovskyi, Dniestrovskyi, etc.), but also with dikes and dike-like intrusion bodies.

In addition, the profile «Kiliya» between the 100—130 km pickets crosses the area of special permits for exploratory development [Yevdoshchuk et al., 2013], which are reserved for increasing oil and gas production in Ukraine.

Along the profile «Reni—Zmiinyi Island» (see Figs. 2, 5) in the vicinity of the 105 km picket, the Primorska structure is located (State Service of Geology and Mineral Resources of Ukraine, 2012, 2012), where Lower Devonian sediments are of interest.

The deep structure in the eastern part of the profile «Reni—Zmiinyi Island» at pickets over 115 km is promising according to geoelectric data, i.e., characterized by the presence of an anomalously conductive near-surface thickness (up to 5 km), inhomogeneities of the Earth's crust and crust-mantle depth interval (16—60 km), and a widespread asthenosphere from 110 to 160 km. However, such a representation cannot be considered detailed and definitive due to the lack of experimental electromagnetic observations in the shelf zone of the northwestern Black Sea, and the distance between the nearest points on the profile «Kiliya» and Zmiinyi Island is 80—90 km.

The geophysical heterogeneities of the subsurface of the northwestern part of the Black Sea have been briefly reviewed in publications [Kushnir, Shirkov, 2013; Burakhovych et al., 2015]. The area is characterized by increased heat flow [Kutas et al., 2004]. According to the results of the 3D *P*-velocity model of the mantle beneath Eurasia [Tsvetkova, Bugaenko, 2012], the territory of the PDT and North Dobrudga belongs to the mantle boundary region beneath the EEP, where a system of inclined layers is distinguished within the upper mantle and the Golitsyn-Geyko layer. A complex and uneven distribution of a set of features of velocity characteristics was revealed, namely: aplume in the middle and lower mantle; high-velocity inclined layers in the upper mantle, its transition layer and middle mantle; subvertical mantle columns in the upper mantle as traces of the passage of deep fluid [Starostenko et al., 2013a].

In the observed hodographs of the Odesa shelf (DSS profiles 26 and 25), waveguides in the basement and upper crust were found, associated with the presence of fault zones filled with rocks of increased fracture redness and porosity, and fluids [Yegorova et al., 2010]. A network of faults of different orientations has been identified in the sedimentary strata and basement, which can control the location of gas occurrences and deposits [Starostenko et al., 2010]. Most of the fields and structures are controlled by fault systems associated with the EEP boundary and the Gubkinsko-Donuzlavska fault zone and their intersections [Makarenko et al., 2021]. It is known that eight fields are being developed in the northwestern part of the Black Sea shelf, the largest of which are Odeske and Bezimenne, where commercial hydrocarbon accumulations have been found in the Upper Cretaceous, Paleocene, Eocene, Maikopian, and Miocene sediments [Chepizhko et al., 2014].

The detected geoelectric heterogeneities between pickets of 50—65 km of the profile DOBRE correspond to the area of special permits of the «Map of oil and gas bearing regions of Ukraine with elements of subsoil use» [Yevdoshchuk et al., 2013], which are reserve oil and gas prospective objects with sufficient resource potential (see Figs. 2, 6, *a*). In particular, information on the oil and gas fields is provided in the monograph [Sheremet et al., 2016, p. 182, Fig. 4.37]. The projected area with uncertain prospects is assumed to be between the 75—85 km pickets, if analyzed in terms of the presence of high electrical conductivity throughout the sedimentary thickness corresponding to the Lebedovskyi deep fault and the absence of any geoelectric anomalies in the consolidated crust, and deeper.

The predicted areas of the profiles DOBRE, «Reni—Bilyayivka» (pickets at 140—155 km) and «Kiliya» (pickets 130—140 km), are mainly confined to the second, third and fourth anomalous areas obtained from a set of geophysical and geological data (the material is given in the prerequisites for the discovery of oil and gas fields [Sheremet et al., 2016, p. 129]).

Thus, there is undoubtedly a relationship between the manifestations of oil and gas content and geoelectric heterogeneities of the lithosphere.

Conclusions. Numerous publications [Dolenko, 1980; Gordienko, 2011; Starostenko et al., 2011; Lukin, 2014; Sheremet et al., 2016; Shestopalov et al., 2018; Stupka, 2018] clearly show that the formation of hydrocarbon accumulations, as well as ore minerals, is spatially and genetically linked to geodynamic processes and the action of deep fluids and their systems in the Earth's interior. It is the influence of fluids that is considered to be one of the main factors in the formation of conductive layers in the Earth's crust and upper mantle.

For the first time, a geological and geoelectrical interpretation of the three-dimensional model of the Earth's crust and upper mantle was carried out for the Pre-Dobrudga Trough and adjacent areas, based on experimental observations of the Earth's low-frequency electromagnetic field conducted in 2009—2012 by the institutes of the National Academy of Sciences of Ukraine.

The main result of the analysis of the obtained resistivity distribution modelis the identification of areas of high electrical conductivity both in the Earth's crust and in the upper mantle, which have different conductivity and depth of occurrence, configuration, and differently characterize geological structures.

Sub-vertical conductive zones or contacts of different resistivity mainly in the near-surface layers usually coincide with deep faults of different ranks and their intersections: Frunzenskyi, Saratskyi, Bolhradskyi, Kahulsko-Izmailskyi, Chadyr-Lunhskyi, Lebedovskyi, Dnistrovskyi, Vladychen-Muravlovskyi, Bolhradsko-Suvorovskyi, Dmitrievskyi, Nerushayskyi, Spaskyi, Hlybochytskyi, Novooleksiyivskyi, etc.

Deeper in the Earth's crust (10—40 km) and at crust-mantle depths (10—60 km), local geoelectric heterogeneities have a complex volumetric shape, some of which coincides with the location of the above deep fault zones. In the Paleozoic PDT and the studied part of the northwestern Black Sea shelf, the upper mantle at depths of 110—160 km is manifested by a regional conductivity anomaly, namely, an asthenosphere with ρ=70 Ohm·m, typical for an inactivated Cimmerian SP with a normal distribution of ρ. Thus, the territory of North Dobrudga and the PDT, as well as the entire southwestern outskirts of the EEP, is replete with anomalous objects of high electrical conductivity in the crust, and the distribution of electrical conductivity in the upper mantle reflects the position of the zone of articulation of the EEP and SP of different ages. This geoelectrically regional structure may reflect the deep structure of the TESZ in a fairly wide and extended area, which updates and details the idea of the depth to the lithosphere-asthenosphere boundary. Heterogeneities at crustal and mantle depths may indicate high permeability to deep fluids and determine the paths of their migration as one of the factors of geodynamic processes relevant to the search for promising structures.

The geoelectric heterogeneities in the Earth's crust and upper mantle are, one way or another, confirmed by the presence of various anomalies in other geophysical fields, for example, the manifestation of subvertical mantle columns in the interval (28—30° E)×(45—46° N) according to the 3D *P*-velocity model. The position and geometry of velocity boundaries in the Earth's crust obtained from the interpretation of DSS materials along the DOBRE-4 and DOBRE-5 profiles are also consistent [Starostenko et al., 2013b, 2015]. As analyzed in the article [Starostenko et al., 2013a], the increased heat flux, electrical conductivity anomalies in the Earth's crust and upper mantle, positive mantle gravity field anomaly, and 3D *P*-velocity modeling of the mantle beneath Eurasia based on seismic tomography data can be explained by the existence of a mantle plume and associated fluids and their migration paths.

The findings confidently indicate that hydrocarbon occurrences are confined to high electrical conductivity anomalies identified by three-dimensional modeling, characterized by subvertical channels (from the surface to 10 km), galvanically connected with sediments, or subvertical contact zones of different resistivity, which are observed not only in the Earth's crust (10—40 km), but also at crust-mantle depths (40—60 km) and in the upper mantle (110—160 km), and may cause the flow of ultra-deep fluids.

Based on the reviewed data from the geological and geophysical interpretation of the 3D geoelectric model of the PDT lithosphere, search criteria were developed and a significant number of local areas were identified that can be considered promising for hydrocarbon occurrence. The geoelectric criteria include:

1) the maximum thickness of the sedimentary layer;

2) sub-vertical rise of electrical conductivity anomalies from the crust-mantle depths or column to the entire thickness of the Earth's crust;

3) sub-vertical boundaries of heterogeneities (ρ contacts) in the consolidated crust and upper mantle;

4) the presence of a highly conductive asthenospheric layer.

Most of the local areas that are promising according to geoelectric criteria spatially coincided with the already well-known oil and gas fields — Skhidnosaratske, Zhovtoyarske, Odeske and Bezymenne — as well as with the explored oil and gas prospective areas — Izmailska, Kyslytska, Primorska, Shyrokivska and those that correspond to the areas of special permits for industrial exploration.

However, there are still areas that meet most of the geoelectric criteria, but for which there is no publicly available information on their oil and gas prospects based on geological and geophysical data. These include sections (pickets, km/criteria numbers) of the profiles: «Reni—Bilyayivka» (45—65/1, 3, 4) and (113—126/1, 2), «Kiliya» (50—75/1—4), DOBRE (75—85/1,2). These areas require additional detailed geological and geophysical studies.

To summarize, we emphasize that zones of high electrical conductivity, which could arise due to the presence of deep fluids, should be considered as deep centers of hydrocarbon generation and ways of their migration to the upper parts of the Earth's crust.

The publication contains the results of research carried out under the theme of the Institute of Geophysics of the National Academy of Sciences of Ukraine No. III-11-21: «Deep structure of the lithosphere and processes of formation of mineral deposits in Ukraine and adjacent regions» (2021—2025).

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Геоелектричні неоднорідності Переддобруджинського прогину як зони проявів вуглеводнів

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Вперше для Переддобруджинського прогину та прилеглих територій проведено геолого-геоелектричну інтерпретацію тривимірної моделі земної кори та верхньої мантії, яку побудовано за експериментальними спостереженнями низькочастотного електромагнітного поля Землі, проведеними у 2009—2012 рр. інститутами Національної академії наук України. Розглянутий матеріал впевнено свідчить про приуроченість проявів вуглеводнів до виявлених аномалій високої електропровідності, які характеризуються субвертикальними каналами (від поверхні до 10 км), гальванічно пов'язаними з осадовими відкладами, або субвертикальними контактними зонами різного опору, що спостерігаються не тільки в земній корі (10—40 км), а й на коромантійних глибинах (40—60 км) та у верхній мантії (110—160 км), і можуть обумовлювати надходження надглибоких флюїдів.

За геоелектричними критеріями (максимальна потужність осадової товщі; субвертикальний підйом аномалій електропровідності з коромантійних глибин або колонки на всю потужність земної кори; субвертикальні границі неоднорідностей (контакти різного опору) в консолідованій земній корі та верхній мантії; наявність високопровідного астеносферного шару) виявлено значну кількість локальних ділянок, які можна вважати перспективними на прояв вуглеводнів. Їх більшість просторово співпала з уже добре відомими нафтогазовими родовищами — Східносаратським та Жовтоярським, з розвіданими нафтогазоперспективними площами (Ізмаїльська, Кислицька, Приморська, Широківська), а також з тими, що відповідають ділянкам спеціальних дозволів на промислово-розвідувальні роботи. Проте виявлені нові ділянки, що відповідають більшості геоелектричних критеріїв, але для яких відсутня будь-яка загальнодоступна інформація про їх нафтогазоносність, однозначно потребують додаткових детальних геолого-геофізичних досліджень. Показано, що зони високої електропровідності, спричинені наявністю глибинних флюїдів, необхідно розглядати як глибинні осередки генерації вуглеводнів і шляхи їх міграції у верхні горизонти земної кори.

Ключові слова: геоелектромагнітні методи, інтерпретація тривимірної моделі, аномалії електропровідності, вуглеводні.