Model of Electrical Conductivity Distribution across Central Europe

Václav Červ, Světlana Kováčiková, Josef Pek, Jana Pěčová, and Oldřich Praus

Geophysical Institute, Academy of Sciences of the Czech Republic,
Boční II/1401, CZ-14131 Prague 4, Czech Republic

(Received November 8, 1996; Revised June 30, 1997; Accepted July 28, 1997)

This contribution is aimed at suggesting and analyzing a thin sheet model of the electrical conductivity structure beneath Central Europe that would fit the induction response data, specifically the in-phase induction vector distribution. In particular, attention is paid to fitting the reversals of the induction vectors that suggest the existence of elongated zones of high electrical conductivity distinguishing main structural units.

1. Introduction

Induction response data at 150 field stations, that were published earlier (Praus and Pěčová, 1991), covering the Bohemian Massif (BM), the Brunovistulicum (BV), and the West Carpathian region (WCP) have been re-analyzed (Pěčová and Praus, 1996). Spatial distribution of both the in-phase and out-of-phase induction vectors, as well as contour maps of the individual elements of the transfer functions (TF) and contour maps of the anomalous vertical field, that were generated from the TFs by a hypothetical field with different polarizations, and systems of related internal anomalous currents (Kováčiková et al., 1997) prove the existence of two zones of anomalous induction at the eastern margin of the BM and near the boundary of the Carpathian plate. The analysis of additional induction data at 958 localities covering mainly the Central European area suggests that these anomalies could be connected with the North-German-Polish anomalous zone, representing an important part of the Trans-European Suture Zone (TESZ). The analysis of regional-scale models of electrical conductivity distribution is performed to fit the anomalous features of the induction response data over the Central European area, specifically the zones of anomalous induction in the eastern margin of the BM, across the entire block of the BV and near the margin of the Carpathian tectonic plate.

2. Geological Setting

Fundamental elements of the central European geological structure that are relevant to our modelling experiment are schematically displayed in Fig. 1. The major geological units over the Czech and Slovak Republics covered by induction response data involved in the modelling process are shown in Fig. 2.

(i) The Tornquist-Teisseyre tectonic zone (T-T) constitutes one substantial part of a number of fault zones and sutures found within the Trans-European Suture Zone (TESZ) that represents the most important geological boundary in Europe, separating mobile Phanerozoic western terranes (Meso-Europe) from the Precambrian east European Craton. The zone crosses the region of our model on the territory of northern Germany and Poland (Fig. 1). It is clearly defined in the deep lithosphere, as well as in the upper crust. The Moho depths increase across this zone from 30 km beneath the Variscan Europe to 45 km beneath the East European Craton. In contrast to the relatively cold eastern craton relatively high heat flow characterizes Western Europe.

(ii) The Bohemian Massif (BM) represents the easternmost consolidated block of the Variscan branch of the European Hercynides (Meso-Europe) that builds up Bohemia and the
western part of Moravia. The major structural elements of the BM are several SW-NE trending zones separated usually by deep-seated faults, which are reflected in the results of the deep seismic profiling, in the gravity, geomagnetic and heat flow maps (Suk et al., 1984). The fault structures are essentially parallel with the boundaries of individual Hercynian zones. The intersection of these zones with the second order system of NW-SE trending faults is responsible for the complicated block structure of the BM. Particular blocks near the east, northeast and southeast margin of the BM related to the region of this study are the Moravian Moldanubicum, the Moravo-Silesian zone (Moravicum and Silesicum) and the Sudeticum (Fig. 2).

(iii) The Carpathians belong to the young Tertiary Alpine-orogenic belt and they constitute the NE branch of the Alpides. Their boundary with the Eastern Alps runs along the Danube Valley. The northern boundary with the East European Platform is defined by the erosive margin of the flysch nappes. The model covers the West Carpathians (WCP), and we distinguish here the inner (central) Carpathians, the Klippen zone, the outer (Flysch) Carpathians and the Carpathian
(iv) The Brno unit, termed recently the Brunovistulicum (BV), lies in between those previously mentioned structural elements (Fig. 2). The BV unit is assumed to be an independent geological structure forming the Precambrian (Cademian) basement (Palaeo-Europe) of both the eastern part of the Hercynides (Variscides) of the BM and the Alpides, i.e. of the WCP in Moravia. Recent geophysical and geological information has shown that the BV and the whole Moravian block occupy a highly independent position and form a separate geological unit belonging probably to the Fenno-Sarmatian Platform (Weiss, 1977; Dudek, 1980; Misař et al., 1983; Suk, 1995).

3. Induction Response Data

Induction response data used in our modelling experiment consist of two sets of estimates. The first data set are estimates of the real and imaginary components of single-station TFs, \( A^* = TF1 + i TF2 \) and, \( B^* = TF3 + i TF4 \) and the corresponding in-phase and out-of-phase induction arrows (vectors) as introduced by Schmucker (1970). They are obtained by analyzing records of the temporal variations of the conventional geomagnetic field components \( H \) (+north), \( D \) (+east) and \( Z \) (vertical, +downward). As the \( Z \)-component is known to be highly sensitive to laterally inhomogeneous distribution of the internal electrical conductivity, maps of these vectors
provide us with a view of the changing anomalous behaviour of the Z-variation as a function of frequency and location. In our definition, the in-phase vectors point away from zones of high and toward zones of low internal conductivity. The reversals of arrows distinguish zones of anomalous induction, which often mark important geological features such as contacts between blocks with different geological histories, zones of past and recent tectonic activity, collision zones and etc. Our estimates of the TFs resulted from analyzing the variation records in frequency and time domains and solving the complex form of the Wiese relation, $Z = A^*H + B^*D$ for $A^*$ and $B^*$. Input data were our own variation records at a total of 150 field sites covering the region of the eastern slopes of the BM, the whole BV and the WCP region marked in Fig. 2 by a dashed rectangle. The moduli and arguments of the in-phase and out-of-phase vectors are defined in terms of TFs according to formulae $IVR = (TF1^2 + TF3^2)^{1/2}$, $\theta_{IVR} = \arctan(TF3/TF1)$, $IVI = (TF2^2 + TF4^2)^{1/2}$, and $\theta_{IVI} = \arctan(TF4/TF2)$.

On investigating detailed structure of the eastern slopes of the BM and BV covered by 57 stations, we used, in addition to the single-station TFs, also a subset of inter-station TFs and corresponding induction vectors related to the permanent electromagnetic observatory of Budkov in South Bohemia as the common reference.

Typical relative errors are between 6 and 14% for the in-phase single-station vector moduli and between 4° and 8° for their azimuths (clockwise angle between N and the vector). Due to reduced amplitudes, the inter-station moduli are estimated with relative errors between 14 and 20%, while the azimuth errors are between 5° and 10°. In general, the out-of-phase induction parameters are estimated with substantially reduced reliability. Relative errors between 40 and 80% are typical of the moduli and about 20° and 50° of the azimuths (Pečová and Praus, 1996).

In the second set of the induction response data, we have collected, from publications and by data exchange, real transfer functions of the Wiese type (Wiese, 1962), corresponding roughly to TF1 and TF3 components, at almost 1000 localities shown in Fig. 8 by diamonds, covering Europe with the highest density across the central and south-eastern sector of Europe. Estimates were obtained by fitting the Wiese relation for visual amplitudes of variation events of duration from about 10 to 45 minutes.

4. Summary of the Results Obtained by Analyzing the Induction Response Data

4.1 Distribution of both the real and imaginary induction vectors

The induction vectors across the WCP show a clear perpendicular orientation with respect to the general trend of the anomalous zone over the central part where their azimuths reverse by 180°. In contrast, the induction vector pattern on the eastern margin of the BM and across the BV is distinguished by vectors oriented predominantly parallel to the general SW/NE trend of the anomalous zone. The reversal of the azimuths of the vectors across the anomalous zone is developed rather poorly. These features are apparent in Fig. 3, where real (full) and imaginary (dashed) vectors are shown for the variation period of 32 minutes.

Details of the anomalous pattern at the eastern margin of the BM are well demonstrated by distribution of reference-station induction response characteristics in Fig. 4. Its upper part displays the anomalous distribution of the reference-station induction vectors estimated for a subset of 57 stations across the BM/BV area. Specifically, the eastern part of the area is distinguished as having relatively long reference-station vectors. The anomalous belt is traced clearly by a computer generated contour map for the azimuths of these vectors across the same area and shown in the lower part of Fig. 4. The anomalous belt is defined by a specific pattern of contours showing large changes in azimuths over a small distance and confined into a relatively narrow belt (marked by a white belt between filled contours) aligned southwest/northeast. A rather dramatic change of the contours over the central part of the area seems to suggest a discontinuous character of the internal field source.
4.2 Distribution of individual TF components

Contour maps of individual TF components were generated for periods of 96, 64, 32 and 20 min. The individual TF components in Fig. 5 are examples for a variation period of 64 minutes.

In separating the induction effect into the real and imaginary NS (TF1 and TF2) and EW (TF3 and TF4) components, we aimed at recognizing more details about the orientation of the deep conductors, and at comparing the individual components of both anomalous belts which behave differently in the eastern part of the BM and the WCP region. As the real part of the NS component has larger amplitude than the EW component, we may speculate about the existence of a deep EW oriented structure beneath the whole region. Joint effect of both polarizations in the eastern part of the BM seems to be connected with a leakage of currents from the north into the WCP area. The results of modelling seem to support partially this assumption.

Both anomalous zones in the BM/BV and WCP regions are distinguished by the zero contour of the TF1 and TF2 components, as shown in Fig. 5a),b) (NS polarization). The pattern of the TF1 component remains almost the same for all periods. The other pair of components TF3 and TF4 (EW polarization) shown in Fig. 5c),d) seems to be more important in the BM/BV region. Specifically, the zero contour of the TF3 component, as the real and dominating part of the response, makes the anomalous zone clearly visible across the BM/BV sector for all periods, while no characteristic pattern comes out of the contours across the WCP region.
Fig. 4. Upper part: Distribution of reference-station in-phase (full) and out-of-phase (thin) induction vectors for a subset of 57 field stations across the BM/BV region and a period of 32 minutes. The profiles are labelled by the year of the field measurement, unit vector is shown by an arrow. Lower part: Computer generated grey-scale contour map of azimuths, defined as clockwise angle between the north and each of the vectors shown in the upper part of the figure. Orientation of vectors is schematically shown together with the grey scale. A white belt (azimuth of 150°) defines the axis of the anomalous belt at the eastern margin of the BM. White diamonds mark the subset of field stations. For errors of the estimates see the text.
Fig. 5. Distribution of single-station TF components across the BM/BV and WCP region (box area in Fig. 2) for the period of 64 minutes: a), b) real and imaginary components of the complex function \(A^*\), c), d) real and imaginary components of the complex function \(B^*\) (see definition in Section 3).

Fig. 6. Contour maps (scale in km) of the vertical component of the anomalous magnetic field (in relative units) generated by external hypothetical fields of four different polarizations across the box area of Fig. 2. Thick arrows mark the polarization of the external inducing field. Areas of positive and negative field values, separated by zero contours, are distinguished by corresponding signs.
4.3 Contour maps of internal vertical field component for different polarizations of the external field

To obtain a closer insight into the sources and the character of the anomalous induction, we applied the approaches suggested in Banks and Beamish (1984) and Banks (1986), and used both the single-station and reference-station TFs to generate contour maps of the internal vertical magnetic field component for different polarizations of the hypothetical external field across the entire region (Kováčiková et al., 1997).

In principle, the most pronounced induction pattern is expected to be obtained if the external inducing field is perpendicular to the strike of an anomalous zone and the currents flow along its strike. As we can see in Fig. 6, both anomalies are well defined by NNE and SSE polarizations of the external field, though NNE-azimuth is practically parallel with the strike of the anomalous zone in the eastern margin of the BM. Both polarizations seem to suggest a strong influence of a conducting structure that is elongated E-W, and of channelling by 3-D structures.

Fig. 7. Real anomalous internal current function for north oriented primary inducing field over BM/BV area (box area in Fig. 2). The upper section corresponds to the depth of the thin-sheet 9 km, the lower part is for the thin-sheet depth of 18 km. The thick arrow marks the N polarization. Scales of sheet current density are in A/m.
4.4 Equivalent current systems at different depths

The anomalous vertical magnetic fields generated by hypothetical horizontal field across an array of stations provide us with an efficient method of qualitative estimation of the depth to the top of anomalous structures. We can generate maps of equivalent current systems that are concentrated within a thin sheet at a specific depth (Kováčiková et al., 1997). A thin sheet approximation can be applied, as we analyze induction characteristics based on long period variations with wave lengths and corresponding skin depths greater than the thickness of the upper layers of the earth crust. Generating equivalent current stream functions for different depths of the thin sheet, we obtain smooth configuration of contours only for those depths that do not exceed the depth of the real anomalous current sources. For greater depths of the sheet, the stream function develops instabilities and the contour configuration disintegrates into isolated closed patterns in virtue of continuing the field beyond the source top level. This process is clearly demonstrated in Fig. 7 for sheet depths of 9 km (upper part) and 18 km (lower part). According to a simplified picture of what is known or can be guessed about the internal structure from independent geophysical and geological information, we expect the internal source of the anomalous fields across the region under investigation to be within the depth range from about 10 to 25 km.

Fig. 8. Zero contour map of transfer function A (Wiese vector). The diamonds mark the localities with induction data estimates. The contours distinguish the zero value of the vertical magnetic field component and separate positive (dark shaded) and negative (light shaded) values of A. Anomalous belts are labelled: NGP—North-German-Polish anomaly; BMA—anomalous belt at BM/BV contact zone; WCA—West Carpathian anomalous belt (section of the Carpathian geoelectrical anomaly); MPA—Moesin platform anomaly. No data were available to us across white and labelled areas. Contours of Europe are shown to guide the eye.
Having generated equivalent current systems corresponding to the NS polarization of the inducing field for a series of different thin sheet depths, we concluded that the source depth can be about 18 km in the WCP region and about 10 km in the BM/BV region. These estimates are suggesting the sources of the anomalies to be in average at shallower depths than those obtained by us previously (16–26 km in northern and eastern parts of the WCP region, see (Jankowski et al., 1985), and 18–23 km at different profiles across the eastern margin of the BM (see Pěčová and Praus, 1996) by separating the magnetic field variations into internal and external parts and applying the line current approximation. Both results are not controversial anyway, as the line current approximation inherently gives the maximum source depths.

4.5 Anomalous induction across Europe

From published data (Calota et al., 1971; Ádám et al., 1972; Rokityanski, 1975; Jankowski et al., 1979; Petr et al., 1984) and by personal exchange of data, we have amassed 958 estimates of TFs (A, B, components of the Wiese arrow). We present the zero contour map of the component A corresponding to the field of external sources linearly polarized in NS direction in Fig. 8. This map shows the most prominent zones of anomalous induction. They are marked by the zero contour of the function A, and elongated conductors and significant inhomogeneities in the distribution of the electrical conductivity may be assumed underneath. We clearly distinguish the elongated North-German-Polish anomaly (NGF) and the Carpathian anomaly (WCA). The map also shows that the eastern slopes of the BM (BMA) and the BV together with NGP and WCA form a continuous anomalous zone encompassing the Brunovistulicum. Thus, its recent geological interpretation as an independent structural block belonging probably to the East European (Fenno-Sarmathian) platform (Dudek, 1980; Misař and Dudek, 1993) is supported. The map of the B component (not shown here) does not clearly reflect these anomalous belts.

5. Conductivity Models

In our modelling attempts, we aimed at finding configurations of good and poor conductors in which the inducing magnetic field generates the current systems that can be mapped by the spatial distribution of complex induction vectors in the BM, BV, WCP and surrounding geological units. We have chosen the modelling region covering the longitudes between 12° and 24°E and latitudes between 46° and 54°N. A regular grid of 32 x 32 square cells 28.5 x 28.5 km² was superimposed across this area (see Fig. 1). A thin-sheet approximation (Vasseur and Weidelt, 1977) was applied in solving for the distribution of induced currents and corresponding induction vectors.

In the first step, the effects of near-surface inhomogeneities were analyzed. A variable conductance $S = \sigma h$ (Siemens), where $\sigma$ is the electrical conductivity (Siemens/m) and $h$ is the thickness of the thin-sheet (m), within an inhomogeneous superficial thin sheet was estimated according to several maps displaying the conductance across the Northern Germany, Poland, both the Czech and Slovak Republics, Hungary, Austria and Romania (Porstendorfer et al., 1976; Majorowicz et al., 1976; Shilova and Sanin, 1982; Ádám et al., 1982; Jankowski et al., 1991; Praus and Tobyvásová, 1992). A three layer horizontally homogeneous medium was assumed at the base of the thin sheet (resistivities in $\Omega$m: $\rho_1 = 10000$, $\rho_2 = 5000$, $\rho_3 = 100$ and thicknesses $h_1 = 10$ km, $h_2 = 90$ km, $h_3$ extending to infinity, period $T = 900$ s).

The computed distribution of the in-phase and out-of-phase induction vectors across this model could explain the belts of anomalous induction only partially. Therefore we do not display, for the sake of brevity, these results but only comment on them here. Superficial structures were found to be traceable by the reversals of induction vectors within the North-German-Polish anomalous belt marking the T-T tectonic zone and the Carpathian geoelectrical anomaly near the boundary of the Central and Outer Carpathians. The zone of anomalous induction marked
by induction arrows in the eastern margin of the BM was not apparent in the distribution of model induction arrows.

In the next step an attempt was made to see the distribution of the induction vectors distribution corresponding to the configuration of blocks with different conductances that range according to the above referred geological and geophysical information from 10 to 5000 S and form a thin sheet at a depth of about 10 km. A three layer horizontally homogeneous structure with the same parameters as mentioned previously was assumed in the basement of the thin sheet. The schematic structure of the model is shown in Fig. 9, the distribution of conductances within the thin sheet is displayed in the upper part of Fig. 10. In devising this model, we treated the BM and the Alps as poor conductors. On the basis of the induction vector pattern and additional geophysical and geological investigations (Dudek, 1980; Misař and Dudek, 1993) the BV unit was incorporated as a poor conductive promontory belonging to the East-European Platform and extending in between the BM and the WCP. A well conductive zone of 1000 S separates the BM from the BV that is assumed in some geological concepts (Misař et al., 1983) to form the termination of the Hercynian (Variscean) units bending into SSW direction (see Fig. 1). This zone allows the leakage of a certain current flow from the northern area into the BM/BV and WCP regions.

The distribution of the real vectors for the model is shown in the lower section of Fig. 10 for a period of 900 s. All main zones of anomalous induction (T-T tectonic zone, Carpathian geoelectrical anomaly) are distinguished by reversals or substantial changes of the vector azimuths. In addition, also a qualitatively good directional compatibility between the model and real patterns can be seen for the real induction vectors in the area of the eastern margin of the BM in contact with the BV unit. Their magnitudes, however, are smaller than those obtained from the real data. Contrary to this, the imaginary vectors (not shown here) are larger and their mutual orientation in relation to the real ones does not correspond to that calculated from the field data. They seem to be collinear with the real vectors, while in the actual situation they are usually anti-parallel.

Fig. 9. Schematic thin-sheet model of the structure assumed in the modelling attempts. Actual resistivities and depths of individual layers are mentioned in the text.
Fig. 10. Upper section: Spatial distribution of the conductance (in Siemens) within the inhomogeneous thin sheet assumed across the model area at the depth of 10 km. Geological units are labelled according to abbreviations in the text. Contours of the Central European countries are shown by full lines to guide the eye. Lower section: Map of real induction vectors across the model area for the period of 900 s. The main zones of anomalous induction are distinguished by thick lines. Central European countries are marked: GR—Germany, POL—Poland, CR—Czech Republic, SR—Slovak Republic, UKR—Ukraine, AUS—Austria, HUN—Hungary. Lines in the central part labelled 57 (km) are the scales of vertical and horizontal axes of both maps, grey scale is labelled in Siemens units.
Model of Electrical Conductivity Distribution

or deviated almost perpendicularly. We have to consider that the imaginary vectors are affected by the schematization of the model. Furthermore, the downward integration of the conductivity does not allow to separate the conductive zones at different depths.

Within the BM block, there is again only qualitative directional coincidence of both the induction vector patterns. They all point towards the south, but the magnitudes of model vectors are much smaller than those of field data.

6. Conclusions Following from the Modelling of Induction Response Data

The geomagnetic TFs are reliable and stable indicators of transitional zones between basic tectonic blocks. The TF coverage is sufficient to allow a detailed 3-D treatment of the anomalous zones to be carried out, provided a homogenization of the induction data precedes the modelling. Analyzing the induction response data across the central European area (Figs. 1 and 2), we emphasize the following features:

(i) Induction vectors across the WCP region show in general N-S orientation, reverse their azimuths by 180° and mark, thus, the Carpathian geoelectrical anomaly. This pattern is fully compatible with a 2-D distribution of the electrical conductivity only in the northern sector of the WCP region. By preserving the N-S orientation in the western contact zone with the submerged block of the BM, a directional discrepancy with respect to a general trend of the anomalous zone seems to appear. A deep-seated W-E large scale regional conductive structure seems to affect the induction response (Fig. 3).

(ii) The induction vector pattern at the eastern margin of the BM and across the BV unit is distinguished by vectors oriented predominantly parallel to the general SW-NE strike of an anomalous zone. The reversal of azimuths is rather poorly developed, (Figs. 3 and 4). These facts clearly indicate a 3-D distribution of the electrical conductivity.

(iii) A zone of anomalous induction at the eastern margin of the BM may be attributed to superposing effects of increased and non-uniform electrical conductivity. The zone seems to delineate a deep-seated boundary of two tectogenes with different electrical conductivities. Contours of arrow azimuths in the central part of the zone (Fig. 4) suggest a discontinuous character of the anomalous field source and its displacement towards the SE along an existing fault system (Hang fault zone).

(iv) Owing to the correlation with elements of the deep geological structure, the conductive zone may distinguish the termination of the Hercynian (Variscean) structures in this sector. The most favoured assumption bends all Hercynian belts in this region from WE to SSW direction assigning them enhanced electrical conductivity.

(v) Contour maps of the internal vertical field component and equivalent current systems generated from TFs for different polarizations of external inducing fields seem to suggest a strong influence of E-W striking conductive structures and subsequent current channelling by the 3-D structure of the region (Fig. 6). The analysis of contour maps (Fig. 7) suggests an anomalous field source at depths of about 18 km in the WCP region and of about 10 km in the BM/BV region.

(vi) The clearest induction pattern should be obtained with the external field polarized perpendicularly to the strike of the conductive zone and the induced currents flowing in this strike direction. Here, in contrary, both anomalous zones are best developed with the NNE and the SSE polarizations of the external field. This is compatible with the E-W trend of the Carpathian anomaly only in the north of the WCP. In other parts of the anomalous zone, the polarization of the most effective external field is nearly parallel to the general spatial trend of the anomalous belts (Figs. 6 and 7).

(vii) Heavy lines in Fig. 8 mark zero contours separating positive and negative values (shaded and light stippled areas, respectively) of the TF1 component. They clearly display the NGP, BMA
and WCP anomalies and suggest them as a continuous system of anomalies. The zero contour also delineates the BV unit as an independent block between the two principal structural units of the BM and WCP and supports geological interpretation, based on geophysical/geological and chronometric studies (Dudek, 1980; Suk, 1995), suggesting the BV to represent a separate geological unit belonging to the East-European platform (Fig. 11).

(viii) The modelling of the real induction vectors shows a satisfactory spatial coincidence between the vector directional characteristics and the main anomalous belts, but only a qualitative agreement of magnitudes of the modelled and the observed vectors. Also, there is disagreement between modelled and observed imaginary vectors. Imaginary model responses are larger, and

![Component TF1: T=64 min](image)

**Fig. 11.** Upper part: Filled contour map of the TF1 induction response component integrating the BMA and WCP anomalous induction belts into the system of the Trans-European Suture zone. Lower part: Geological interpretation of the Brunovistulicum as the promontory of the East European platform, assumed penetration of which into the space between the BM and WCP is marked by arrow sign (according to Suk et al., 1984). Original map by (Weiss, 1977) was adapted by the authors. Geological symbols: 1—East-European Platform and BV unit, 2—BM, 3—Alpine-Carpathian system, 4—fault zones. Extent of the upper box is marked as a region bounded by thick lines.
their orientation does not fit that of the field data. They seem to be collinear with the real vectors, while in the actual situation they are usually anti-parallel or deviated to perpendicular position.

The recent results of induction data modelling are satisfactory to only a certain degree. No effects of the asthenosphere and its depth variations across the region have been taken into consideration. Also inhomogeneities of the external source field across the models have been neglected. With the periods used in the modelling, mutual interaction of conductive structures on a regional scale seems to be apparent. Induction anomalies are undoubtedly due to combined effect of both local and remote structures. Therefore, further modelling is being carried out to better understand the induction phenomena across central Europe.

The authors gratefully acknowledge support for this work through research Grant No. 205/95/1305 from the Grant Agency of the Czech Republic. We also would like to thank the staff of the Geophysical Institute of the Academy of Sciences of the Czech Republic for supporting this investigation. G. Schwarz and an anonymous reviewer greatly assisted the improvement of this manuscript by their comments. Sincere appreciation is expressed to both of them.

REFERENCES

Ádám, A., J. Verö, and Á. Wallner, Regional properties of geomagnetic induction arrows in Europe, *Acta Geod. Geophys. et Montan. Acad. Sci. Hung.*, 7 (3–4), 251–287, 1972.

Ádám, A., L. L. Vanyan, D. A. Varlamov, I. V. Yegorov, A. P. Shilovski, and P. P. Shilovski, Depth of crustal conducting layer and asthenosphere in the Pannonian basin determined by magnetotellurics, *Phys. Earth Planet. Inter.*, 28, 251–260, 1982.

Banks, R. J., The interpretation of the Northumberland trough geomagnetic variation anomaly using two-dimensional current models, *Geophys. J. R. astr. Soc.*, 87, 595–616, 1986.

Banks, R. J. and D. Beamish, Local and regional induction in the British Isles, *Geophys. J. R. astr. Soc.*, 79, 539–553, 1984.

Calotă, F., I. Căltan, A. Ionescu, A. Soare, and V. Șteflea, Înregistrări de variații geomagnetice pe teritoriul României (Partea I), *Stud. Cerc. Geol. Geogr. Geofiz.*, Ser. Geofiz., 9, 323–331, 1971.

Dudek, A., The crystalline basement block of the Outer Carpathians in Moravia: Brunovistulicum, *Rozpr. Čs. Akad. Věd. ř. mat. přír. věd, Praha*, 90, 1–85, 1980.

Gutcher, A., U. Lueosto, M. Grad, J. Vlha, K. Jirny, E. Egorov, H. Korbonen, T. Janik, P. Lindblom, R. Materzok, and E. Perchuc, Seismic studies of crustal structure in the Teisseyre-Tornquist zone in Northwestern Poland (Preliminary report), *Pubs. Inst. Geophys. Pol. Acad. Sci.*, A–19 (236), 147–156, 1991.

Jankowski, J., V. Petr, J. Štefka, and O. Praus, Induction vector estimates in the Polish-Czechoslovak part of the Carpathians, *Studia geoph. et geod.*, 23, 89–93, 1979.

Jankowski, J., Z. Tariłowski, O. Praus, J. Štefka, and V. Petr, The results of deep geomagnetic soundings in the West Carpathians, *Geophys. J. Roy. astr. Soc.*, 80, 561–574, 1985.

Jankowski, J., I. Pavlisezn, W. Józwiak, and T. Ernst, Synthesis of electrical conductivity surveys performed on the Polish part of the Carpathians with geomagnetic and magnetotelluric sounding methods, *Pubs. Inst. Geophys. Pol. Acad. Sci.*, A–19 (236), 183–214, 1991.

Kováčiková, S., V. Červ, and O. Praus, Modelling of geomagnetic transfer functions on the eastern margin of the Bohemian Massif, *Ann. Geophys.*, Suppl. 1 to Vol. 15, 15 C 159, 1997.

Majorowicz, J., S. Plewa, and M. Węsiarska, The terrestrial thermal field in Poland, in *Geolectric and Geothermal Studies*, edited by A. Ádám, pp. 402–413, KAPG Geophysical Monograph, Akadémiai Kiadó, Budapest, 1976.

Misar, Z. and A. Dudek, Some critical events in the geological history of eastern margin of the Bohemian Massif, *J. Czech Geol. Soc.*, 38, 9–20, 1993.

Misar, Z., A. Dudek, V. Haviena, and J. Weiss, *Geologie ČSSR J. Český Masív*, pp. 11–23, SPN Praha, 1983.

Petr, V., J. Štefka, and O. Praus, Induction vector estimates in the Bohemian Massif and in the transition zone to the Carpathians, *Studia geoph. et geod.*, 26, 172–177, 1984.

Pěčová, J. and O. Praus, Anomalous induction zones in the Czech Republic in relation to large scale European anomalies, *Studia geoph. et geod.*, 40, 50–76, 1996.

Porstendorfer, G., W. Göthe, K. Lengning, Ch. Oelsner, R. Tanzer, and E. Ritter, Nature and possible causes of the anomalous behaviour of electric conductivity in the North of the GDR, Poland and the FRG, in *Geolectric and Geothermal Studies*, edited by A. Ádám, pp. 487–500, KAPG Geophysical Monograph, Akadémiai Kiadó, Budapest, 1976.

Praus, O. and J. Pěčová, Anomalous geomagnetic fields of internal origin in Czechoslovakia, *Studia geoph. et geod.*, 23, 89–93, 1979.
Praus, O. and M. Tobýšková, Electrical conductance of sediments overlaying the basement of the Czech Republic, *Studia geoph. et geod.*, 36, 161–167, 1992.

Rokityanski, I. I., *Investigation of Electrical Conductivity Anomalies by the Method of Magnetovariation Profiling*, pp. 131–133, Naukova Dumka, Kiev, 1975 (in Russian).

Schmucker, U., Anomalies of geomagnetic variations in the southwestern United States, *Bull. of the Scripps Inst. of Oceanography*, University of California Press, 13, 13–32, 1970.

Shilova, A. M. and S. I. Sanin, *Conductivity of the Sedimentary Cover over the Carpathian Region*, pp. 1–3, AN SSSR, IZMIRAN, 1982.

Suk, M., Regional geological division of the Bohemian Massif, *Exploration Geophysics, Remote Sensing and Environment*, II, No. 2, 25–30, 1995.

Suk, M., M. Blžíkovský, T. Buday, I. Chlupáč, I. Cicha, A. Dudek, J. Dvořák, M. Eliáš, V. Holub, J. Ibrmajer, O. Kodym, Z. Kukal, M. Malkovský, E. Menčík, V. Müller, J. Tyráček, Z. Vejnar, and A. Zeman, *Geological History of the Territory of the Czech Socialist Republic*, pp. 65–81, Geological Survey, Prague, 1984.

Vasseur, G. and P. Weidelt, Bimodal EM induction in non-uniform thin sheets with an application to the Northern Pyrenean Anomaly, *Geophys. J. R. astr. Soc.*, 51, 669–690, 1977.

Weiss, J., Basis of the Moravian block in the structure of the East European platform, *Folta Univ. Purkyn. brun. Geol.*, 18, 5–64, 1977 (in Czech).

Wiese, H., Geomagnetische Tiefentellurik Teil II: Die Streichrichtung der Untergrundstrukturen des elektrischen Widerstandes, erschlossen aus geomagnetischen Variationen, *Geofisica pura e applicata*, 52, 83–103, 1962.