

APPLICATION OF SPACE GENERATED GEOMAGNETIC  
VARIATIONS FOR OBTAINING GEOELECTRICAL  
CHARACTERISTICS AT PANAGYURISHTE  
GEOMAGNETIC OBSERVATORY REGION

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**Abstract**

For the first time tipper vector in time period range of 240–8000 s for the area of Panagyurishte Geomagnetic Observatory (PAG) is obtained. The comparison of the tipper vector with the seismic activity in the region of 150–200 km around PAG shows correlation between tipper vector changes and the seismic activity. The regional magnetovariational sounding method was used for estimation of the Earth's mantle conductivity model at PAG. Inversions of the magnetovariational sounding allow for obtaining the one-dimensional conductivity model.

**Key words:** tipper, Earth's mantle, electrical conductivity, magnetovariational sounding, seismicity

**Introduction.** Short period geomagnetic field variations registered at the Earth surface as we know are generated in the Earth space environment. For example: daily geomagnetic variation [1] as a result of the ionosphere current system changes during the day and depends on the point of measurements; the main part of the global geomagnetic storm time variation  $D_{st}$  [1] formed by ring current system situated in the magnetosphere and the local ionosphere also influences this geomagnetic index and on the territory of Bulgaria it is analyzed in the works [2, 3]; the geomagnetic pulsations are also generated in some parts of the magnetosphere and as a result alfvénic waves are propagated to the boundary of

the neutral atmosphere and then as electromagnetic waves to the Earth surface. All short period geomagnetic variations mentioned above are also related to the solar activity and interplanetary space conditions.

As we know, short period geomagnetic variations caused electromagnetic induction in the Earth core and mantle and thus the telluric current system was formed. These induction phenomena are used for obtaining the geoelectrical characteristics of the Earth interior by using different methods of investigation, named “induction”. In the present work, similar methods are used for investigation of the geoelectrical characteristics at Panagyurishte observatory (PAG) region.

The geoelectrical investigations are intended for showing the electrical conductivity anomalies, which are connected with the processes in the Earth interior and are also conditioned by the birthplace of mineral deposits. The geoelectrical investigations are important for the creation of complex geophysical models of the depth crust and lithosphere structures, which are further used for solving the problems to predict catastrophic natural events. In the process of the investigations, are studied the changes of specific electrical conductivity  $\rho$ , caused by the mineral composition variations of the rocks, degree of filling with fluids, rock mineral phase changes related to temperature and pressure.

At the end of last century, Bulgarian and Russian geophysicists carried out a large scale depth investigation of the geoelectrical structure on the territory of Bulgaria based on measurements of the variations of the natural Earth’s electromagnetic field (magnetotelluric (MT) field). For this aim analogous geomagnetic field registration devices were used [4].

In the present work, for obtaining of the tipper, the numerical one-minute PAG data for 2007 were used. These data were registered by the three-component fluxgate magnetometer FGE produced by Danish Meteorological Institute [5]. For the magnetovariational sounding especially, mean hour data for the time period 1988–2008 were used.

**Definition of the tipper.** The method for geomagnetic deep sounding uses interpretation of the parameters obtained from the component of the geomagnetic MT field. These parameters are the results of data processing by using the relation proposed by U. SCHMUCKER [6]:

$$(1) \quad B_z(\omega, r) = W_{zx}(\omega, r)B_x(\omega, r) + W_{zy}(\omega, r)B_y(\omega, r).$$

Here  $B_x(\omega, r)$ ,  $B_y(\omega, r)$ ,  $B_z(\omega, r)$  are the observed geomagnetic field components of the MT field. In the case of flat electromagnetic waves, it is accepted that  $B_{z0}(\omega, r)$  is absent and in relation (1) the third term is also absent, which is available in general. Thus the observed value of  $B_z(\omega, r)$  occurs as a result of electromagnetic induction in the not uniform electro-conductivity area. All quantities in this equation are complex. The transfer functions  $W_{zx}(\omega, r)$ ,  $W_{zy}(\omega, r)$

are presented by induction arrows (the azimuth is accounted along the clock arrow movement from north direction) and are in the form

$$(2) \quad \begin{aligned} C_u &= \operatorname{Re}W_{zx}(\omega, r) + \operatorname{Re}W_{zy}(\omega, r), \\ C_v &= \operatorname{Im}W_{zx}(\omega, r) + \operatorname{Im}W_{zy}(\omega, r). \end{aligned}$$

Here  $C_u$  is the real and  $C_v$  is the imaginary part of  $\mathbf{W}(\omega, r)$  [6]. In matrix form, relation (1) has the form [7]

$$\mathbf{H}_z = [\mathbf{W}] \mathbf{H}_\tau$$

$$\text{here } [\mathbf{W}] = [W_{zx}W_{zy}], \mathbf{H}_\tau = \begin{bmatrix} H_x \\ H_y \end{bmatrix}.$$

VOZOFF [8] has offered to call this a matrix tipper and this name is used in the geoelectrical investigations. Relation similar to (1) was introduced for the first time in the works [9, 10], but in this case the phase differences between the components were ignored, i.e. only visible amplitudes of the selected variations were analysed.

For obtaining of the tipper, at PAG region one-minute data for geomagnetic field components variations for 2007 were used. Processing was performed by the software [8].

Initially the tipper was obtained for the first 5 days of May 2007. The used time step allows for obtaining of the tipper values for periods larger than 240 s. The values of the tipper components were obtained with a small error of 10% and  $5^\circ$ , respectively for the  $C_u$  amplitude and for its azimuth, and for  $C_v$  the same values were 30% and  $20^\circ$  (which determined the smallest value for  $C_v$ ).

The maximum of the frequency characteristics  $T_m$  for  $C_u$  is in the period range of 400–600 s (Fig. 1A). The maximal values of  $C_u$  reach 0.17, and in  $T_m$  round  $C_v$ , is reduced to values of about 0.06–0.08. The change of  $C_v$  azimuth is clearly visible, which is more than  $180^\circ$  at crossing from short to long periods. Such behaviour of the real and imaginary parts of the tipper (accordance of  $C_u$  maxima with  $C_v$  minima; accordance of the directions of  $C_v$  and  $C_u$  for periods to the maximum of the frequency characteristics and opposite change for long periods) is characteristic of 2D conductive structures [11]. In Figure 1B is shown the tipper represented on the new Bulgarian tectonic activation map (the black arrow at PAG observatory point).

For obtaining the depth anomaly formation object, which determines the tipper behaviour, we analyze the influence of the sedimentary rocks. In the middle part of Srednogorie, crystalline rocks are mixed with Oligocene sedimentary-volcanic rocks in the graben structures (from east to west – Straldzha, Kazanlak–Sheinovo and Karlovo areas), with thickness of Oligocene sediments of no more than 500 m [13]. The major part of Srednogorie sedimentary rocks consists of limestone. According to the data from borehole resistivity method [13], lime

stones are component rocks with equal age and their  $\rho$  is in the interval of 150–1000  $\Omega\cdot\text{m}$ . For sedimentary-volcanic rocks, according to borehole and laboratory investigations [14], depending on the contents in these rocks of clay inclusions,  $\rho$  can get a value of less than 10  $\Omega\cdot\text{m}$ . Taking this into account, we can confirm that the total longitudinal conductivity of the sediments  $G$  around the PAG grabens does not exceed 200 s. In accordance with some theoretical estimates [11], such  $G$  corresponds with  $T_m$  values of less than 100 s. On the other hand, the component  $C_u$  is directed contrary to the axial part of the anomalous object and the observed values of the  $C_u$  azimuth also show absence of relation of the tipper with sedimentary rocks. Thus the anomalous object, which defines the tipper behaviour, must be situated in the consolidated earth crust. It is interesting to trace the tipper parameter perseverance at the time. For that reason, the tipper for the first five days was calculated of every month of the year 2007. During this time period, strong volatility of the tipper parameters was observed, which exceeded measured errors of every parameter (Fig. 1A).

**Tipper behaviour and seismic activity in 2007.** A possible reason for the geoelectric characteristic changes of the anomalous object in PAG region may be its relation to the seismic activity. To clarify this assumption, the earthquakes with magnitude of more than 2 were taken into account, occurring to distances of 150–180 km from PAG (NEIC: Earthquake Search Results). The comparison of the earthquake time distribution with the real part of the tipper vector is shown in Fig. 2A. To say that the tipper depends entirely on seismic activity is exaggerated, but it has a visible relation to the reduction of  $C_u$  values with increasing of the number of earthquakes. For a more concrete answer to this question, we must obtain the tipper during the year and observe its variations in relation to seismic activity around PAG.

In Figure 2B the epicentres of all earthquakes for the time interval of 1980–2010 around PAG region are presented (NEIC: Earthquake Search Results) and the real part of the tipper is also shown at time with the maximum value ( $C_{u\text{max}}$ ) and the minimum value ( $C_{u\text{min}}$ ). In the area with radius of 100 km (Figs 2B – 3) from PAG are situated almost 10% (about 1280 of 13860) of all earthquakes registered on the surface range with coordinates 21°–30° east longitude and 40°–45° south latitude. The  $C_u$  direction is almost perpendicular to the area of earthquake space distribution around PAG (less than 50 km).

This can serve as a proof for existing of one electro conductivity object in the consolidated crust, which is related to the source of the earthquakes.

Fig. 1. Tipper parameter changes in PAG Observatory for the period from month 01 to month 11, 2007 (A) and tipper image on the new tectonic activation map of Bulgaria (B) →

**Earth mantle conductivity structure estimation at PAG observatory region by magnetovariational data.** The regional magnetovariational sounding method is based on using magnetosphere equatorial ring current as a source of MT field of the periodic  $D_{st}$  variations. These storm time variations are raised by the ring current system situated at altitudes of 3–6 Earth's radii. It was shown that [15] single zonal spherical harmonic  $P_1^0$  describes correctly the geomagnetic field component variations at the Earth surface in time periods in the range of 2–400 days. If the source structures are known in advance the Earth's response function may be represented by the ratios of local magnetic field components:

$$(3) \quad C(\omega) = \frac{R \tan(\theta) B_z(\omega)}{2 B_h(\omega)},$$

where  $R$  is the radius of the Earth,  $\theta$  is the geomagnetic co-latitude of the site of measurements,  $\omega$  is the angular frequency. The response function  $C(\omega)$  can be easily recalculated into the magnetotelluric impedance.

The time series of daily mean values for 1988–2008 for each of the three geomagnetic components  $B_x, B_y$  and  $B_z$  from PAG Observatory were used as input data. For calculation of the geomagnetic co-latitude  $\theta$  and for obtaining the function  $C(\omega)$  simultaneous data from the Polish Observatory of Belsk (BEL) and Russian Novosibirsk (NVS) were also used. All used data were downloaded from the server of World Data Center for Geomagnetism, Edinburgh (<http://www.wdc.bgs.ac.uk>).

The azimuth of the ring current pole must be calculated for each of these observatories by minimizing the coherence between  $B_x$  and  $B_y$  spectra. If the source field is entirely zonal, the correlation between  $B_x$  and  $B_y$  would not exist. Then a rotational transformation was applied to the  $B_x$  and  $B_y$  spectra for obtaining the horizontal  $B_h$  component. Using these azimuths and the formulas of spherical trigonometry, the geographical coordinates of the ring current pole were calculated. After this the geomagnetic co-latitude for the site of interest was calculated too. The spatially and temporally coherent geomagnetic field structure was extracted from the partially incoherent geomagnetic variations using the principal component method [13] and after this the response function  $C(\omega)$  was calculated.

In Figure 3A are shown the curves  $\rho_k$  (apparent resistivity) and phase of the impedance, calculated from  $C(\omega)$ . The geoelectrical parameters of the deep

← Fig. 2. A – comparison of the seismic activity ( $a$ ) and the change in the real part of tipper parameters in PAG observatory for the period from month 01 to month 11, 2007 ( $b$ ). B – earthquake epicentres (1), values of  $C_{umax}$  ( $2a$ ) and  $C_{umin}$  ( $2b$ ), in a circle with radius of 100 km (3)

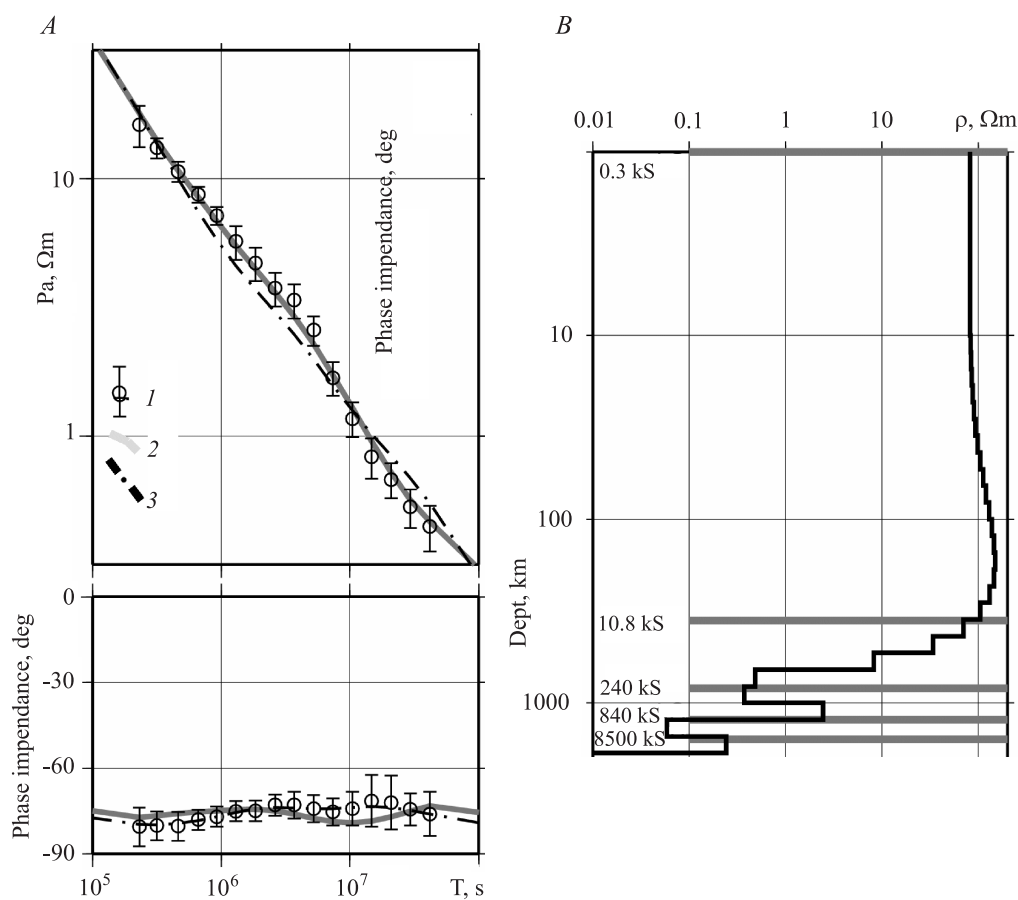


Fig. 3. Curve MVS for PAG (A) and geoelectrical model of 1D inversion (B). 1 – experimental data, 2 – model of  $D^+$ , 3 – model of Occam

section (Fig. 3B) were obtained using a 1D inversion algorithms  $D^+$  [17, 18] and OCCAM [19]. Agreement between the experimental and simulated data is shown in Fig. 3A. The used frequency range of the data allows for determining the section parameter at depths greater than 100 km. From the features of the section, we note the presence of a conductive layer at depths of 700–900 km. This layer is located between the middle and lower mantle and is also uncovered by other observations in Europe [20, 21]. Its conductivity  $G = 240$  kS is in accordance with the parameter of the layer on the other observatories from the Carpathian region — SUA, THY, NCK, LVV [21].

**Conclusions.** In this work, for the first time are defined the tipper values for PAG region in a wide range of time periods, and the magnetovariation sounding curve is constructed. By one-dimensional inversion of this curve, it is possible to determine the geoelectric characteristic of the Earth's mantle from 200–300 to 800–1000 km.

For the first time, the tipper of PAG was created in the time period range of 240–8000 s. This tipper suggests the presence of a conductive object near the observatory, in the depths of overlying crust.

The obtained PAG tipper and its parameter value changes during 2007 in comparison with the seismic activity of the region show that a correlation between them is possible.

As a result of the analysis and the processing of the time series of three geomagnetic observatories – PAG, BEL, NVS, for a time period of 20 years (1988–2008) the magnetovariation sounding (MVS) curve was constructed in the range period of 2.7–490 days ( $2.3 \cdot 10^5$ – $4.2 \cdot 10^7$  s). 1D inversion of the obtained curve was also made and the presence of one conductive layer was revealed in the transitional zone between the middle and lower mantle. The curve for PAG would be used as referent information for defining the “normal” section parameters in the cases of MT sounding data interpretation on the territory of Bulgaria.

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