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MODERN MAGNETOTELLURIC RESEARCHES OF THE UKRAINIAN CARPATHIANS

In order to study the deep structure of the southwestern Ukrainian Carpathians, where the Carpathian conductivity anomaly is located, in 2015 and 2020, modern synchronous magnetotelluric studies were carried out on the profiles of Mukachevo-Skole, Seredne-Borynya and Karpatsky at twenty-three points and the spatiotemporal distribution and the electric field on the Earth's surface, which can be used to assess the conductivity and geoelectrical structure of the region, was obtained. Processing of experimental data was performed using the software PRC_MTMV, which provides a common noise-canceling impedance estimation for synchronous magnetotellurical recordings. Curves of apparent electrical resistivity (amplitude values and phases of impedance) from 10 to 10000 s were obtained reliably. A joint analysis of the apparent resistivity and impedance phases and the formal interpretation of the deep magnetotellurical sounding curves using the Niblett transformation indicate the presence of the spatially inhomogeneous conductor both in the earth’s crust and in the upper part of the upper mantle. The chain of local conductive sections in the earth's crust coincides with the axial part of the Carpathian conductivity anomaly. High conductivity of the upper mantle was recorded in the Ukrainian Carpathians from the Transcarpathian Depression to the Skiba cover. It is shown that it is not a homogeneous layer, there is a general deepening of the upper edge to the northeast from 40–60 km (Transcarpathian depression) to 90–100 km (Krosno cover). Sharp deepening along the Porkulets and Dukla covers is revealed. Information about the existence of a deep conductor and its parameters should be the basis for quantitative interpretation and construction of the 3D deep geoelectrical model.

Key words: South-west of the Ukrainian Carpathians; Carpathian conductivity anomaly; deep magneto-tellurical sounding; anomalies of electrical conductivity.

Introduction

The distribution of electrical properties (eg, conductivity) in the earth’s crust and upper mantle has been obtained in recent decades mainly from deep magnetotelluric (MT) soundings (DMTS), which are based on measuring the magnetic and electrical components of the Earth's natural low-frequency electromagnetic field.

High conductivity of geological structures in some local areas of the Earth can be caused by the following mechanisms:

– high electronic conductivity of ore minerals, graphite, etc;

– high ionic conductivity of mineralized fluids that fill the pores, intergranular space and cracks of the Earth’s rocks. These fluids can be formed as a result of metamorphism and dehydration of rocks under high temperature, which arose during the action of the modern tectonic processes;

– partial melting of crust and upper mantle rocks;

– combination of all the above constituens, or their parts.

On the territory of Ukraine and abroad, the Carpathian conductivity anomaly, the length of which reaches several hundred kilometers, is widely known and well described in the scientific literature. It was first discovered in 1963, when unique studies of geomagnetic field variations were carried out and their anomalous local values were analyzed [Wiese, 1963]. Since then, a rapid study of the earth's crust and mantle deep horizon conductivity of the Carpathian region has begun. Excellent results of experimental mapping and interpretation of possible high conductivity causes of early research data have been published in Geoelectric and Geothermal studies KAPG Geophysical monograph [Adam, 1976], as well as in a special issue of Acta Geodaetica, Geophysica et Montanistica Hungarica [Acta…, 1984].

This area has been repeatedly studied by many researchers – geoelectricians from Hungary, the Czech Republic, Poland, Ukraine, Romania, Slovakia and Russia. Hundreds of induction parameter values and MTS curves were obtained, the maximum number of points is concentrated near the axis of the

Carpathian and Transdanubian anomalies. The main results indicate a complex deep structure and allowed to identify numerous conductive objects in the earth's crust and mantle of the study region.

The latest most complete reviews of previously performed electromagnetic studies of the Carpathian region of Ukraine can be found in the publication [Burakhovych, 2004] and special chapters of monographs [Gordienko et al., 2011, Tretyak et al., 2015]. The articles [Kováčiková et al., 2016, 2019] are devoted to the resesrch of possible connection between the Eastern Carpathians seismicity and the earth's crust geoelectrical parameters.

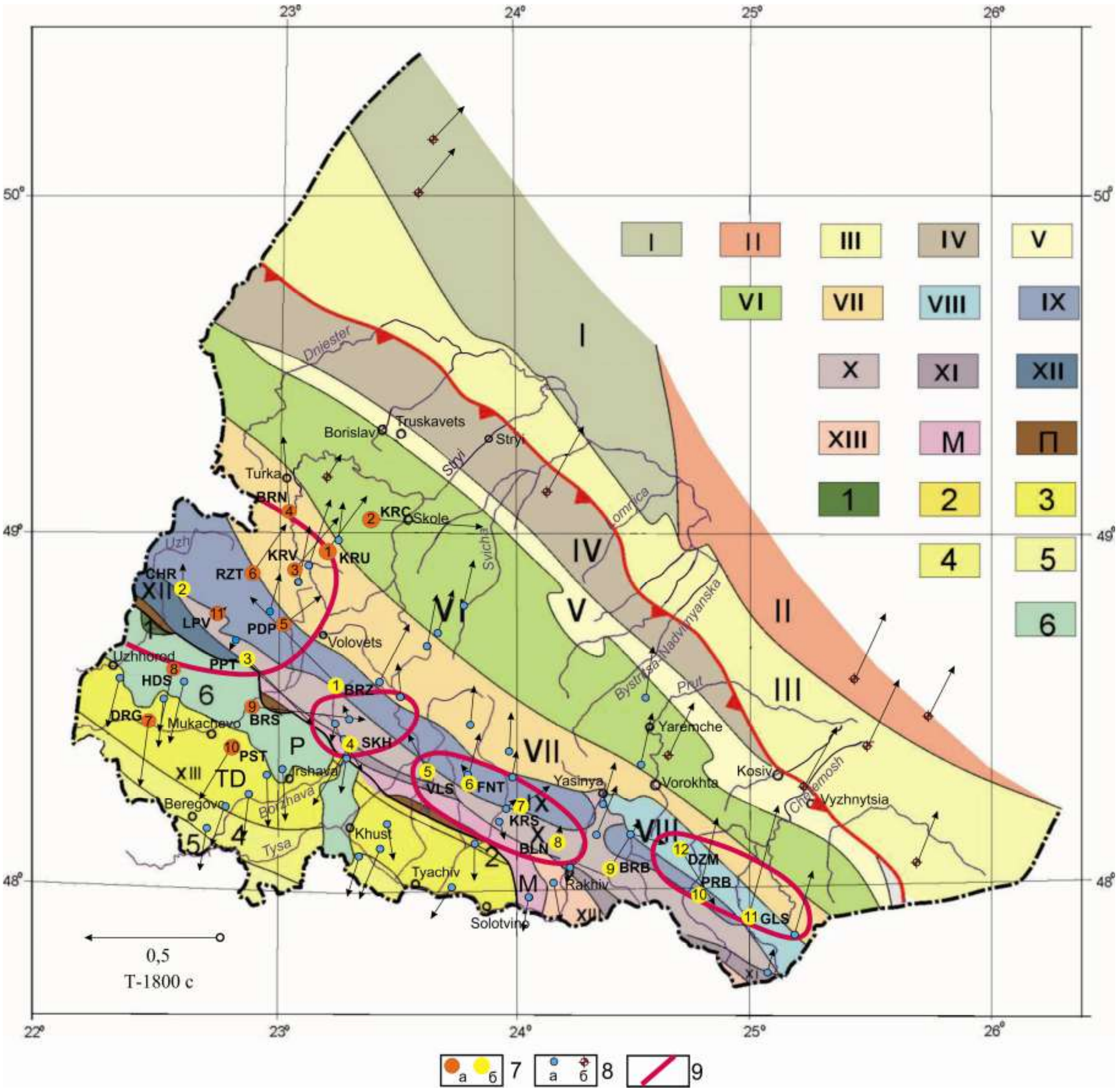


Fig. 1. The scheme of location of MVP and DMTS points and anomalous zones according to the qualitative interpretation results of electromagnetic data (2015 and 2020) on the scheme of tectonic zoning of the Ukrainian Carpathians according to [Glushko, Kruglov, 1986]:

I – Western European platform; II – Eastern European platform; III – Pre-Carpathian depression, covers: IV – Sambir; V – Boryslav-Pokutsky; VI – Skiba; VII – Krosno; VIII – Chornogora; IX – Dukla; X – Porkulets; XI – Rakhiv; XII – Magura; XIII – Marmaros massif, Zones of clips: M – Marmaros; P – Pieniny. Transcarpathian Depression (TD) and its zones: 1 – Pidhallia; 2 – Craiova; 3 – Central; 4 – Prepannonian; 5 – Pannonian depression; 6 – Vyhorlat-Huty volcanic ridge; 7 – observation points: a – 2015; b – 2020; 8 – observation points of previous researchers: a – according to [Rokityansky and Ingerov, 1999; Tretyak et al., 2015]; b – according to [Gordienko et al., 2011]; 9 – conductivity anomalies, which are alocated as a result of qualitative interpretation of DMTS data

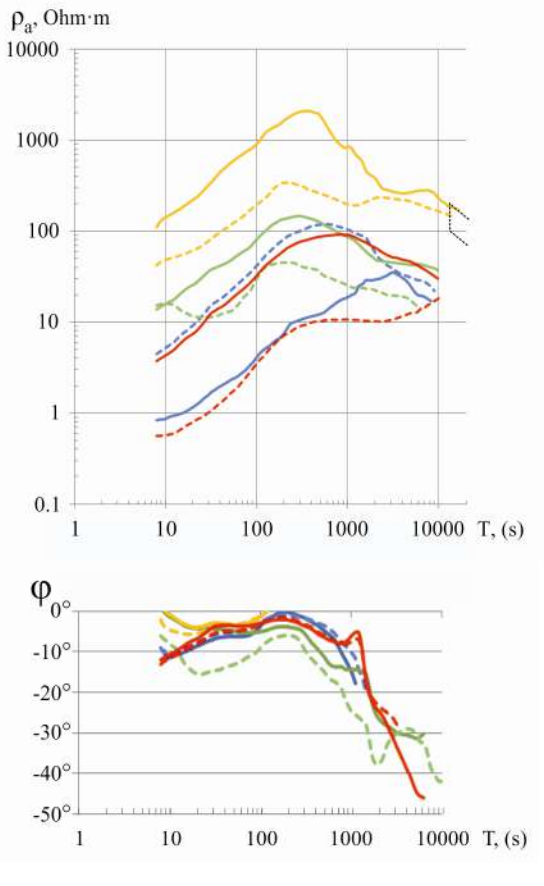
Despite the detailed all-around geoelectromagnetic study of the Ukrainian Carpathians, the range of unresolved issues to determine the nature and depth of the upper margin of the anomaly, as well as the construction of the deep three-dimensional model according to modern experimental geoelectromagnetic data, remains open and relevant. In part, such problems are justified for further research in the conclusions of the chapter "Conductivity Anomalies in Central Europe" [Tretyak et al., 2015, p. 319].

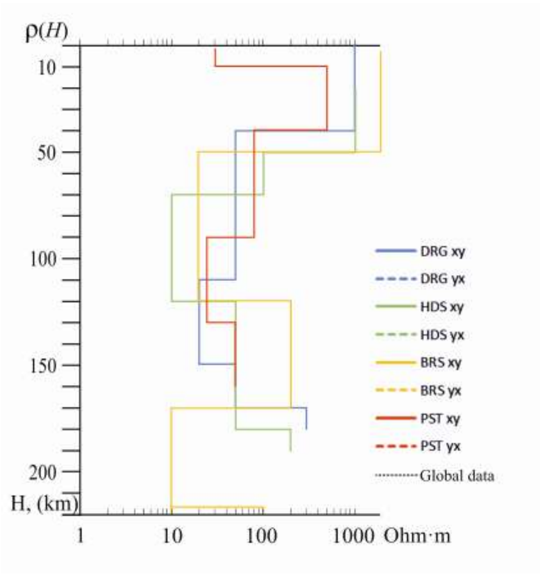
The purpose of this article is to analyze modern experimental DMTS research of the Ukrainian Carpathians, to identify at a qualitative level the parameters of the conductivity anomaly, which will serve as a basis for three-dimensional depth model building.

Modern experimental DMTS studies (2015 and 2020)

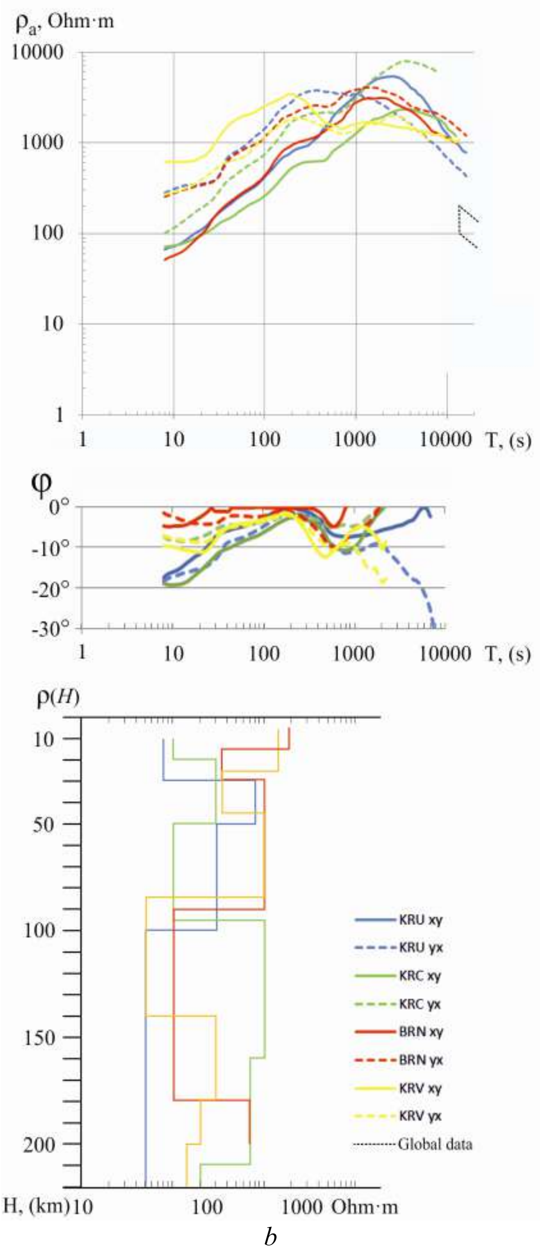
All field experiments were performed using the method of simultaneous observation of MT/MV fields using two long-term digital devices LEMI-417 with flux-gate magnetometers, which is extremely effective in deep sounding of the earth's crust and upper mantle. The stations were synchronized using GPS.

Experimental observations of MT and MV fields were carried out in the western part of the Ukrainian Carpathians (Fig. 1): in 2015 – in the cross of tectonic structures – along the two profiles of Mukachevo – Skole and Seredne – Borynya in the amount of 11 points (the distance between which was 10–15 km), in 2020 – along the western part within the known Carpathian anomaly [Rokityansky, Ingerov, 1999; Zhdanov et al., 1986; Burahovich, 2004; Gordienko, 2011], the Carpathian profile – in the amount of 12 points (the distance between which was 20–30 km). Observations in the field points were carried out from 3 to 12 days.





a



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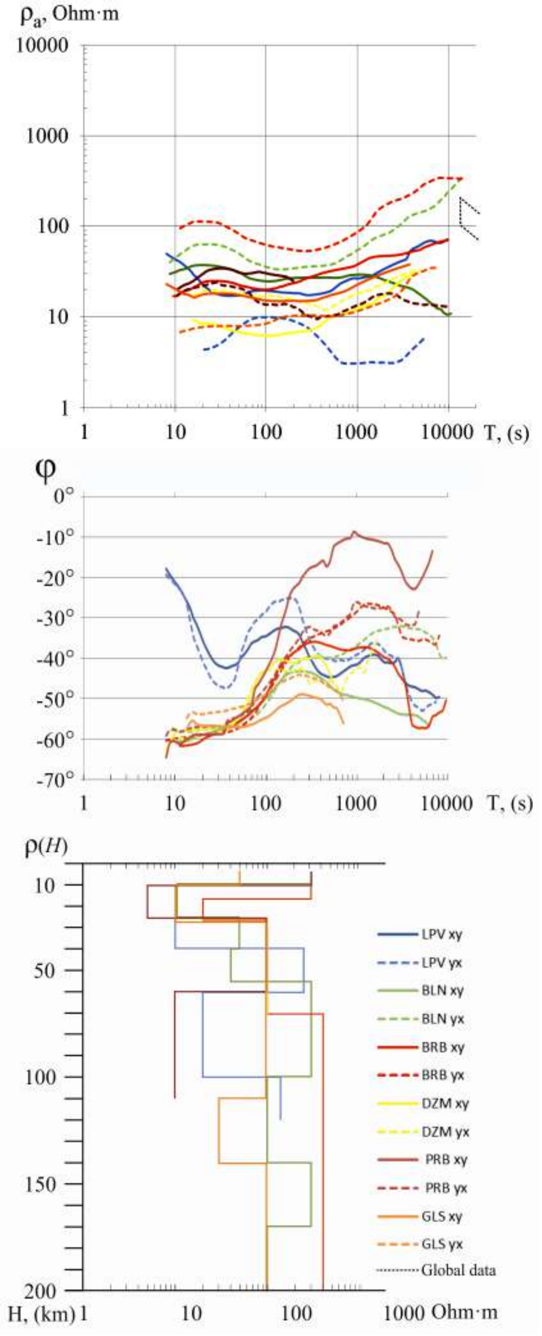
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ρ(H)
H, (km)
Ohm·m
LPV xy
LPV yx
BLN xy
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Global data

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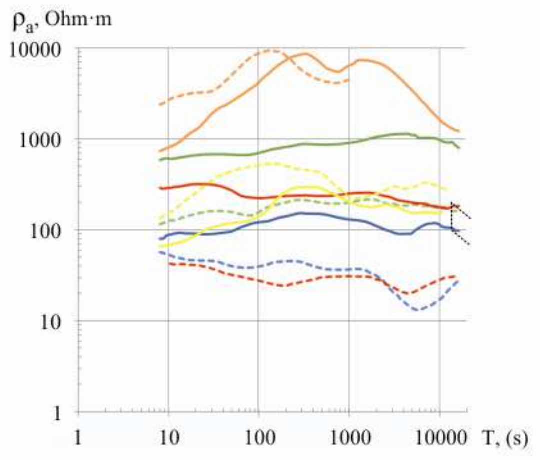
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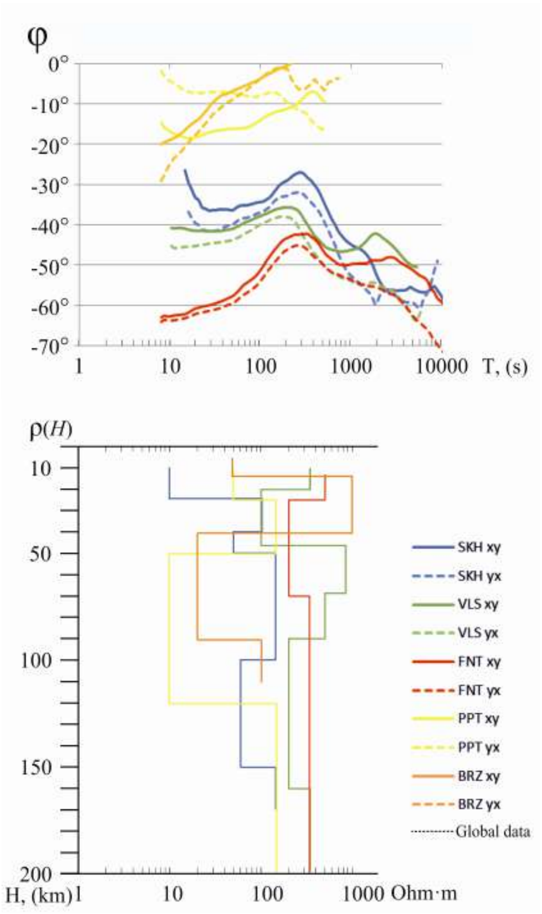
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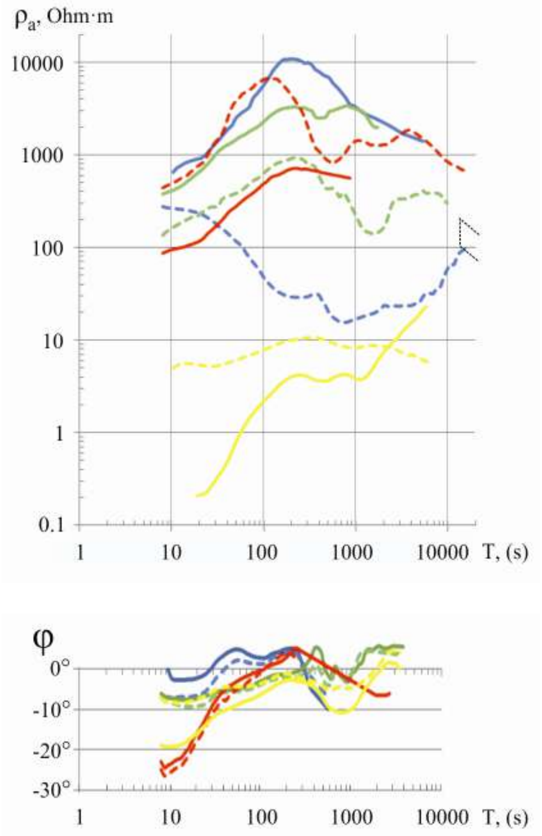
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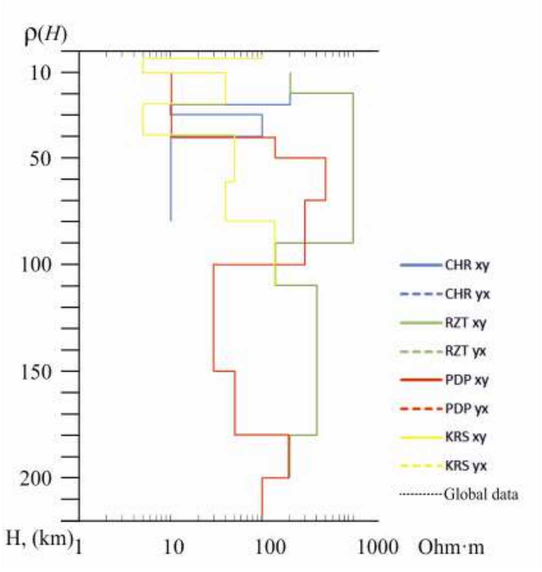

e

Fig. 2. Experimental DMTS curves obtained using software PRC_MTMV
(ρ_{xy} – south-north; ρ_{yx} – west-east); φ – impedance phases (φ_{xy} – south-north; φ_{yx} – west-east) and Niblett transformation $\rho(H)$ of effective amplitude curves ρ_a

Most modern methods of transfer operator estimating are based on the general principles of harmonic analysis and robust methods of linear estimation in the frequency domain. After rejection of substandard records and suppression of interference (preprocessing), a sequential Fourier analysis of sequence segments of variations and accumulation of linear equations connecting the spectral components of MT fields is performed for each interval of evaluation periods. The obtained redundant systems of equations are solved in parts with subsequent averaging or in full. This approach is implemented using the PRC_MTMV software, developed by I. Varentsov [Varentsov, 2007]. As a result of the modern approach to the experimental synchronous MT/MV data processing, DMTS curves (amplitudes and phases of apparent resistivity ρ_a) were obtained for a wide period range of geomagnetic variations of 10–10000 s in different tectonic structures of the Ukrainian Carpathians (Fig. 2, a-e).

Despite modern approaches to processing, most DMTS curves are obtained with a significant variance in ρ_a (sometimes a few orders of magnitude) for periods more than $5 \cdot 10^3$ s. Even in the observations of 1976 which are considered in [Tretyak et al., 2015] the transverse impedances had so wide range that the MTS curve building was impossible. On the other hand, it is known that for periods longer than 1000 s there is a significant variance of ρ_a values and the phase of the impedance (φ). Small values of impedance in this range are the reason for the small amplitude of variations of the natural electric field, which causes low estimate accuracy.

Periods of variation of about 10.000 s to some extent, can be considered critical, as the depth of penetration of the electromagnetic field into the conducting Earth becomes proportional to the geometric dimensions of the current systems, which are a source of variation. Therefore, when using long periods for induction sounding, it is necessary to take into account the spatial structure of the field source, i.e. requires an alteration in sounding methods or other theoretical approaches to electromagnetic methods. Classic MT/MV operators, as a rule, have a partial and approximate character and are realized only at obligatory requirements to the primary field structure.

Thus, the study area should be classified as quite complex in terms of satisfactory experimental material obtaining. Significant man-made impacts caused by electrified railways, oil and gas pipeline transport systems and their cathodic protection become an obstacle.

First, we analyze and distinguish zones by types of DMTS curves, i.e. by the shape and level of ρ_a, the ratio of curves for different (ρ_{xy} – north-south; ρ_{yx} – west-east) directions and approaching to global data (Fig. 2, a-e).

Thus, the curves ρ_a (DRG, HDS, BRS, PST) in the Transcarpathian Depression (Fig 1, Fig 2, a) differ in the ascending branch in periods up to $3 \cdot 10^2$–10^3s, the maximum reaches 50–500 Ohm·m, with increasing period ρ_a decreases and has a minimum of $5 \cdot 10^3$s. The curves are influenced by galvanic distortion, their level is lower than typical for global data. The difference of curves in the directions is observed in almost the whole frequency range and does not exceed one order. The impedance phase in the frequency ranges corresponding to the ascending and descending branches approaches zero (calculated with high accuracy) and goes to -90° (with increasing period the accuracy decreases, sometimes the value of φ passes through all quadrants, making almost full rotation). That is, the disperse relations exist for the transformation of the curves ρ_a into φ for the one-dimensional Tikhonov – Cagniard model. It is known that for periods up to the maximum, we have information about the total conductivity of the upper layer, and for longer periods – about the depth to the conductive basement. This behavior of the DMTS curves can be explained by the combined effect of conductive near-surface sedimentary strata (S_s from 250 to 1000 S) and high conductivity of the asthenospheric layer.

The group of curves ρ_a (KRU, KRC, BRN, KRV) in the northern part of the Ukrainian Carpathians (Fig. 2, b) also has an ascending branch to periods of more than 10^3s, which is complicated by small minima, the maximum level of ρ_a does not exceed 10^4 Ohm·m, all curves are an order of magnitude higher than global data, the difference in directions is not more than half the order, which increases for periods greater than $3 \cdot 10^3$s. The impedance phase has similar features as in the previous group of DMTS curves. Such features of the curves can be explained by the combined effect of near-surface sedimentary strata with S_s from 100 to 500 S and the high conductivity of the layers at different depth H.

The group of curves ρ_a (LPV, BLN, BRB, DZM, PRB, GLS), which are located in different parts of the Ukrainian Carpathians, but mostly in the south (Fig. 1, Fig. 2, c), are united by the following features: no ascending branch on short periods, the presence of the prolonged minimum for periods from 30 to 2–$5\cdot10^3$s with an amplitude of up to half an order, the level of ρ_a to 10^2 Ohm·m, some curves are on global data, others are lower. Curve differences: LPV – almost an order of magnitude in the entire frequency range; BLN – up to two orders of magnitude for periods longer than 1000 s. Impedance phases for short periods for two directions are less than –45° and reach –75°, the difference φ for different polarization is mainly observed for periods longer than 300–700 s and is 45°. And although most of the curves φ are calculated with unsatisfactory accuracy, qualitatively they correspond to the amplitude curves ρ_a. All points are located in the zone of low S_s up to 100 S, with probable conductors in depth.

In the central part of the south of the Ukrainian Carpathians, two groups of types of GMT curves can be distinguished (Fig. 2, d). The first one – curves at points SKH, VLS, FNT – is characterized by the absence of an ascending branch, almost maintained in the entire frequency range level ρ_a (according to each point ρ_{xy} varies from 100 to 1000 Ohm·m, ρ_{yx} – from 30 to 200 Ohm·m). It is clear that DMTS curves diverge by almost an order of magnitude in all periods, and therefore it is difficult to clearly analyze their position relatively to global data (most of them are lower, but sometimes higher or reach the level of 100–200 Ohm·m for periods longer than 10^4s). In this case, small fluctuations in ρ_a are observed in different frequency ranges. The values of φ are less than –45°, the divergence in the directions of polarization is on average 10°, sometimes 80° (VLS for a period of more than 5000 s), in general, the errors increase for periods of more than 700 s. The second group – curves at points PPT, BRZ – is a slight upward branch to 100 s, the presence of a clearly expressed minimum in the periods of 500–1000 s, the curves in the directions intersect several times at different periods, in general, they are higher than global data. The first part of the curve φ has a value at the level up to –20° for periods of less than 200 s, with increasing of the period the error increases sharply, which makes interpretation impossible. In the considered sections S_s does not exceed 100 S. The difference of curves and minima at different periods may indicate increased anomalous conductivity at different depths.

In the western part of the Ukrainian Carpathians, two CHR and RZT points can be distinguished (Fig. 2, e), in which curves in different directions are characterized by a gradual difference, which increases with the period and reaches three orders of magnitude. The downward curve ρ_{yx} is complicated by a significant minimum in the periods of 1000–3000 s, and reaches a level lower than global data. The ascending ρ_{xy} curve has a common level of 10^3–10^4 Ohm·m, minima for the same periods and a level higher than global data. This behavior of the curves is characteristic of long fault structures. The impedance phases are confidently built up to 200 s and during these periods correspond to the curves ρ_a. Subsequently, the accuracy decreases, the values pass through all quadrants, making an almost complete φ rotation. The area is characterized by S_s up to 200 S.

DMTS curves at PDP and KRS points (are located in different parts of the Dukla cover of the Ukrainian Carpathians) are characterized by a peculiar lack of conformity, although S_s is the same and is up to 100 S (Fig. 2, e). ρ_{xy} has an ascending branch with a maximum of about 700 Ohm·m for a period of 300 s (PDP) and a sloping descending part, which reaches the level of global data; ρ_{yx} is characterized by significant gradients of ρ_a, several maxima (up to 6000 Ohm·m) and minima (from 100 Ohm·m) at different periods, are one order of magnitude higher than global data.

At the KRS point, ρ_a curves in the directions are not conformal: ρ_{yx} has an almost flat shape and is in the interval between 4–12 Ohm·m with slight inflections on the periods of 30 and 1000 s; ρ_{xy} is characterized by different behavior in the corresponding frequency ranges: 10–200 s – well-manifested minimum of $2\cdot10^{-1}$ Ohm·m for a period of 20 s, 200–1200 s – slight fluctuations in ρ_a at the level of 4 Ohm·m, 1200–8000 s – ascending branch up to 25 Ohm·m, which can be taken into account in the interpretation, ≥8000 s – ascending branch with a significant gradient of ρ may reflect, firstly, the unnatural source, and be associated with the influence of man-made factors, or secondly, disregarding the heterogeneity of the source of the natural electromagnetic field and the spherical symmetry of the Earth, and the inadmissibility of processing the observed data within the Tikhonov-Cagniard model.

There may be structures that create ρ_a and φ that are unrelated by the Hilbert transformation. There are examples when a violation of the dispersed relation is detected, which is characteristic of models of superpositions of structures that contain local near-surface inhomogeneity over a deep regional structure [Berdychevsky, Dmitriev, 2009].

Despite the synchronous field recording and two-point processing, the obtained DMTS curves are complex, so individual interpretation is difficult.

Formal interpretation of DMTS curves

Formal interpretation of DMT curves was performed using the Niblett transformation, or so-called transformations ρ_a (T) into curves that determine the resistivity dependence on depth ρ (H), where resistivity ρ and the margin H are not real, but approximate values ("effective"). Niblett's transformation is based on the next assumptions

$$S = 1/\sqrt{\rho_T \omega \mu_0}\ ,\ H = \sqrt{\rho_T}/\sqrt{\omega \mu_0}\ .$$

The most complete geoelectrical section can be obtained from 1D inversion of generalized sounding curves built by combining magnetovariational sounding curves at the reference geomagnetic observatory Lviv [Semenov et al., 1996] with the field curve DMTS. The parameters of the formal interpretation of the effective amplitude curve ρ_a Niblett transformation are presented (all lower parts of all subfigures a-e).

The first group of DMTS curves at the DRG, HDS, BRS, PST points (Transcarpathian Deflection) is characterized by series of low ρ intervals (Fig. 2a). The first conductive layer appeared in the range of depths (H): 3-4÷10 km with ρ = 30-60 Ohm·m (S = 100-200 S) – PST point; 10–20 km with ρ = 80 Ohm·m (S = 125 S) – HDS point, but it is missed in BRS point. Most likely, this conductive layer corresponds to the high conductivity of surface sediments with S_s from 250 to 1000 S within the Chop-Mukachevo depression and the upper layer of reduced velocities Vp = 6÷6.2 km/s [Murovska, 2019]. Only the HDS point (Vygorlat-Gutyn volcanic ridge) can be confined to the marginal part of the Carpathian anomaly.

The second conductive layer is provided in H: 40–70–120–170 km with ρ = 10–80 Ohm·m. Within the boundaries of the Chop-Mukachevo depression, it is internally inhomogeneous (stratified), namely at depths of (90–110)–(130–150) km ρ increases 2–3 times to 20–25 Ohm·m. In the area of the Vygorlat-Huty volcanic ridge, the upper margin of the layer deepens to 50–70 km, S is 3500–5000 S. There may be another layer in the upper part of the upper mantle (BRS point) at depths of 170–220 km with ρ = 10 Ohm·m (S = 5000 S). Thus, the asthenosphere is distinguished in the upper mantle, which can be represented not by a single homogeneous layer at a depth of 70–170 km with ρ = 25 Ohm·m, but by the stratified structure both in depth and in ρ.

In the earth's crust, according to the ρ_a curves transformation data at the points KRU, KRC, BRN, KRV (northern part of the Ukrainian Carpathians, Fig. 2, b), the layer of high electrical conductivity in H from 10 to 45 km, 10–20 km thick, from 50 to 350 Ohm·m is revealed (Fig. 2, c). Almost everywhere the asthenosphere appeared with the upper margin at the depth of 90–100 km, thickness 50–150 km, with ρ from 50 to 100 Ohm·m, S from 900 to 3000 S. Note the result of qualitative interpretation at the points KRC and BRN, which are the northernmost of the Carpathian anomaly axis. The obtained parameters of the asthenosphere at the point KRC (50–90 km with ρ = 100 Ohm·m (S = 400 S)) can be considered debatable, given the resolution of the method, namely the relatively high compatible conductivity: near-surface S_s about 200 S and in the earth's crust more than 200 S (anomalous part contribution up to 100 S). Another picture with the obtained geoelectrical parameters is observed at BRN, where S is very low, both in the earth's crust up to 60 S and in the upper mantle up to 900 S. There is an impression that there are no anomalous zones under the last points, and the interpretive parameters reflect the lateral influence of the inhomogeneous conductive distribution, but this assumption must be verified by three-dimensional geoelectrical model building.

Points CHR, RZT, LPV (Fig. 2, c) and PDP are combined into one group based on the results of qualitative interpretation of MVP data, which carry information about the Carpathian conductivity anomaly (Fig. 2, e). In the earth's crust, the conductor with an upper margin of 10 km, thickness of 10–30 km, and a ρ of 10 to 200 Ohm·m was detected at almost all points. An exception is the CHR and RZT points, where the upper margin deepens to 20–25 km with ρ 10 Ohm·m. There are significant differences in the location of the upper margin of the asthenosphere: CHR, LPV – 40 and 60 km, thickness of 20 km; RZT, PDP – 90 and 100 km, with thickness of 20 to 50 km. In almost all points S of the asthenosphere is from 1600 to 4000 S (significantly low S is characterized by the point RZT). In this point, such low values of S both in the earth's crust up to 50 S and in the mantle 130 S may indicate an increasing of the conductivity anomaly influence on the observed values. The given geoelectrical parameters indicate that at a short distance of 10–30 km along the structure the upper margin of the asthenosphere deepens sharply: to the north from 60 to 90 km and to the south from 60 to 100 km.

Beyond the Carpathian anomaly southern boundary, the PPT point is located (Fig. 1, Fig. 2, d), which in its geoelectrical parameters is similar to HDS (Fig. 2, a): in the earth's crust – 10–25 km with ρ = 50 Ohm·m (S = 300 S), in the upper mantle – 50–120 km with ρ = 10 Ohm·m (S = 7000 S). In this part S is low in the earth's crust against the background of 3000 S, which are characteristic of these depths within the anomalies, can be explained by the link of its extreme part or its lateral effect on the parameters at the points of PPT and HDS. It is observed arising of the upper margin of the asthenosphere to 50 km and increase S by 1.5–3 times in accordance with the characteristic parameters for the Carpathian Depression and Vygorlat-Huty volcanic ridge.

Formal interpretation using the Niblett transformation (Fig. 2, d) found at BRZ an anomaly in H from 5 to 12 km with ρ = 50 Ohm·m (S = 200 S), which probably reflects the conductivity of surface sedimentary strata, and at SKH it is already H 10–25 km in the consolidated earth's crust, in addition, S reaches 750 S and significantly exceeds S_s (up to 100 S). The difference is also observed at greater depths in the upper mantle. In the first point, the upper margin of the asthenosphere continues to rise to

40 km, which is represented by a single layer with a thickness of 50 km with ρ = 20 Ohm·m (S = 2500 S, we emphasize that here S decreases almost 3 times relative to the PPT point). In the second there are several deep mantle intervals: 40–60 km with ρ = 50 Ohm·m and 100–150 km with ρ = 60 Ohm·m, but their total S is smaller and reaches 1200 S.

Further along the Carpathian profile (Figs. 1, 2d) immersion of anomalies in the earth's crust and upper mantle is observed at the VLS points (H = 20–45 km, ρ = 100 Ohm·m, S = 250 S; H = 90–160 km, ρ = 200 Ohm·m, S = 400 S) and FNT, where it is represented by the single weakly conducting horizon: H = 25–70 km, ρ = 200 Ohm·m, S = 250 S. It can be assumed that here the asthenosphere of the Transcarpathian Depression and the north of the Ukrainian Carpathians disappears, and the upper margine of the southern local structure of the Carpathian anomaly is immersed as much as possible.

South of the profile at the points KRS, BLN (Fig. 1, 2, c) again appears local stratification of the region conductivity, the rise of the upper anomaly margins in the earth's crust (from 25 to 10 km, thickness 15 km, ρ = 5–10 Ohm·m, S = 1500–3000 S) and the upper part of the upper mantle (from 40 to 65 km, thickness 15 km, ρ = 40 Ohm·m, S = 400 S). The distribution is complicated by local anomalies in the sedimentary layer (3–7 km, ρ = 5 Ohm·m, S = 800 S) at the KRS point and the upper mantle (100–140 km, ρ = 100 Ohm·m, S = 400 S) in BLN points.

The following two points BRB, DZM (Fig. 2, c) differ in the presence of only an anomaly in the earth's crust, characterized by different geoelectrical parameters: H 18–25 km and 7–27 km, ρ = 10–20 Ohm·m, which form significantly different values of S – 350 and 2000 S, respectively. Analyzing, we can assume that the BRB point is outside the anomalies or under their induction influence, and the DZM point may be the beginning of a new local conductive structure in the south of the Ukrainian Carpathians. It was well manifested in the PRB and GLS points, where almost the same geoelectrical parameters were obtained in the earth's crust: 10–30 km, ρ = 5–10 Ohm·m, S = 2000–2400 S The anomaly at asthenospheric depths can be considered as an invasion from the south or vertical penetration, because the upper margin is immersed from 60 (PRB) to 110 km (GLS) at a distance of up to 25 km, thickness 30–50 km, S from 1000 to 5000 S.

The final result of experimental data interpretation and construction of a deep model of the Carpathian region on their basis should be obtained only by three-dimensional modeling of the Earth's electromagnetic field.

Anomalous conductivity distribution in the Carpathian region according to DMTS

According to the qualitative interpretation of tippers, four local differently oriented anomalous zones or their axes can be distinguished (the variant of the single longitudinally inhomogeneous conductive structure can be considered within the hypothesis of the axial zone of the Carpathian magnetovariational anomaly) (Fig. 1):

In the earth's crust

– south-west of the Ukrainian Carpathians (parts of the Vyhorlat – Hutyn volcanic ridge, Magura, Porkulets, Dukla and Krosno covers). The local isometrically conductor is provided. It spatially coincides with the location of the Carpathian magnetovariational anomaly according to (Burakhovich, 2004).

– the central part of the southen Ukrainian Carpathians (mostly part of the Porkulets cover). The narrow local conductor situated along the general direction of Mizhhirya – Mukachevo zone is assumed, which manifested itself both in different types of DMT curves and inhomogeneous ρa distribution.

– south-east of the Ukrainian Carpathians (mainly parts of Dukla, Porkuletsk, Rakhiv covers and Marmaros massif). It is possible to exist of two local areas with the gap along the line of Rakhiv – Yasenya. The variant of two spatially separated areas also needs to be tested: the single elongated structure that coincides with the axial part of the Carpathian magnetovariational anomaly according to (Burakhovich, 2004) and local structure (mostly parts of the Chornogora, Dukla and Porkulets covers).

In the upper mantle

– the asthenosphere is revealed in the region of the Ukrainian Carpathians from the Transcarpathian Depression to the Skiba covers;

– the asthenosphere is not a homogeneous layer; there are areas with the homogeneous layer, and differentiated with different resistivity within it, in addition, possible areas of conductivity branching with depth are revealed;

– there is the general deepening of the upper margin of the asthenosphere to the northeast: from 40–60 km (Transcarpathian trough) to 90–00 km (Krosno cover) and sharp deepening along the Porkulets and Dukla covers;

– the variation of the asthenosphere upper margin and its galvanic breaks are possible along the extension of the inner and central zones of the Outer Carpathians. There are three sections: the northern – to the line of Tyachiv – Fontinyasi (deepening to the south of the upper margin from 40–50 km to 90 km), central – represented by the differentiated sequence with ρa from 100 to 1000 Ohm·m below core-mantle inhomogeneity, southern – vertical penetration or from the south direction, because the upper margin is deepening from 60 to 110 km.

Conclusions

New experimental data were obtained by MTS methods with the help of modern equipment using advanced observation technologies within the Carpathian region of Ukraine. Experimental data processing and analysis of MT field transfer operators were performed. New estimates of the resistivity curves and impedance phases from 10 to 10000 s were obtained. According to the qualitative interpretation of the results of magnetotelluric studies, the anomalous inhomogeneous distribution of conductivity was determined and detailed, which complements modern ideas about the structure of the earth's crust and upper mantle. At this stage of interpretation, the existence of a chain of local anomalies of the earth's crust within the boundaries of Vyhorlat – Huty volcanic ridge, Magura, Porkulets, Dukla, Krosno, Rakhiv covers and Marmaros massif, which spatially coincides with the location of the Carpathian anomaly axis, is assumed. An inhomogeneous distribution of the layer of anomalous conductivity at the depths of the upper mantle was recorded from the Transcarpathian Depression to the Skiba covers.

The obtained conductivity distribution in the earth's crust and upper mantle of the Ukrainian Carpathians can be used in the construction of deep geological and geotectonic models, as well as to explain the geodynamic processes of the region.

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СУЧАСНІ МАГНІТОТЕЛУРИЧНІ ДОСЛІДЖЕННЯ УКРАЇНСЬКИХ КАРПАТ

Для дослідження глибинної будови південного заходу Українських Карпат, де розташована Карпатська аномалія електропровідності, в 2015 та 2020 рр. виконано сучасні синхронні магніто-телуричні дослідження за профілями: Мукачеве – Сколе, Середнє – Бориня та Карпатський в двадцяти трьох пунктах та отримано просторово-часову картину розподілу геомагнітних варіацій та електричного поля на поверхні Землі, за якою можна оцінити електропровідність та геоелектричну структуру регіону. Експериментальні матеріали опрацьовано за допомогою програмного комплексу PRC_MTMV, що забезпечує спільне перешкодозахищене оцінювання імпедансу за синхронними магнітотелуричними записами. Надійно отримані криві позірного питомого електричного опору (амплітудних значень та фаз імпедансу) від 10 до 10000 с. Спільний аналіз кривих позірного питомого електричного опору і фаз імпедансу та формальна інтерпретація кривих глибинного магнітотелуричного зондування із використанням трансформації Ніблетта свідчать про наявність просторово неоднорідного провідника як у земній корі, так і у верхній частині верхньої мантії. Ланцюг локальних електропровідних ділянок у земній корі збігається із осьовою частиною Карпатської аномалії електропровідності. Високу електропровідність верхньої мантії зафіксовано в Українських Карпатах від Закарпатського прогину до Скибових покривів. Показано, що вона не є однорідним шаром, спостерігається загальне поглиблення верхньої кромки на північний схід від 40–60 км (Закарпатський прогин) до 90–100 км (Кросненського покриву), різке поглиблення вздовж Поркулецького та Дуклянського покривів. Інформація про існування глибинного провідника та його параметри повинні стати основою для кількісної інтерпретації та побудови 3D глибинної геоелектричної моделі.

Ключові слова: південний захід Українських Карпат; Карпатська аномалія електропровідності; глибинне магнітотелуричне зондування; аномалії електропровідності.

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