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Geoelectrical properties of earth's crust and upper mantle rocks according to the 1D inversion results of DMTS curves

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SUMMARY

According to the DMTS experimental data from different geological regions of Ukraine, one-dimensional OCCAM inversion and transformations of Schmucker, Niblett, Molochnov – Le Viet are carried out. The amplitude and phase curves obtained as the result of processing using the PRC MTMV program in the range of periods from 1–10 to 10000 s are extended by DMTS data. As a result of 1D inversion it is seen that under the north-western part of the USh the deep section of the mantle corresponds to the "normal" ρ distribution, while the northeast of the Prydniprovskiy and the eastern part of the Ingul megablocks are 2-5 times larger. On the northern board of the Belgorod-Sumy megablock DDB, the northern slope of Bug-Ros' and the southwestern part of the Kirovograd megablocks USh, the northwestern part of the Black Sea shelf deep sections are characterized by the series of conductivity layers both in the earth's crust and mantle.

Introduction

One of the main issues in electromagnetic field modeling is the choice of the "normal" depth electrical conductivity distribution, based on experimental data. The variance of resistivity values (ρ) at the same depths reaches 3 - 4 orders for the territories of ancient shields and platforms, and equally both in natural and in artificial fields (Feldman and Zhamaletdinov, 2009). According to the results of the international project "BEAR" there is also a difference in resistivity values of 3-4 orders at the same depths. This fact shows that the situation has not changed for the better and work on a comprehensive study of the lithosphere deep electrical conductivity using natural and controlled sources has not lost relevance to this day.

Numerous experimental MTS data, obtained within the Ukrainian Shield (USh) allow us to conclude that the lower values of "normal" ρ (≈1000 Ohm · m) of the upper thickness (about 160 km), relative to the "normal" geoelectric section (≥5000 Ohm · m) for the territory not only of the Baltic Shield and the Russian Plate of the Eastern European Platform, but also for other shields. The "normal" distributions for regions of Ukraine with Cimmerian (depth range (H) 110-140 km, ρ = 40 Ohm · m) or alpine (H = 70-170 km, ρ = 25 Ohm · m) geological history are characterized by increased conductivity in mantle (Tab. 1).

Methods of investigation

Experimental deep magnetotelluric soundings (DMTS) were carried out in different geological regions of Ukraine using long-period digital stations LEMI-417 with ferrosonde magnetometers. Their main advantages are very low time drift (<± 5 nT/year) and high measurement accuracy (0.02% for 2 years), which is extremely effective in deep sounding of the earth's crust and upper mantle. Processing of experimental data using the program PRC_MTMV allowed to obtain amplitude (ρ_a) and phase (φ) resistivity curves in the range of periods 1-10 ÷ 11000-55000 s. Parker and OCCAM inversions were used for the GMTS data set (Parker and Whaler, 1981). The first method is based on the representation of the section in the zero power layer form with a fixed conductivity. The second method is to select a model with a given number of layers that smoothly change their resistivity, approximating the experimental data. The discrepancy of the global data and the experimental curves ρ_a in some places reached several orders of magnitude, so first of all the result of the one-dimensional OCCAM inversion by phase data was analyzed. The final result obtained taking into account the "shift effect" from the experimental GMTS curves (Figure 1), it well confirms the dependence of resistivity on the depth ρ(H), which were calculated using the Schmucker, Niblett, Molochnov-Le Viet transformations (Burakhovych et al., 2016).

Results of investigations

The geoelectrical asthenosphere is revealed everywhere in the Cimmerian and Alpine formations and only in fragments under the Precambrian USh. The term "asthenosphere" in geoelectrics is slightly different from the rheological layer of low viscosity. Here, the "asthenosphere" is the conductive layer in the upper part of the mantle, at the depth about 50 to 200 km with ρ not more than 100 Ohm·m and a total conductivity of not less than 400 S. It can be assumed that in the mantle of the USh there is a boundary that divides it along 29-30° E. In the southwestern part of the USh found the conductor with the upper edge at the depth of 50 - 70 km, differentiated by ρ from 48 °N: north to 50° N (south of the Ros'-Bug megablock USh) ρ = 50 Ohm·m, to the south (the slope of the USh and partially the Black Sea depression) ρ = 25 Ohm·m. The adjusted boundaries of the mantle conductor are partially traced by the Talne and Odesa fault zones (FZ) in the east, the northern one gradually shifts along Khmelnytskyi FZ, where it further goes sublatitudinally and corresponds to the ledge of the Mokho surface, the southern one passes along the Chisinau FZ at the USh southern boundary.

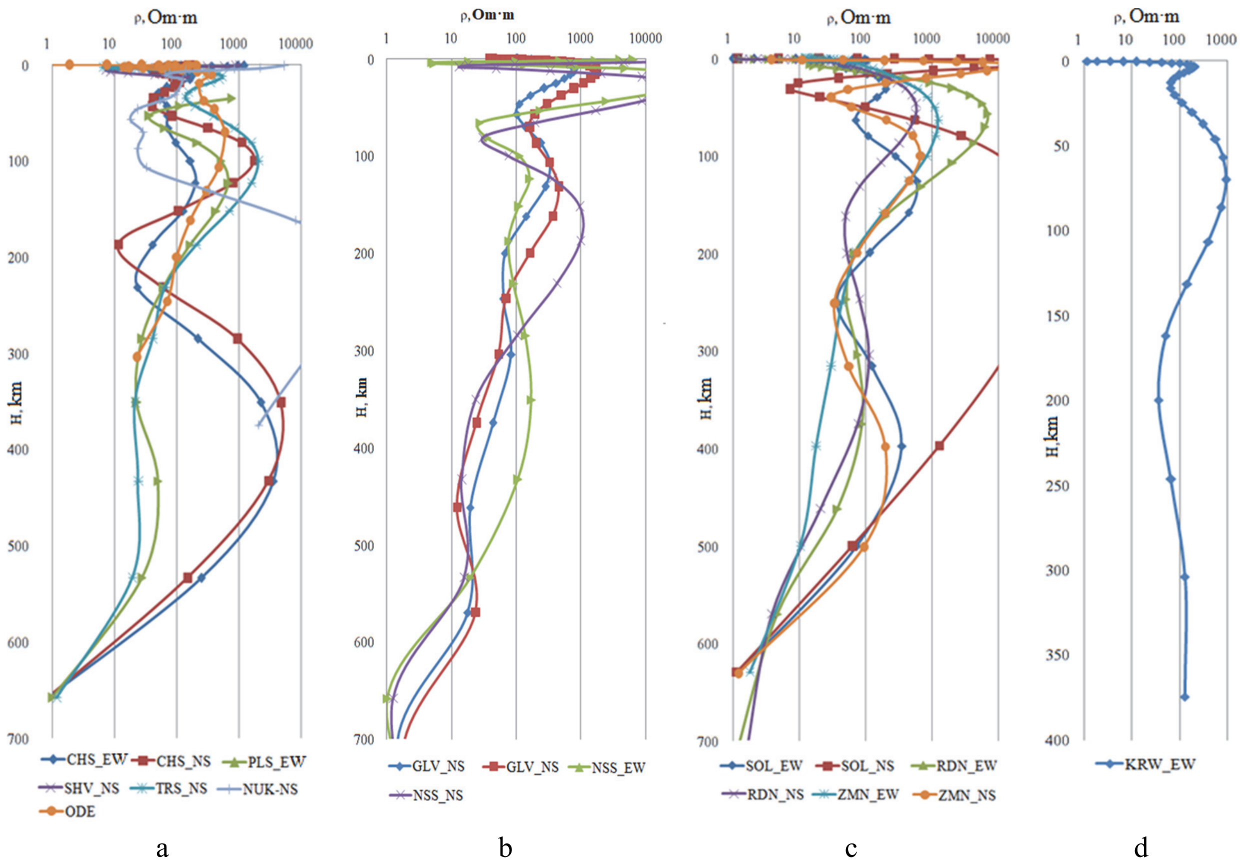

Figure 1 *1D OCCAM inversion (Parker and Whaler, 1981) of DMTS curves. Points:* ***USh*** *– CHS (Chervona Sloboda), PLS (Ploska), SHV (Shevchenkove), TRS (Tarasivka), GLV (Golovuriv), NUK (Novoukrainka);* ***DDB*** *– NSS (Neseno-Irzhavets);* ***Scythian plate*** *– SOL (Solone), RDN (Rodnoye), ZMN (Zmiiny island);* ***Black See basin****: ODE (Odessa Observatory);* ***Carpathians*** *– KRW (Kryve)*

Normal geoelectrical section for the Precambrian platform		Volyn megablock USh				Ros’ megablock USh				Yatran’ block GSZ of the USh	
		Ploska 50°29′42″N 27°01′36″ E		Rudka 50°05'31.6" N 29°28'42.1" E		Rogizna 49°32'25.5" N 29°47'41.1" E		Golovuriv 50°11′01″ N 30°58′59″E		Tarasivka 48°31'53.0" N 30°36'56.0" E	
h, km	ρ_a, Om·m	*h*, km	ρ_a, Om·m	*h*, km	ρ_a, Om·m	*h*, km	ρ_a, Om·m	*h*, km	ρ_a, Om·m	*h*, km	ρ_a, Om·m
0-160	1000	16-30 80-125	100-1200 400-800	15-40 130-150	100-200 100	55-80	30	30-50 90-160	200 180	2-10	50
160-200	600	–	–	–	–	–	–	–	–	–	–
200-250	250	–	–	–	–	–	–	220-260	100	–	–
250-320	100	250-500	300-60	–	–	–	–	–	–	–	–

Ingul megablock USh				Prydniprovskiy megablock USh		USh south slope	
Chervona Sloboda 49°22′48″ N; 32°09′07″ E		Novoukrainka 48°30′27″ N; 31°56′52″ E		Shevchenkove 48°12'02.4" N; 35°35'22.8" E		Stepanivka 46°47′37″ N; 29°59′13″ E	
h, km	ρ_a, Om·m	*h*, km	ρ_a, Om·m	*h*, km	ρ_a, Om·m	*h*, km	ρ_a, Om·m
10-50 90-150	200 600	30-60	300	25-100	3000-10000	<7 15-40 >140	30 250 ~100
160-200	2 000	–	–	–	–	–	–

DDB		
Bragin-Loyev uplift, Berezivka 51°40'52.8" N; 30°41'38.9" E	South slope, Lohvytsia block Neseno-Irzhavets 49°56'35.9" N; 32°41'41.4" E	North slope, Belgorod-Sumy megablock, Chumakove 51°13′27″ N; 33°53′49″ E

h, km	ρ$_a$, Om·m	*h*, km	ρ$_a$, Om·m	*h*, km	ρ$_a$, Om·m
35-(60-110)	100	5-15 40-140	50 100	25-30 50-160	50 20

Scythian plate							
Normal geoelectrical section for Crimean chimerids		North-western part of the Black Sea shelf Zmiiniy island 45°15′18″ N; 30°12′15″ E		Indole-Kuban' depression, Solone 45°19′40″ N; 35°24′51″ E		Sivash depression, Rodnoye 45°42′35″ N; 34°37′10″ E	
h, km	ρ$_a$, Om·m	*h*, km	ρ$_a$, Om·m	*h*, km	ρ$_a$, Om·m	*h*, km	ρ$_a$, Om·m
0-110	1 000	< 30 60-100	~ 200 100-200	10-30 50-100	< 1 000 ~ 80	< 5 ~10-20 50-80	20 100 300
110-140	40	100-140	100-200	–	–	110-140	80
140-200	600	180-340	50-100	–	–	–	–
200-250	250			200-250	25	–	–

Normal geoelectric section for the Carpathian alps		Central Carpathians, Kryve 48°57′32.0″ N; 23°12′48.0″ E	
h, km	ρ$_a$, Om·m	*h*, km	ρ$_a$, Om·m
0 – 50	2000	6-40	70
50-70	500	–	–
70-180	25	90-250	40
180-200	200		
200-250	100		

Table 1 *Results of DMTS curver interpretation*

In the west, the conductor is immersed to the depth of 90-100 km and is galvanically connected with the upper mantle anomaly of the Carpathian region. In addition, it is safe to assume the existence of the mantle conductor on the depths of 50-120 km in the southern part of the Ingul megablock. Its northern boundary should be to the south of 47º20′ N. To the east of 32º E it reaches 47º40′ N. The maximum spread to the north is observed along the Kirovograd anomaly, in the deep FZ – West-Ingulets and Kirovograd. There are several local (30-50 km ÷ 15 km) upper mantle inhomogeneities in the area of Kirovohrad and Subbot-Moshorin FZ intersection and along the Kherson-Smolensk transect. A deep (with the upper edge of 10-50 km) low-resistivity (ρ up to 100 Ohm·m) area is predicted near the border of the USh Eastern Preazov with the Scythian plate near the Gruzko-Yelanchyk FZ.

For example, according to the interpretation results of the ρ(H) curve under the Volyn megablock of USh at the point Ploska (Figure 1 a) the geoelectrical section is characterized by ρ = 1000-1200 Ohm·m from 16 to 30 km, deeper than 180 km there is a gradual decrease up to 800-900 Ohm·m, against which the depth interval of 80-125 km from 400 <ρ <800 Ohm·m is fixed (Burakhovych et al., 2016). It is observed only according to one of the transformations, which takes into account the phase curve of the impedance and was determined with a large measurement error. It is difficult to take into account the geoelectrical parameters of the medium if they are obtained as a result of one-dimensional OCCAM inversion by only one polarization of the DMTS curve. Therefore, we can assume that up to 240 km and deeper than 500 km, the distribution of ρ corresponds to the "normal" for US, and in the interval between them (240-500 km) is 1.5-3 times higher. Similarly, it is difficult to distinguish the asthenosphere at depths of 40-100 km on the curves calculated by OCCAM inversion at the Golovuriv point (Ros' megablock USh), if ρ>100 Ohm·m (Figure 1). According to the interpretation results of the curve ρ(H), obtained by the Schmucker's transformation, an asthenosphere at depths of 55–80 km with ρ=30 Ohm·m confidently appeared under the Ros' megablock of the USh at the Rogizna point (Tab. 1).

The geoelectrical section under different DDB blocks (Shyrkov et al., 2015), according to the transformation and one-dimensional OCCAM inversion results, contains the asthenosphere with ρ below 100 Ohm·m at depths from 40 to 150 km (Figure 1 b; Tab. 1).

Almost all transformations of the Zmiinyi Island point assume the presence of several depth intervals with high conductivity: 1) H_1 <30 km, $\rho \approx 200$ Ohm·m; 2) H_2 = 60–140 km, ρ = 100–200 Ohm·m; 3) H_3 = 180–340 km, ρ = 50–100 Ohm·m (Kushnir and Shyrkov, 2013). Zmiinyi Island, as well as Zmiinyi Island and Vilkiv uplifts are composed of Lower Paleozoic semi-metamorphosed rocks with ρ=1000 Ohm·m. The conductivity anomaly, manifested in the depth range H_1 and H_2, is elongated in the sublatitudinal direction and confined to the wide zone between two deep faults (Kiliya and Pechenga-Kamena). According to the results of the OCCAM inversion interpretation, the asthenosphere at depths of 50–100 km with ρ=80 Ohm·m appeared confidently at the Solone point, in contrast to the Rodnoye point, where only the asthenosphere of the "normal" section is clearly fixed (Figure 1 c; Tab. 1).

Observations of the Earth's electromagnetic field in a wide range of periods in the central part of the Carpathians allowed to confirm the presence of the Carpathian anomaly and to specify the parameters of the geoelectrical section of the Earth's crust ($H \approx 10$ km, $\rho \approx 50$ Ohm·m) and mantle ($H \approx 100$ km, $\rho \approx 30$ Ohm·m) (Figure 1 d; Tab. 1).

Conclusions

Under the north-western part of the USh, the deep section of the mantle corresponds to the "normal" distribution ρ, while the northeast of the Dnieper and the eastern part of the Ingul megablocks are characterized by values 2–5 times larger. On the northern side of the Belgorod-Sumy megablock DDB, the northern slope of the Bug-Ros' and the southwestern part of the Kirovograd megablocks USh, the northwestern part of the Black Sea shelf deep sections are characterized by the series of conductive layers, in the formation of which the main role probably belongs to the deep fluids.

The obtained conductivity distribution in the earth's crust and upper mantle of Ukraine territory can be used in the construction of deep geological and geotectonic models, as well as to explain the geodynamic processes of the region. Anomalies of increased electrical conductivity at depths of up to 30 km make it possible to develop allocation criteria of prospects for the detection of new petro- and ore manifestations of minerals.

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