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Donbas geoelectrical structure

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The Donbas was formed as the result of Late Devonian rifting of the East European craton. During the Carboniferous, the subsidence of the basin and sedimentation were at their maximum, and a 15-kilometer stratum of Carboniferous deposits formed in the Donbas. The total thickness of the deposits reaches more than 20 km. The next important event was folding, which occurred in the Late Triassic — Early Jurassic and Late Cretaceous — Early Tertiary. The inversion lifted the upper part of the folded Donbas and subsequent erosion exposed the Carboniferous coal-bearing strata on the surface of the earth. Deep electrical conductivity was studied by the methods of magnetovariational profiling (MVP) and magnetotelluric sounding (MTS). The first large survey (13 long-period MTS sites and 32 MTS points) was carried out in 1986; in 1988 another 30 MTS were performed. In 2012-2013, a profile of 15 MVP-MTS sites was made with modern instruments that allow obtaining more accurate results. The data interpretation yields the following conclusions. The intense Donbass electrical conductivity anomaly (DAE) runs along the main anticline of the folded Donbass. In the northwest, it continues in the DDD, in the southeast — on the Karpinsky swell. DAE parameters obtained by the MVP method: Based on the frequency response of the anomalous field, the total longitudinal conductance G = $(8\pm2)\times10^8$S×m was estimated. Profile graphs of the anomalous field of geomagnetic variations give an estimate of the maximum possible depth of the anomalous currents center $h_{max.c.curr}$, which depends on the variations period. For DAE at the maximum frequency response $T_0\approx3600$ s, it turns out to be equal to $h_{max.c.curr}=18\pm2$ km. The upper edge of the anomaly is estimated from MTS data. Most of the available 70 MTS $\rho_к$ curves begin at periods of 0.1—1 s from approximately the same level of 15 Ohm·m±half an order of magnitude. This means that in the Donbass, the rocks of the upper approximately half-kilometer layer have, as a rule, electrical resistivity in the range of 5—50 Ohm·m. Deeper, the resistivity can increase to hundreds and thousands of Ohm·m or decrease to units or fractions of Ohm·m. An analysis of the MTS by area showed that objects of low resistance (LRO) are located in two conductive bands, the upper edge of which varies from 0.3 to 5 km. The bands are parallel to the DAE axis and can be considered as some part of the anomaly. A very large value of G leads to the assumption that the anomalous body extends to a considerable depth. When compared with the data of other geophysical methods, it turned out that the DAE spatially coincides with an intense (up to 90 mW/m^2) linear anomaly of the deep heat flow. This fact suggests that the nature of the DAE lower part can be a partial melting of fluid-enriched heated local rocks or intrusion of mantle magma. The obtained geoelectric results support the idea of the modern tectonic activation in Donbas.

Key words: geomagnetic variations, magnetotelluric sounding, magnetic variation profiling, electric conductivity anomaly, folded Donbas.

Introduction to the geological history of the region. The object of study is the electrical conductivity structure of the Folded Donbas (FD), located inside the Precambrian East European Craton (EEC). The FD is part of an elongated chain of sedimentary basins: the Pripyat trough, the Dnieper-Donetsk depression (DDD) in the west-northwest, the Karpinsky swell, the Caspian basin, and, possibly, the Mangyshlak on the Turan plate, in the east-southeast. The DDD and FD were formed as a result of the Middle-Late Devonian rifting accompanied by intense magmatism. During the Carboniferous, subsidence, and sedimentation continued in the Donbas, resulting in the formation of coal-bearing deposits strata up to 15 km thick. The total sedimentary thickness here reaches 20 km. The next important event in the geological history of the Donbas was folding, which occurred in the periodic compression mode during the Cimmerian time (Late Triassic — Early Jurassic) and Late Cretaceous — the beginning of the Tertiary period. Then the inversion uplifted the upper part of the folded Donbas and subsequent erosion exposed carbon formations on the Earth's surface, including coal-bearing seams (Fig. 1). Many outcrops, hundreds of mines and wells provide rich material for studying the geological history and upper layers structure of the Donbas. Significant assistance in these studies is the use of geophysical data.

Electromagnetic (EM) studies in the Donbas — field measurements. In June-July 1986, on the initiative of A.A. Zhamaletdinov, the all-Union experiment «Volga-86» was carried out with the wide participation of Ukrainian geophysicists. The Institute of Geophysics of the Ukrainian Academy of Sciences performed observations at 13 points with analog magnetovariational stations (MVS) of Bobrov system using the method of magnetovariational profiling (MVP). The Central Geophysical Expedition (CGE) of the Ministry of Geology sciences of Ukrainian SSR

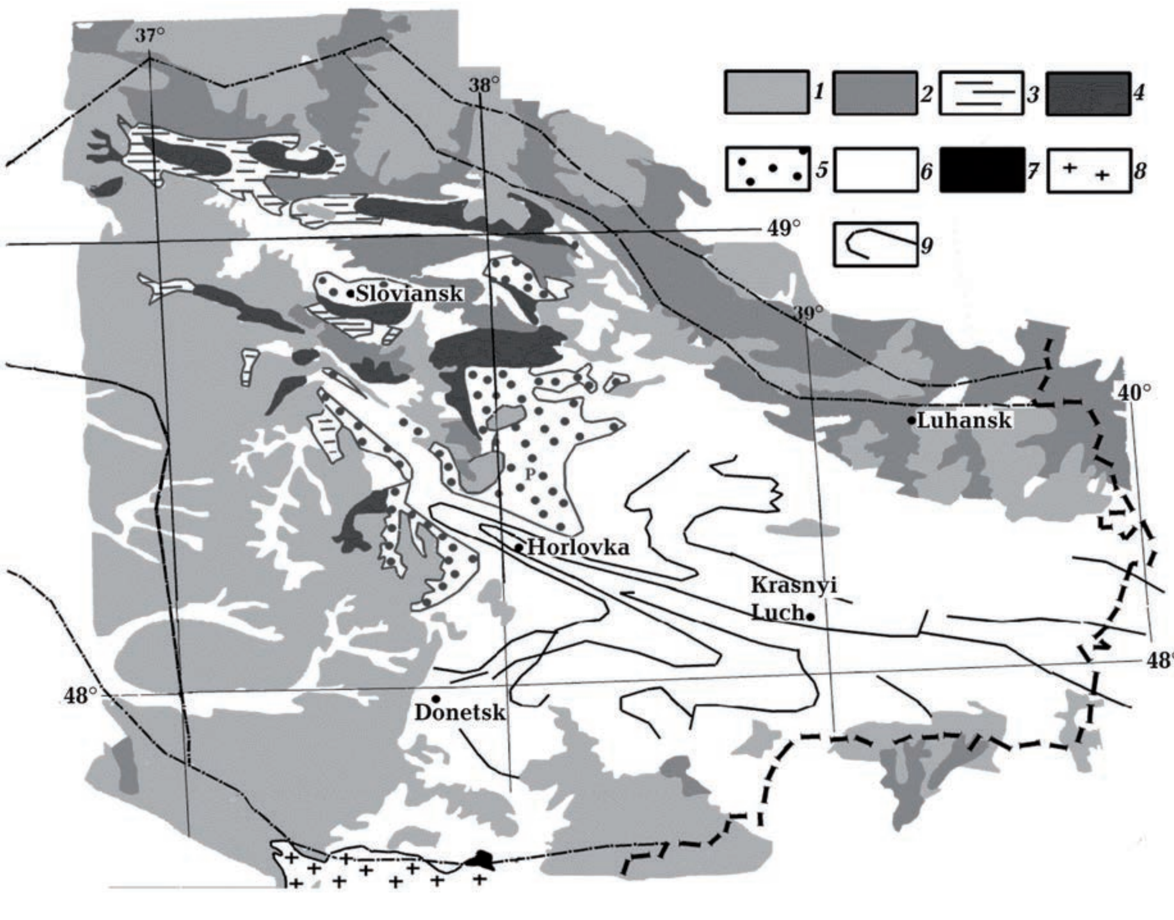

Fig. 1. Schematic geological map of Donbas. Rocks: *1* — Cenozoic, *2* — Cretaceous, *3* — Jurassic, *4* — Triassic, *5* — Permian, *6* — Carboniferous, *7* — Devonian, *8* — crystalline rocks of the Azov massif, *9* — outcrops of limestone layers marking the folded structures of the Carboniferous, in particular, the Main Anticline (passes through Gorlovka), along which the Donbas anomaly of electrical conductivity extends [Lazarenko et al., 1975, Gordienko et al., 2015].

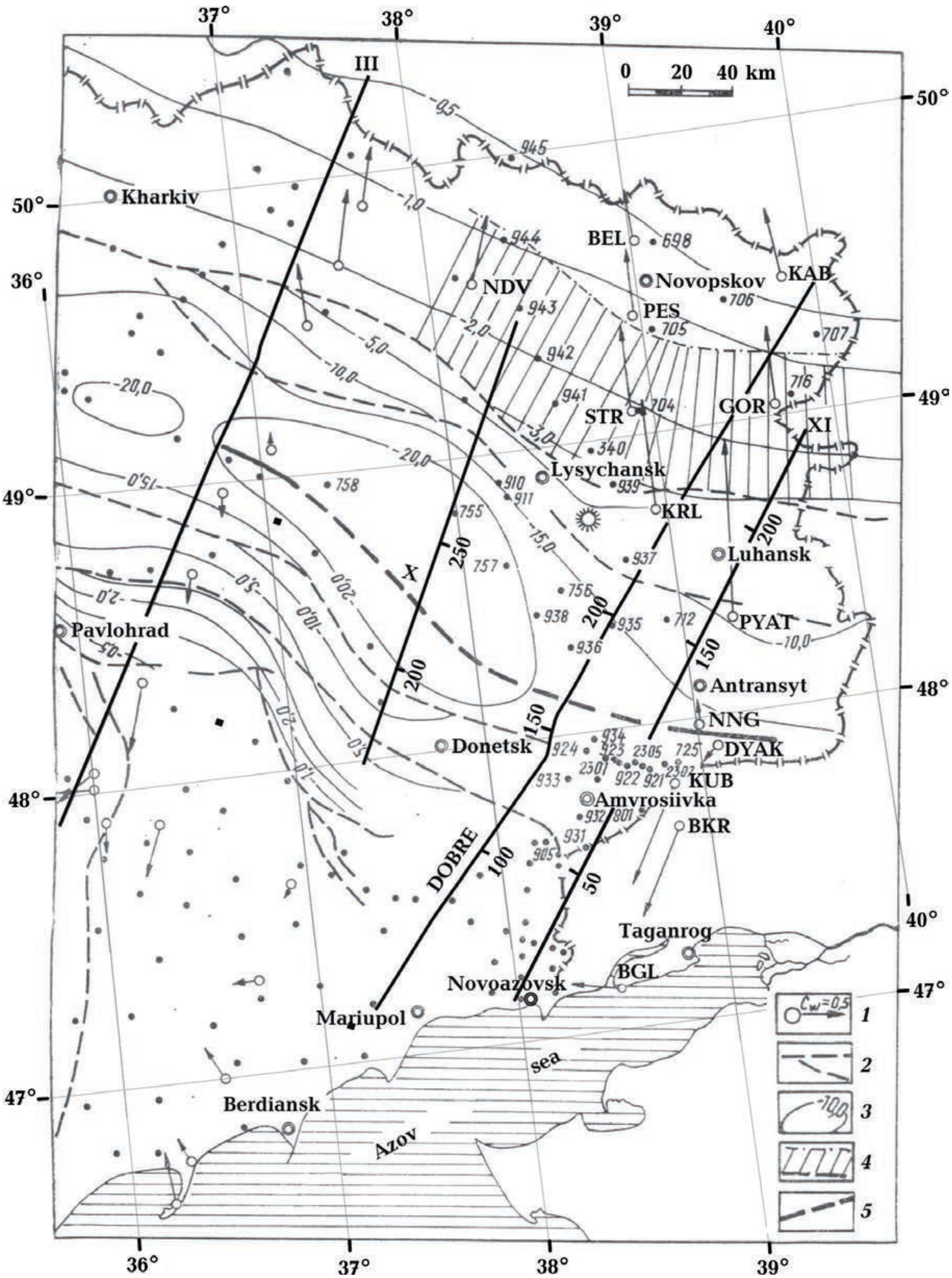

Fig. 2. Points of MVP—MTS in Donbas: *1* — MVP points (with a three-letter code) with real induction vectors for the periods interval 1800—5400 s, *2* — deep faults, *3* — depth to the crystalline basement, *4* — conductive layer in the sediments at a depth of several hundred meters, *5* — axis of the Donbass electrical conductivity anomalies (DAE). Dark dots with numbers in the study strip are MTS points, some of which are shown in fig. 3 [Rokityansky et al., 1989].

performed magnetotelluric soundings (MTS) with five-component digital stations DES-2 in the range of periods 0.1—3000 s at 32 points. The MVP and MTS points were located in a wide quasi-meridional strip called the Novoazovsk (between Mariupol and Taganrog) — Novopskov profile (Fig. 2). In the southern part, this profile approximately coincides with deep seismic sounding (DSS) profile XI; in the northern part, it occupies a wide strip from DSS profile XI to DOBRE line and west of it to profile X [Rokityansky et al., 1988, 1989]. In this article, previous results are generalized, supplemented with new observations, partially reinterpreted, and refined anomaly parameters with uncertainty estimates are obtained.

The MVP method clearly identified an intense anomaly of geomagnetic variations with a maximum at a period of 3600 s, which gave an estimate (in a two-dimensional approximation) of the total longitudinal conductance of the anomalous body $G \approx 10^9$ S×m. Using the induction vectors, the position of the axis of the Donbas conductivity anomaly (DCA) was determined with good accuracy. On the meridian 39° E, the axis runs approximately 3 km south of parallel 48° N between the settlements of Nizhniy Nagolchik and Dyakovo, where MVS stations operated (NNG and DYAK points in Fig. 2).

The available MTS curves at 32 points were divided into 10 groups, each of which was located in a strip parallel to the DCA axis. In each band, the curves had some common behavior, however, differences were also observed due to the deviation of the structure from two-dimensional and the presence of distortions, including geological ones. In two bands, the MTS data reliably established the presence of shallow-lying conductors, but in the DCA axis region, no MTS points were made. In 1988, the CGE made more than 30 additional MTS observations in a wide area from Amvrosievka to Lugansk [Rokityansky et al., 1994]. Let us briefly present the results of the three works mentioned above, representing 13 MVP points and about 70 MTS points.

On Fig. 3 16 MVP-MTS curves in five characteristic strips from north to south are presented. Most of the curves in the Donbas begin at periods of 0.1—1 s from approximately the same level of 15 Ohm·m±half an order of magnitude. This means that in the Donbas, the rocks of the upper approximately half-kilometer layer have, on average, as a rule, a specific electrical resistivity (SER) in the range of 5—50 Ohm·m. Deeper, the resistivity can increase to hundreds and thousands of Ohm·m or decrease to units or fractions of Ohm·m, as it happens in those 2 conductive strips mentioned above and indicated in the caption to Fig. 3. At periods of the order of 100—200 s, the MTS curves already contain sufficient information about the crustal conductors. To map them, we will use the distribution of the effective apparent resistivity amplitude and the effective impedance phase [Berdichevsky, Dmitriev, 2009] on a period of 150 s (Fig. 4).

The quantities values in Fig. 4, a, b show that even the effective parameters have a strong scatter from point to point, significantly exceeding the error in processing digital records of DES-2 stations. Nevertheless, the conductive strips are reliably contoured.

The southern conducting strip begins 20 km south of the DCA axis and is observed at a distance of up to 10 km north of the DCA axis. The depth of the upper edge varies from a few hundred meters to 2—5 km. Some ρ_{app} curves fall below the level of 1 Ohm·m, which indicates even lower specific resistivity values of underground conductive objects. After the descending branch, many longitudinal curves begin to reach the ascending asymptotes S = 10000–30000 S, a value comparable to $G \approx 10^9$ S×m obtained from MVP data.

The northern conductive strip begins 35 km north of the DCA axis and ends at 55 km. On the MTS curves (see Fig. 3, second column), two conducting layers can be distinguished. The depth of the upper edge of the first layer varies around 1 km, the longitudinal conductivity S is about 100 S, the depth of the second one is several kilometers, and S is 1000—3000 S. In all parameters (apparent resistivity level, impedance phase), this stripe is less conductive compared to the southern one.

Figure 5 shows DCA models that include

both conductive strips and do not go beyond them. Each model used a slightly different set of observation points, different models of the normal depth section, for example, without asthenosphere (model 11) and with a 500 S asthenosphere (model 12). Both models correspond to the available observational data in the approximation in which the two-dimensional model can correspond to the real three-dimensional structure of the Donbas. The MVP data for long periods are close to two-dimensional behavior, but the MTS data are much more complicated.

New measurements of magnetotelluric field variations with modern equipment along the GSS profile XI Novoazovsk-Titovka were carried out in 2012—2013 at 15 points [Logvinov, Tarasov, 2015] with the construction of a geoelectric model using the 2D inversion method. As a result of careful processing by several programs, the authors determined the components of the MTS response functions with an uncertainty of 7—10 % in absolute value and 5—7° in phase, the MVP components (tipper and horizontal magnetic tensor M) with an uncertainty of 0.01—0.03 in amplitude, and up to 5° in phase [Logvinov, Tarasov, 2015]. Part of the data or all of the data was used for inversion. When using the TE-mode impedance and the tipper, the result was obtained with a minimum statistical error, when using all response functions (both impedance modes and MVP data), the error increased by 20 %. The authors present both versions of the inversion (Fig. 6). The differences between the two options are quite expected and natural, since the structures of the Donbas are not entirely two-dimensional, there is «geological noise» from small near-surface inhomogeneities and strong industrial noise. These circumstances affect various response functions differently, which explains the different results of the inversion. The reliability of the 2D inversion results is evidenced by the following fact: in the polar diagrams of the anomalous horizontal magnetic field (Fig. 7), it is seen that the maximum DCA conductivity is located under the ILN point

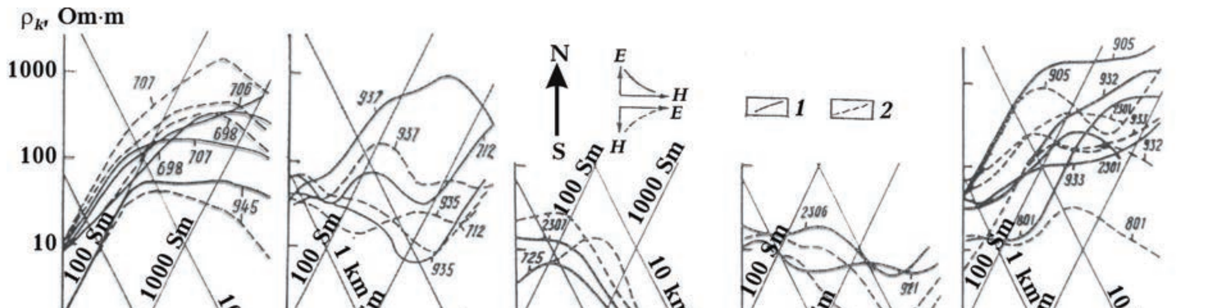

Fig. 3. MTS—MVP curves along the quasi-meridional (38—39° E) Novopskov—Novoazovsk strip crossing the Donbas. The first column on the left is on the slope of the Voronezh massif, the second is above the Northern conductive band, the third and fourth are above the Southern conductive band, the last fifth column is on the Azov massif, where the longitudinal curves still feel the presence of the DAE anomaly. The dotted lines represent the longitudinal polarization (E—W), the solid lines represent the transverse polarization (N—S) relative to the quasi-latitudinal strike of the Donbass.

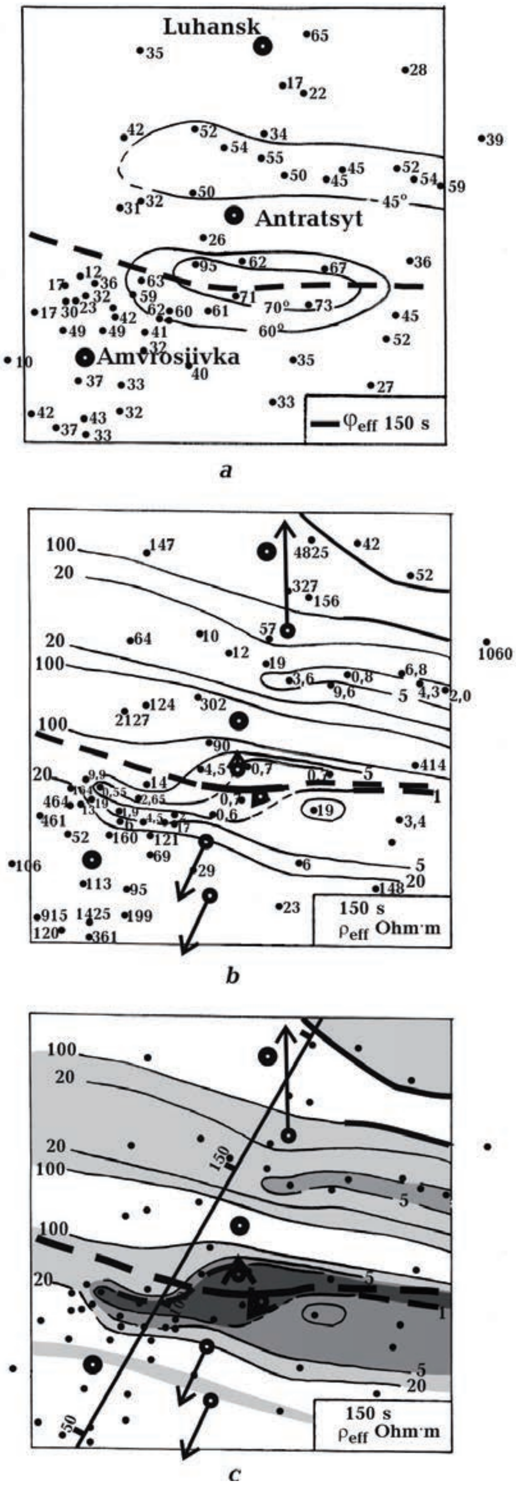

Fig. 4. Phases of the effective impedance in degrees (*a*) and amplitudes of the effective apparent resistivity (*б*) at a period of 150 s for each MTS point with isolines constructed from them. On (*в*) the profile of DSS XI is given and the resistivity of the conductive bands is described by a shade: the darkest — ρ_{eff}<1, less dark — 1<ρ_{eff}<5, light gray — 5<ρ_{eff}<100. The induction vectors and the DAE axis, as in fig. 2.

(Ilyinka). In Fig. 6 under the ILN point (located approximately in the middle between the ESL and PWL points), both variants of the two-dimensional inversion gave lower conductivity values compared to the adjacent points, which contradicts the obtained polar diagrams. Unfortunately, the article under consideration does not present the induction vectors and MTS curves, by which it is easier to understand the obtained experimental results and the resulting geoelectric structure than by inadequate 2D inversions.

Discussion of observation materials. It was noted in [Rokityansky et al., 1989, 1994] that the observed graphs of the anomalous field in the vertical and horizontal components do not satisfy the Hilbert transform, as it should be for two-dimensional anomalies, namely, the estimate of the scale (moment) of the anomaly by the vertical component turned out to be almost twice as much as horizontal. Back in 1989, it was suggested that in this highly elongated anomaly, the Hilbert transform should and does hold, but we do not see this, since the observation points were distributed over a sparse and inhomogeneous network. Two points — NNG (Nizhny Nagolchik) and DYAK (Dyakovo), separated by only 8 km, successfully turned out to be on opposite sides of the anomaly axis, and the induction vectors confidently looked in opposite directions from the anomaly axis. As a result, using these data, it was possible to determine the position of the DCA axis with high accuracy: on the meridian 39.05° E, the Axis of DCA is at latitude 47.98°±0.02° N. However, the next station north of the NNG point is at a distance of 45 km, and the next one south of the DYAK point is at a distance of 23 km. In [Logvinov, Tarasov, 2015], in our northern «gap» there are measurement points ESL (8 km north of the DCA axis), ILN (15 km), and PLV (30 km), and the maximum anomalous field in the horizontal magnetic component M is observed at the point ILN (see Fig. 7), which confirms and concretizes the assumptions made in (Rokityansky et al., 1994) that the M maximum is located not at the near-axial points of the NNG and DYAK, but is shifted to the north. In the southern «gap» at the DMT (6 km south of the

DCA axis) and STP (10 km) points, a significant *M* is also visible in Fig. 7. At six northern points of the [Logvinov, Tarasov, 2015] profile (at the latitude of Lugansk and north of it) and at the PBD point near the southern end of the profile, polar diagrams M are small and almost identical (see Fig. 7). In [Rokityansky et al., 1989, see Fig. 2] graphs of changes (along the meridianal direction) in the amplitude of variations in the northern and eastern components of the magnetic field are given for 6 intervals of periods in the range of 2—120 min. At all six points north of Lugansk, the horizontal components of the magnetic field were the same within the measurement error, one of the points (PES — Peski) was taken as the base one, and the fields of the remaining points were normalized to it. Above the axis of the anomaly (NNG and DYAK points), the northern component increased by 2.8 times for about an hour period. In this article, we like to fill in the considered «gaps» in the meridional observation profile of 1986 by the observations described in [Logvinov, Tarasov,

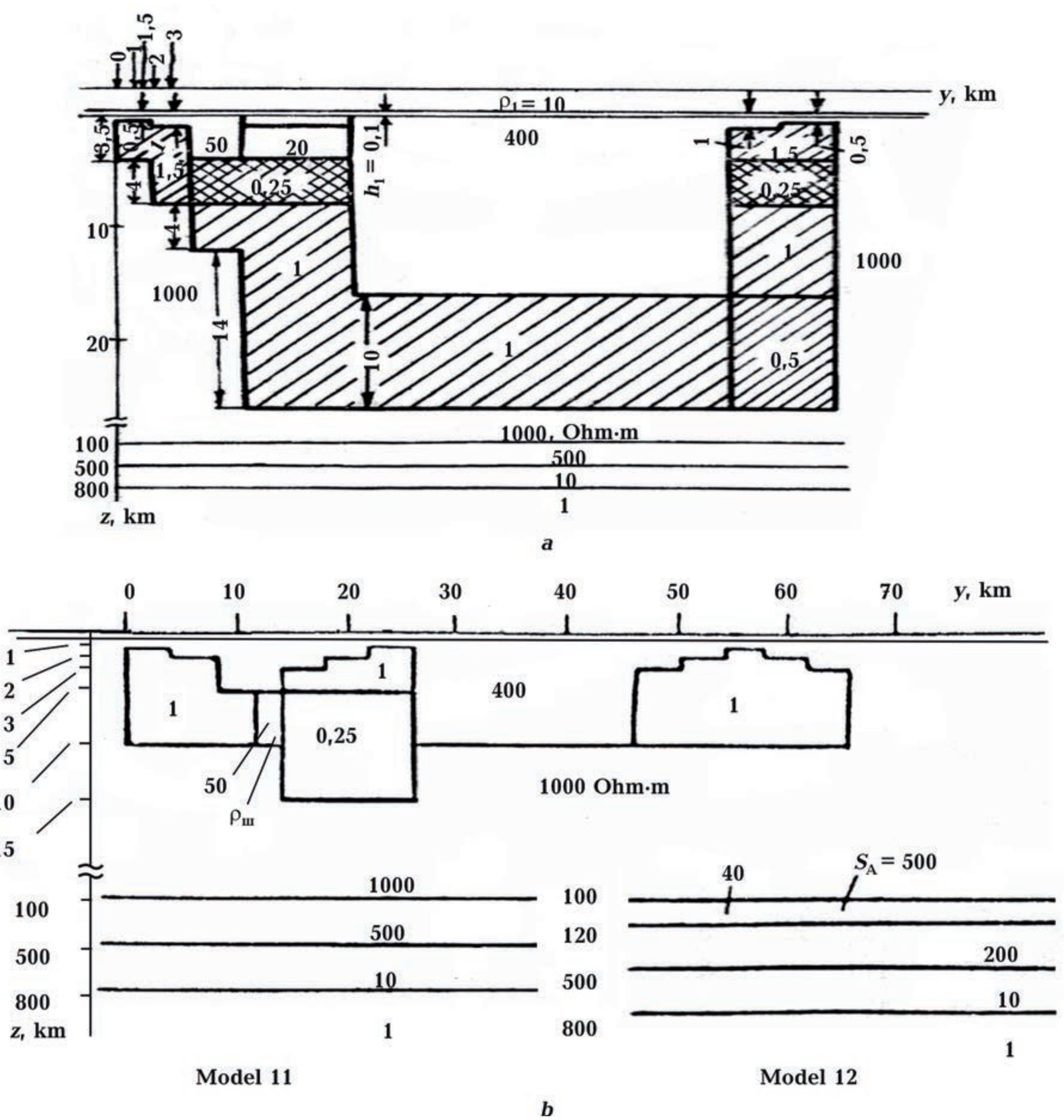

Fig. 5. Two-dimensional models of the Donbass electrical conductivity anomaly obtained by the fitting method: *a* — from [Rokityansky et al., 1989], *б* — from [Rokityansky et al., 1994]. The *x*-axis of homogeneity is directed along the W—E line perpendicular to the plane of the drawing, the *y*-axis is directed to the north.

2015]. To do this, it is necessary to get rid of ellipses in the normal field (at six northern and two southern points), which arose due to the use of the Kyiv (Dymer) observatory as a base point, which is located on a not quite homogeneous structure, as indicated by profile measurements performed by I.M. Logvinov and colleagues 20 years ago [Gordienko et al., 2005], and by the results of the induction vector periodic variations study in [Rokityansky et al., 2012]. The amplitudes additivity of the maximum axes of the magnetic tensor polar diagrams was assumed, and the anomalous horizontal fields at the anomalous points were obtained by subtracting the average diameter at eight (six northern and two southern) points with a normal field from the diameter of the polar diagram at this point. The additivity was unlikely to be completely satisfied, and the assumption could overestimate the obtained anomalous field at the ILN point, but by no more than 0.4. In Fig. 8, the error is the same everywhere ±0.15. In the measurements of 1986, which lasted about a month in every point, for the maximum frequency response of the anomalous field at 15—90 min, the phases of the anomalous field were small, and manual processing fully ensured such accuracy. In the works of 2012—2013 [Logvinov, Tarasov, 2015], the statistical error of the obtained magnetic response functions was estivated as small as 0.01—0.03. Given for selected points in Fig. 2 of [Logvinov, Tarasov, 2015], the frequency characteristics of horizontal anomalous field amplitude show scattering of the order ±0.15, but for the most

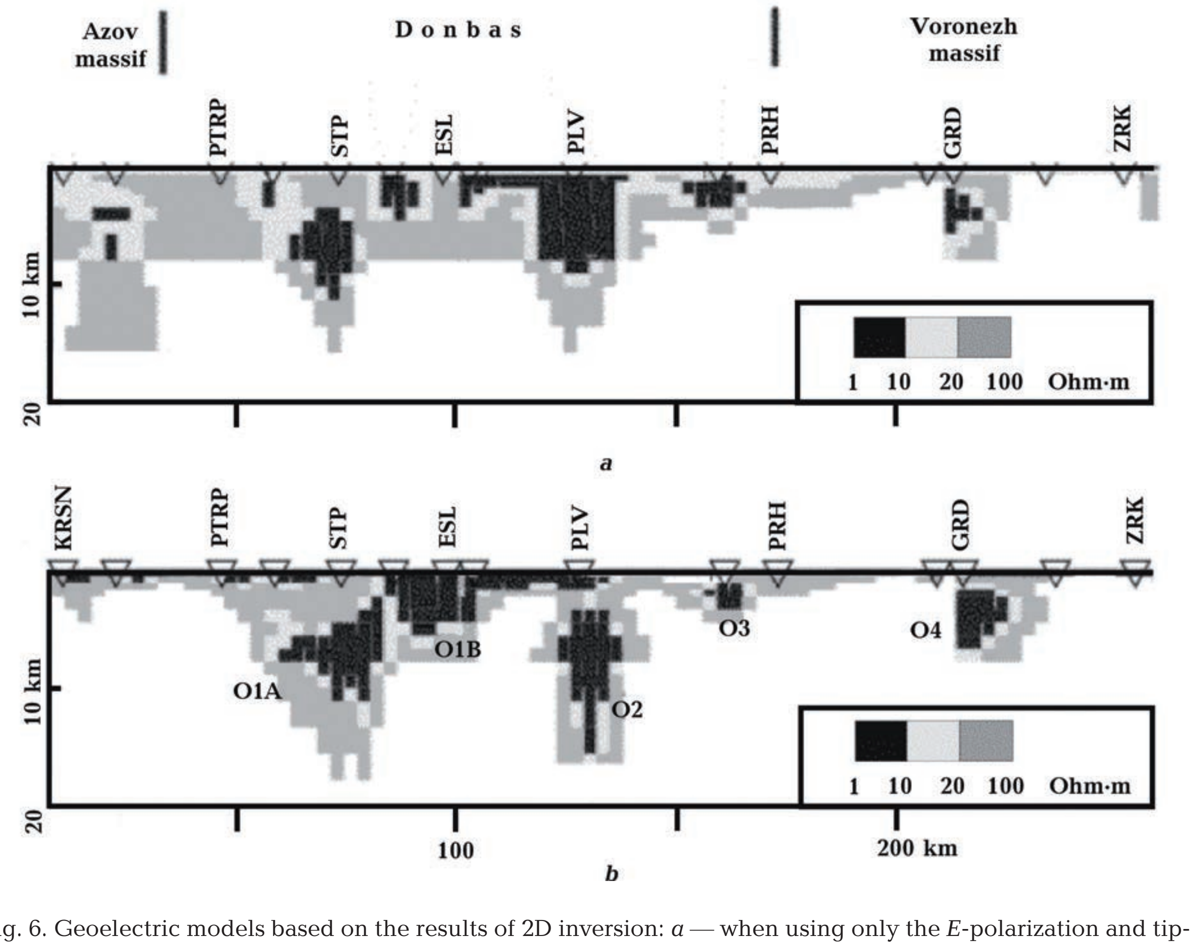

Fig. 6. Geoelectric models based on the results of 2D inversion: *a* — when using only the *E*-polarization and tipper data, *б* — when using all the data [Logvinov, Tarasov, 2015]. When copying from the original, we leveled the horizontal scales and discarded the deep part with the mantle anomaly under the Azov massif, which was obtained due to the lateral influence of the conductive strata of the Indolo-Kuban trough and, possibly, the DAE itself. Point «ИЛН» displaced from its place and not named.

interesting point ILN with the maximum amplitude of the anomalous field, the frequency characteristic is not given. Therefore, the amplitude can be taken only from the graphs (see Fig. 7), which are drawn with excessively thick lines without maintaining the symmetry of the polar diagrams relative to the center and are not completely identical in the two original publications. Taking into account all the factors considered, the most probable value of B_{ya} for the ILN point was estimated and may be too favorable uncertainty ±0.25 was prescribed to it. As a result, the graphs of the horizontal and vertical components were obtained (Fig. 8), which a little better correspond to the Hilbert transform than before the introduction of data from the ILN (Ilyinka) station obtained in [Logvinov, Tarasov, 2015].

The nature of the reduced resistance objects (ORR). This issue for coal-bearing regions is considered in [Logvinov, Tarasov, 2015]. It presents graphs of the dependence of the special resistivity of coals of various grades on the percentage of carbon in them. When this content exceeds 90 %, there is a sharp decrease in resistivity to 1—0.01 Ohm·m. Approximately the same special resistivity is assumed by the above authors in porous rocks filled with highly mineralized solutions. Hence, it can be concluded that the decrease in the apparent resistivity curves level to 1 Ohm·m and below, observed in some areas, is a response to real ORR in the upper parts of the earth's crust.

On the ambiguity of the inverse problem. Fig. 5 shows two DCA models obtained from different sets of observation points. The models were built taking into account the analysis of the MTS curves at each point and their approximate one-dimensional interpretation. Some 2D model was put forward, a direct problem was solved, the result was compared with observations, the interpreter, based on the accumulated experience, determined how to change the model parameters to bring the result closer to the observation data. In [Rokityansky et al., 1989, 1994], 12 DCA models were calculated.

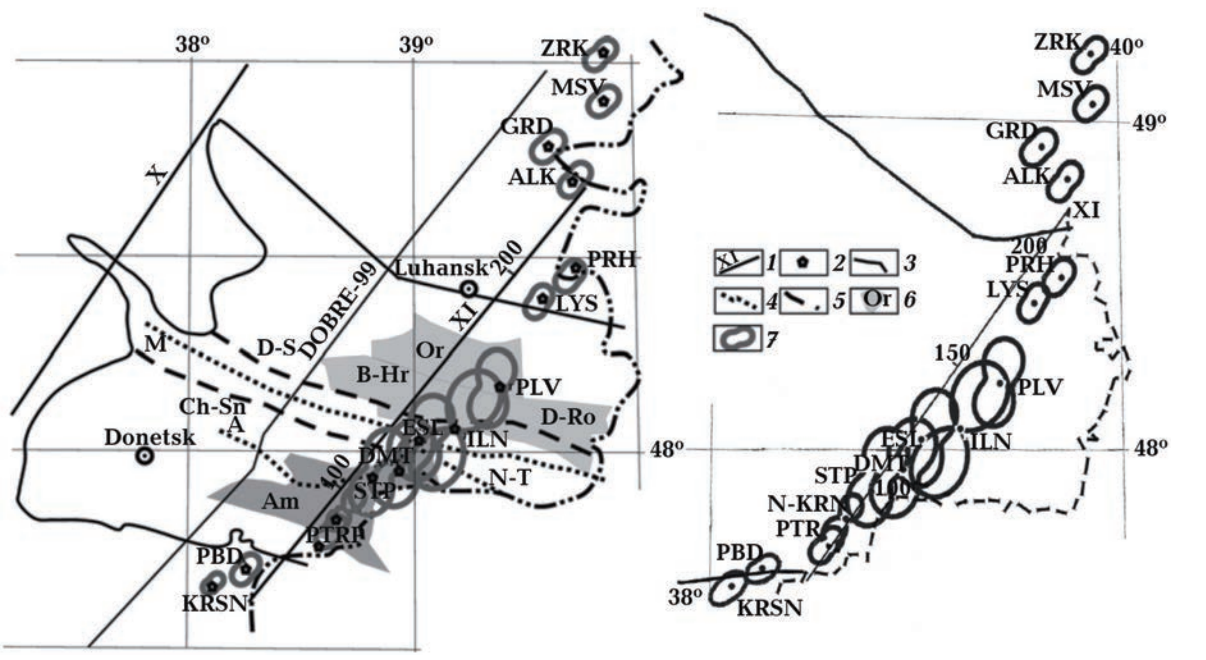

Fig. 7. Polar diagrams of the anomalous horizontal magnetic field. The left part is taken from [Logvinov, Tarasov, 2015], the right part is taken from Logvinov, Tarasov (Ch. 5. Geoelectric Models., p. 90—107 in the book [Gordienko et al., 2015]): *1* — DSS profiles, *2* — MVP-MTS points, *3* — boundary of the folded Donbass, *4* — anticlines (Г — Main, Н-Т — Nagolno-Tarasovskaya, А — Amvrosievskaya), *5* — synclines (Ч-С — Chistyakovo-Snezhnyanskaya, Д-С — Dolzhansko- Sadkinskaya), *6* — coal-bearing areas, *7* — polar diagrams. The designation of the Ilyinka point has been corrected from ИЛЛ to ИЛН.

Two models presented in Fig. 6 were obtained by the authors of [Logvinov, Tarasov, 2015], in which the authors «assigned» the labor-intensive work of selection to the automaton, namely, to a good internationally recognized 2D inversion program. Which of the two obtained models is better, i.e. closer to the «true» 2D section, the authors did not write. And this is correct, because a «true» 2D section may not exist for the data they received in Donbas.

Geothermal results and the idea of modern tectonic activation of Donbas. Donbas is one of the most geothermally studied regions in the world. On its territory, about 6,000 individual measurements of deep heat flow (HF) were made in individual wells, grouped into 2,700 points.

The measurements were carried out carefully, with the introduction of all necessary corrections, and are described in detail in the literature (Gordienko et al., 2015 and references therein to previous works), which makes it easy to make new refinements. The error in determining the deep HF has been increased to 1.5 mW/m^2. The latest version of the HF map is shown in Fig. 9. When considering Fig. 9, attention is drawn to an intense linear anomaly in the lower right corner, which spatially coincides with the DCA along its strike and location. This fact attracts our special attention.

V.V. Gordienko, on the basis of a thorough study of the geological history and geophysical information, developed the advection-polymorphic hypothesis, one of the conclusions of which is the formation and rise of partial melting zones in the Earth's mantle. With the accumulation of sufficient energy, the «quantum of action», the heated volume

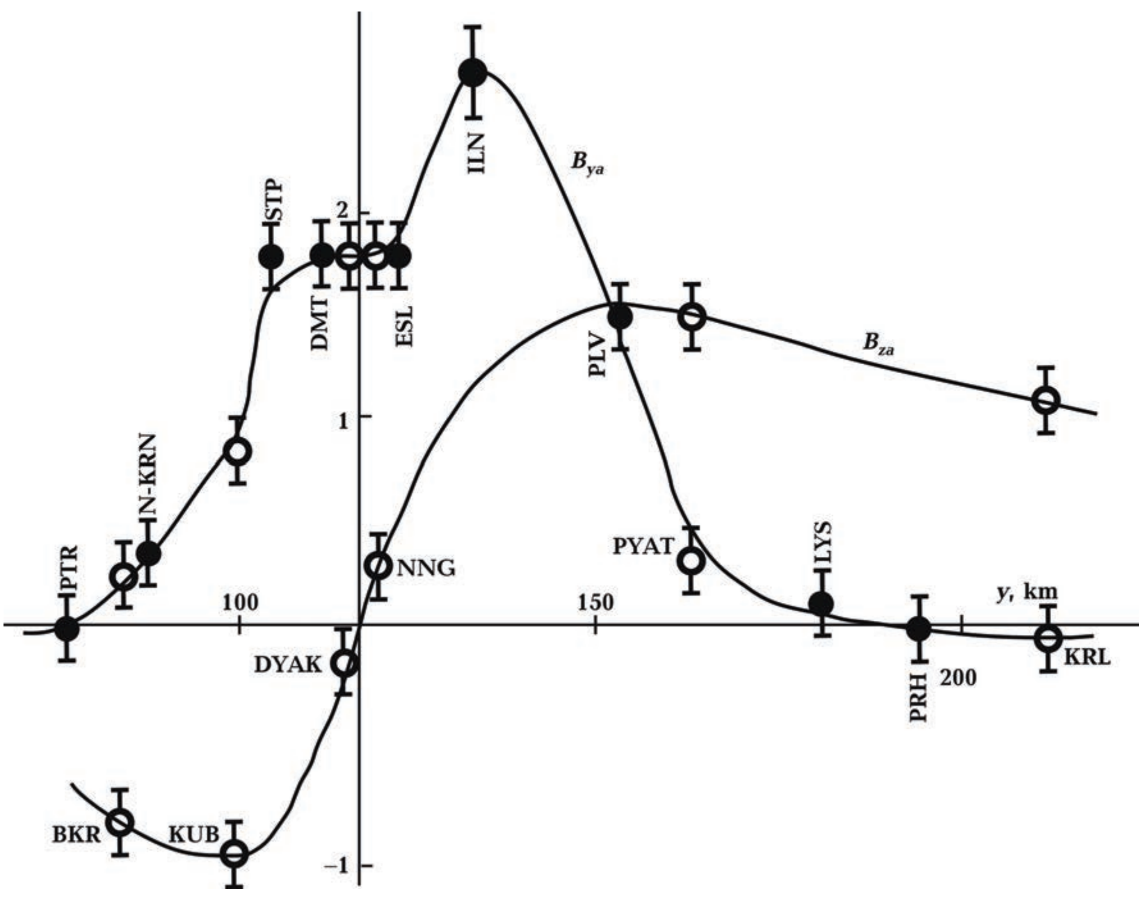

Fig. 8. Changes in the anomalous field amplitude for the horizontal and vertical components of geomagnetic variations with periods 30—90 min. Empty circles are data from [Rokityansky et al., 1994], black circles are corrected data from [Logvinov, Tarasov, 2015].

of the mantle substance rises successively to the shallower mantle levels and then to the crustal levels. In the upper zones of the formed magma chambers, volatiles, in particular water, are released, and convective cells are formed, through which the heat flow relatively quickly reaches the surface. Magma, zones of partial melting, characteristic of the low-temperature (≈600 °C) amphibolite facies of regional metamorphism, and convective cells are characterized by low special resistivity of the order of 1 Ohm·m or less. They can be components of the described Donbas electrical conductivity anomaly.

The works [Ilchenko, Stepanenko, 1998; The DOBRE, 2003, etc.] present the results of seismic soundings along the XI and DOBRE profiles, which will be useful in a more wide discussion of the DCA nature.

Conclusions about the geoelectric structure of Donbas. Magnetovariational profiling determined the position of the DCA axis: on the meridian 39.05° E the sign change of the vertical component is located at the latitude of 47.98°±0.02° N, or in the reference system of the DSS XI profile pickets — at the 116±3 km picket. Based on the anomalous field frequency response, the total longitudinal conductivity was estimated as G=(8±2)×10^8 S·m. In addition, profile graphs of the anomalous field of geomagnetic variations (see Fig. 8) give an estimate of the maximum possible depth of the anomalous currents center $h_{\text{max.c.c.}}$, which depends on the variations period. For DCA at the maximum frequency response T_0≈3600 s, it is equal to 18±2 km. It should be emphasized that we are talking about the center of the anomalous currents, the depth of the anomalous body lower edge is not limited by geoelectric data.

The upper edge of the anomaly is estimated according to the MTS data. The works

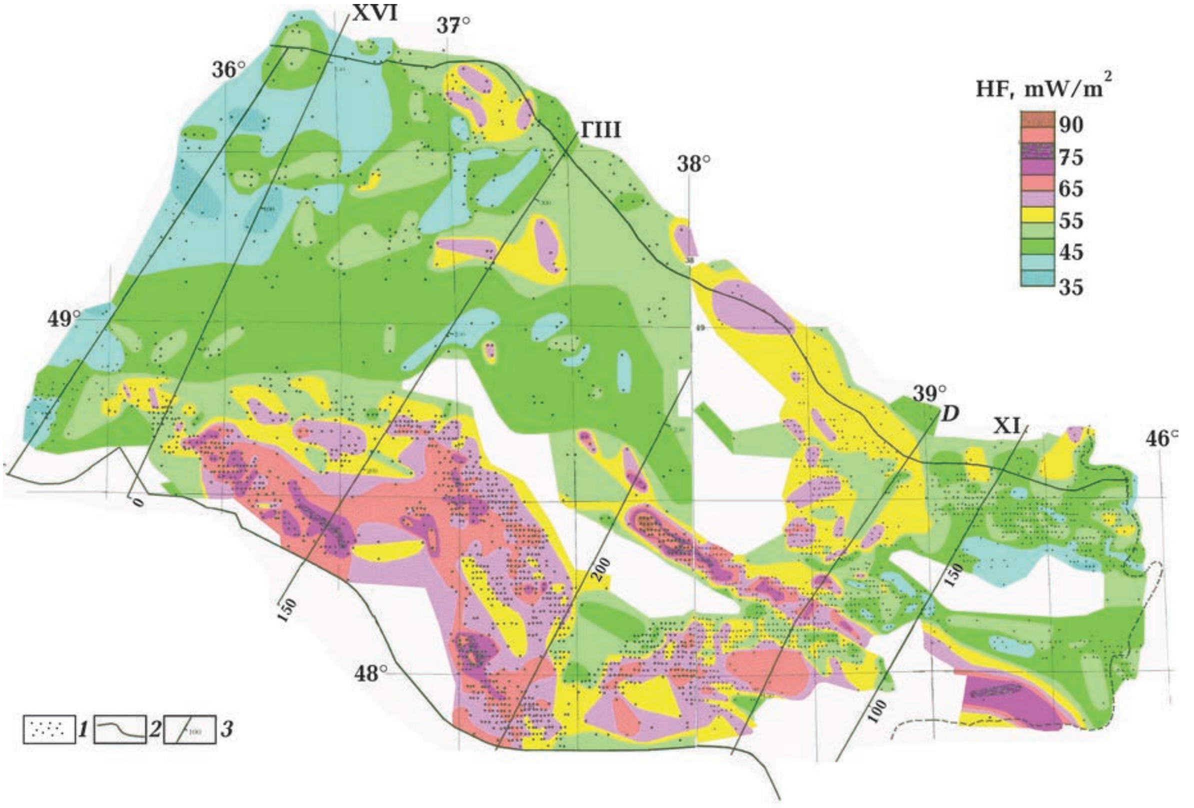

Fig. 9. Map of the deep heat flow (HF) of Donbass in mW/m^2: *1* — points are measurement sites, *2* — boundary of the folded Donbas, *3* — seismic profiles of the DSS. The dotted line on the right is the border between Ukraine and Russia, D —DOBRE profile. The linear HF anomaly in the lower right corner coincides with the Main anticline of Donbas [Gordienko et al., 2015].

(Rokityansky et al., 1989, 1994) present 70 MTS ρ_{app} curves, most of them begin at periods of 0.1—1 s from approximately the same level of 15 Ohm·m ± half an order of magnitude. This means that in the Donbas the upper layer rocks, approximately half a kilometer, have, as a rule, resistivity in the range of 5—50 Ohm·m. Deeper, the special resistivity can increase to hundreds and thousands of Ohm·m or decrease to units or fractions of Ohm·m, as it happens in the described conductive stripes, i.e. in the body of the DCA. The question arises to what depth these conductors are located. The MTS method, in addition to the upper edge depth, gives an estimate of the total longitudinal conductance S of this object but does not determine the lower edge depth. How the results of MTS (S) and MVP (G) can correlate is considered in [Rokityansky, 1975, p. 116—122].

The final model includes two conductive stripes, the southern one is wider and more conductive. The upper edge of the stripe lies at a depth from the first hundreds of meters to the first kilometers. The total width of two stripes, including the gap between them, is 70—90 km, the effective width (within which half of the anomalous currents are concentrated) is about 40 km. The total longitudinal conductivity of the entire anomaly is $G=(8\pm2)\times10^8$ S·m. If the average specific resistivity of the anomaly is taken equal to 1 Ohm·m, then its cross-sectional area Q will be 800 km^2=40 km×20 km≈28 km×28 km — the dimensions are on the verge of acceptability from the point of view of the restrictions imposed by the shape of the horizontal field profile curve (see Fig. 8) and the width of the anomalous stripes according to the MTS data (see Fig. 4). If the average special resistivity of the main conducting body is taken equal to 0.2 Ohm·m, then the body can be placed in a relatively small section shown in Fig. 10.

The simplified DCA model (see Fig. 10) shows two conductive stripes in the upper part of the sedimentary sequence, obtained from the MTS data, and the main conductor lying at a greater depth, the parameters of which are determined mainly by the MVP data, i.e., the values of G and the maximum possible width and depth of the conductor (the last parameters are limited by the shape of the profile curve of the horizontal anomalous field). The upper conductors in the figure are not connected to the lower conductive body, reflecting the fact that the available geoelectrical data do not provide a clear answer to the question of whether they are connected. The lower conductor is completely arbitrarily placed in the lower part of the sedimentary basin (20 km deep), and from above it is limited by the 600 °C isotherm, drawn just as approximately, based on the assumption of modern tectonic activation in this place and, therefore, allowing for the possibility of explaining the nature of the deep part of the DCA as rise from the mantle of a magmatic intrusion and/or partial melting of host crustal rocks. The melt zone may not be limited to the bottom of the sedimentary sequence, but most likely extends down, possibly until it joins with the mantle asthenolite. Fig. 11 shows one of the igneous intrusions left from the ancient (Early Carboniferous) tectonic activation in the Main Anticline, where the DCA passes and where, possibly, modern tectonic activation is developing.

Materials used and prospects for further research. The recordings of the CES-2 were carried out on a magnetic tape, which, after 10—15 years of storage, «crumbled» and the

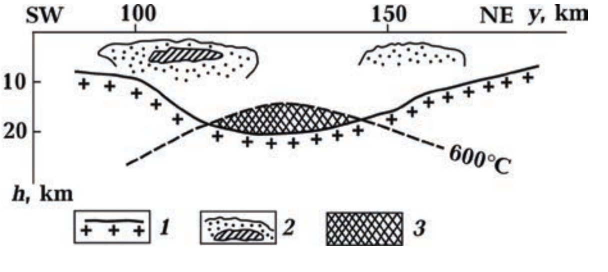

Fig. 10. Simplified model of the DAE section under the assumption of the existence of a well-conductive zone of partially molten rocks: *1* — boundary between the sedimentary sequence and the crystalline basement; *2* — two bands — conductive formations in the upper part of the crust, identified by the MTS method; oblique shading highlights a section with a resistivity less than 1 Om·m; *3* — zone of (partial) melting, dashed line — isotherm drawn according to the data of [Usenko, 2002; Gordienko et al., 2015].

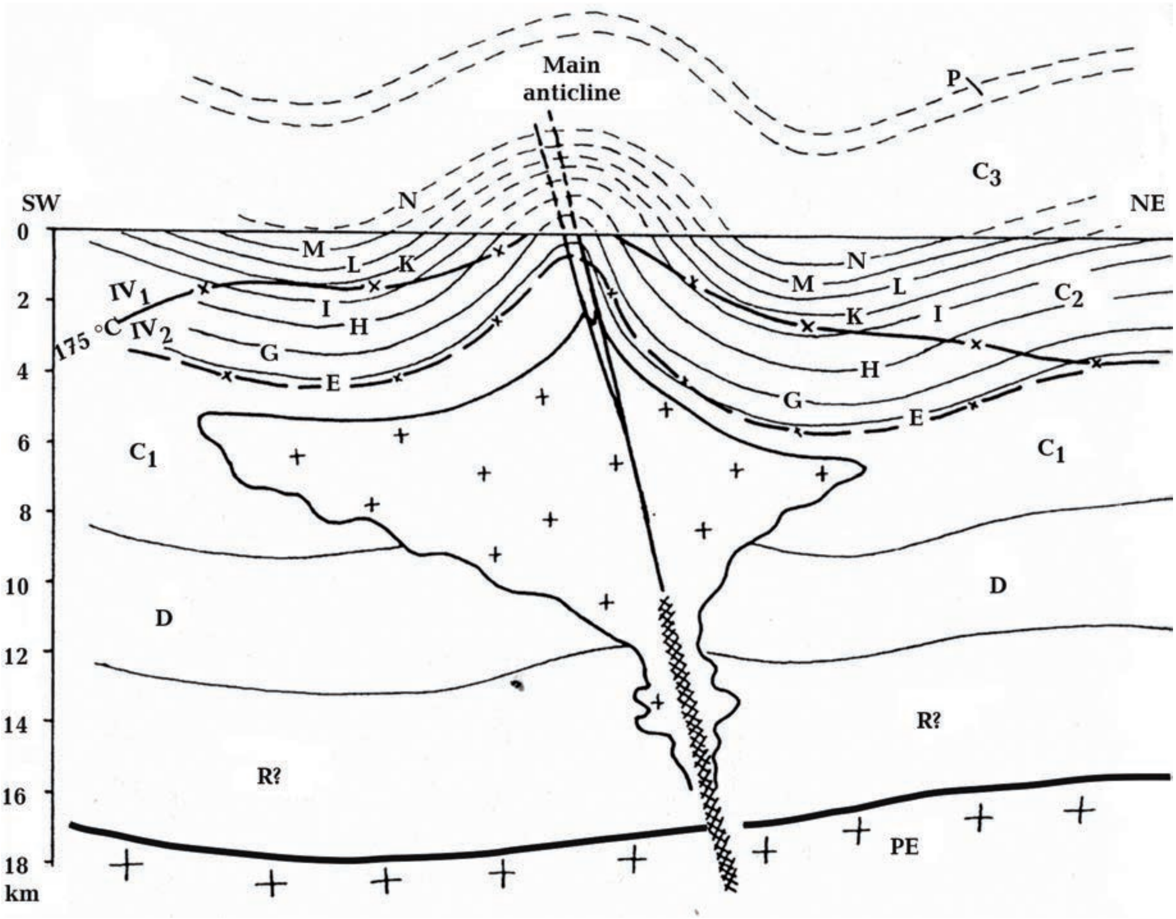

Fig. 11. Intrusion inherited from magma emplacement during tectonic activation in the Lower Carboniferous [Aleksandrov et al., 1996].

original recording of the electric and magnetic fields disappeared. The results of the old processing remained, but not in digital form, but in the form of graphs of dependence on the period of the amplitude and phase of the impedance or apparent resistance along the measurement direction and sometimes effective. Rotating the curves and entering data for inversion requires laborious digitizing, but accurate results are not guaranteed by old processing. The MVP data are recorded on photographic paper, they are carefully processed manually, but without phase measurements. They can be digitized, reprocessed, and anomalous fields can be obtained in the form of complex numbers. It will not give fundamentally new results. And these records hardly can be found. And one more drawback of the old data: the location of the measurement points was determined from old maps, sometimes distorted, and only the names of the settlements in which (or near which) the equipment was located were preserved. Therefore, the location of the measurement points is known to us with a 2—3 km uncertainty. Measurements 2012—2013 were performed by modern equipment with GPS synchronization and the most accurate determination of the location of points, using advanced processing programs and an internationally recognized program for 2D inversion. However, the concept of not publishing, not showing to anyone (and, possibly, not analyzing with due completeness) the primary processing materials - response functions (induction vectors, MTS curves...), but thoughtlessly trusting the results of 2D inversion, led to the fact that in the publication [Logvinov, Tarasov, 2015], the results of these good measurements did not provide new reliable information about the geoelectric structure of Donbas. New was the publication of polar diagrams of the horizontal anomalous field, but it revealed a discrepancy between both models of 2D inversion and observational data.

It is necessary to reprocess the observations of 2012—2013, describe and analyze all the obtained response functions and, as a result, build an updated geoelectric model of Donbas.

In the future, it is planned to clarify the parameters of reliably established fragments of the geoelectric model of the Donbas, find and analyze geoelectric materials along the Karpinsky swell, and compare the results of the analysis with the Donbas.

References

Alexandrov, A.L., Gordienko, V.V., Derevskaya, E.I., Zemskov, G.A., Ivanov, A.P., Panov, B.S., Shumlyanskiy, V.A., & Epov, O.G. (1996). *Deep structure, evolution of fluid-magmatic systems and prospects for endogenous gold potential in the southeastern part of the Ukrainian Donbass*. Kiev: IFIUNA, 74 p. (in Russian).

Berdichevskiy, M.N., & Dmytriev, V.I. (2009). *Models and methods of magnetotellurics*. Moscow: Nauchniy Mir, 680 p. (in Russian).

Gordienko, V.V., Gordienko, I.V., Zavgorodnyaya, O.V., Logvinov, I.M., & Tarasov, V.N. (2005). Dnieper anomaly of heat flow and electrical conductivity. *Geofizicheskiy Zhurnal, 27*(4), 597—611 (in Russian).

Gordienko, V.V., Gordienko, I.V., Zavgorodnyaya, O.V., Logvinov, I.M., & Tarasov, V.N. (2015). *Donbass (geophysics, deep processes)*. Kiev: Logos, 123 p. (in Russian).

Ilchenko, T.V., & Stepanenko, V.M. (1998). Velocity model of the earth's crust and upper mantle of Donbass and its geological interpretation. *Geofizicheskiy Zhurnal, 20*(2), 95—105 (in Russian).

Lazarenko, E.K., Panov, B.S., & Gruba, V.I. (1975). *Mineralogy of the Donets Basin. Part 1*. Kiev: Naukova Dumka, 254 p. (in Russian).

Logvinov, I.M., & Tarasov, V.N. (2015). Geoelectrical model of the Earth's crust and upper mantle along the Novoazovsk-Titovka DSS profile. *Geofizicheskiy Zhurnal, 37*(3), 139—152 (in Russian).

Rokityansky, I.I. (1975). *Investigation of electrical conductivity anomalies by magnetovariational profiling*. Kiev: Naukova Dumka, 279 p. (in Russian).

Rokityansky, I.I., Ingerov, A.I., Baysarovich, M.N., Dzyuba, K.I., Zamaletdinov, A.A., Lysenko, E.S., Popov, V.M., Rokityanskaya, D.A., & Shuman, V.N. (1989) Donbass electrical conductivity anomaly. *Geofizicheskiy Zhurnal, 11*(3), 30—40 (in Russian).

Rokityansky, I.I., Ingerov, A.I., & Lysenko, E.S. (1994). New data on the Donbass electrical conductivity anomaly. *Geofizicheskiy Zhurnal, 16*(1), 67—71 (in Russian).

Rokityansky, I.I., Lysenko, E.S., & Rokityanskaya, D.A. (1988). Geomagnetic variations anomaly in Donbass. *Doklady NAN USSR. Ser. B*, (7), 11—14 (in Russian).

Usenko, O.V. (2002). Heat flow and modern activation of the Donets Basin (according to new data). *Geofizicheskiy Zhurnal, 24*(5), 102—111 (in Russian).

Rokityansky, I.I., Klymkovych, T.A., Babak, V.I., & Isac, A. (2012) Annual and diurnal variations of induction vector in relation to geodynamic processes study. *Geomatics, Natural Hazards and Risk, 3*(3), 239—249. https://doi.org/10.1080/19475705.2011.601432.

The DOBREfraction'99 Working Group. (2003). «DOBREfraction'99» — velocity model of the crust and upper mantle beneath the Donbas Foldbelt (East Ukraine). *Tectonophysics, 371*(1-4), 81—110. https://doi.org/10.1016/S0040-1951(03)00211-7.

Геоелектрична структура Донбасу

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Донбас утворився в результаті пізньо-девонського рифтогенезу Східно-Европейського кратону. На протязі карбону опускання басейну і осадонакопичення були максимальними, на Донбасі утворилась 15-кілометрова товща кам'яновугільних відкладень. Загальна потужність відкладень досягає більш ніж 20 км. Наступною важливою подією була складчастість, що відбувалась у пізньому тріасі — ранній юрі та пізній крейді — на початку третинного часу. Інверсія підняла верхню частину складчастого Донбасу і слідом за нею ерозія оголила на поверхні землі кам'яновугільні вугленосні товщі. Дослідження глибинної електропровідності проводилось методами магнітоваріаційного профілювання (МВП) та магнітотеллуричного зондування (МТЗ). Перший значний сеанс спостережень (13 пунктів довгоперіодних МВП та 32 пункти МТЗ) був виконаний у 1986 році, у 1988 виконано ще 30 МТЗ. У 2012—2013 роках за допомогою сучасних приладів, що дають змогу отримувати більш точні результати, було виконано профіль із 15 пунктів МВП-МТЗ. Інтерпретація отриманих даних дозволяє зробити такі висновки. Уздовж головної антикліналі складчастого Донбасу проходить інтенсивна Донбаська аномалія електропровідності (ДАЕ). На північному-заході вона продовжується у ДДВ, на південному-сході — на валу Карпінського. Параметри ДАЕ, що отримані методом МВП: за частотною характеристикою аномального поля оцінена сумарна поздовжня провідність $G=(8\pm2)\times10^8$См×м. Профільні графіки аномального поля геомагнітних варіацій дають оцінку максимально можливої глибини центру аномальних струмів $h_{\text{макс.ц.струмів}}$, яка залежить від періоду варіацій. Для ДАЕ на максимумі частотної характеристики $T_0\approx3600$ с вона виходить рівною $h_{\text{макс.ц.стрімів}}=18\pm2$ км. Верхній край аномалії оцінюється за даними МТЗ. Більшість із наявних 70 кривих МТЗ $\rho_к$ починаються на періодах 0.1—1 с приблизно із одного рівня 15 Ом·м±пів порядку. Це означає, що на Донбасі гірські породи верхнього приблизно півкілометрового шару мають, як правило, питомий електричний опір (ПЕО) у діапазоні 5—50 Ом·м. Глибше ПЕО може збільшуватись до сотень і тисяч Ом·м або зменшуватись до одиниць або частин Ом·м. Аналіз МТЗ по площі показав, що об'єкти зниженого опору (ОЗО) розміщені у двох провідних смугах, верхній край яких змінюється від 0.3 до 5 км. Смуги паралельні вісі ДАЕ і їх можна розглядати, як складову частину аномалії. Дуже значна величина G приводить до припущення, що аномальне тіло розповсюджується на значну глибину. Під час зіставлення із даними інших геофізичних методів виявилось, що ДАЕ просторово збігається з інтенсивною (до 90 мВт/м^2) лінійною аномалією глибинного теплового потоку. Цей факт дає змогу зробити припущення, що нижня частина ДАЕ може бути зумовлена частковим плавленням збагачених флюїдами розігрітих місцевих порід або вмістом мантійної магми. Отримані результати геоелектрики підтримують ідею про сучасну тектонічну активізацію Донбасу.

Ключові слова: геомагнітні варіації, магнітотеллуричне зондування, магнітоваріаційне профілювання, аномалії електропровідності, складчастий Донбас.