New magnetotelluric measurements in West Bohemia: detecting geoelectrical changes to the east *

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Abstract

Long period magnetotelluric and magnetovariational (MT/MV) measurements in West Bohemia carried out along the profile Cheb—Tachov—Nýrsko, close to the Czech-German border, display a striking similarity with analogous data from the immediate vicinity of the KTB borehole. On the other side, broad band AMT/MT/MV data along the seismic reflection traverse 9HR, measured by the Free Univ. of Berlin and Geofyzika Inc. Brno, show a substantially more complex geoelectrical structure in the region to the east of the West Bohemian fault zone, indicating a discontinuous geoelectrical character when approaching the western margin of the Bohemian Massif. To assess the large scale geoelectrical changes in the E-W direction, additional long period MT measurements have been carried out at 8 localities in the area between the two basic NW-SE profiles. The new stations were arranged along two short profiles, one traversing the West Bohemian faults into the Teplá-Barrandien zone and the other running just along the Central Bohemian deep fault. Preliminary analysis of those measurements is presented in this contribution.

1 Regional induction studies in West Bohemia

In the last six years two large scale geoelectric induction projects have been organized in West Bohemia, both of them motivated by the nearby deep drilling experiment KTB in Oberpfalz, Germany. The first one [1, 2], organized by the Geofyzika Inc. Brno and the Geophysical Institute Prague, and measured and processed by the colleagues from the Free University of Berlin, team of dr. G. Schwarz, consisted of a broad band AMT/MT/MV profile, about 230 km in length (see Profile 1 in Fig. 1), which followed the seismic reflection traverse 9HR, performed earlier in the region involved. In several field campaigns, altogether 56 short period (period range 10^{-3}—10^{2} s) and 15 broad band AMT/MT/MV stations (period range 10—4096 s) were set up and run along that profile, which means a relatively close spacing of 2—3 km for the AMT and about 12—15 km for the long period MT/MV soundings. The profile 1 covers all the principal geological units of the West Bohemian region, from the Saxothuringicum in the north to the Teplá-Barrandien Proterozoic unit to the South Bohemia Moldanubicum in the south, and crosses the distinguished tectonic lines of the area—the Litoměřice deep fault in the north and the Central Bohemian deep fault (suture zone) at the contact between the Teplá-Barrandien zone and the South Bohemia Moldanubicum (Fig. 1).

The other main project of the regional geoelectrical studies in West Bohemia was a profile of 14 long period MT/MV stations, about 100 km in length, arranged immediately along the Czech-German border (Profile 2 in Fig. 1)[3]. The profile was measured in 1991—93 by the Geophysical Institute Prague. Besides the 14 basic long period soundings (period range 10—4096 s), several additional AMT soundings were performed at selected localities on the profile by teams of the University of Frankfurt (dr. K. Bahr and dr. M. Eisel) and cooperation teams from Italy (dr. A. Zaja, Univ. of Padova, dr. A. Manzella, IIRG CNR Pisa).

In [3, 4] a detailed analysis of the data from the profile 2 was given, with the following principal conclusions summarized here:

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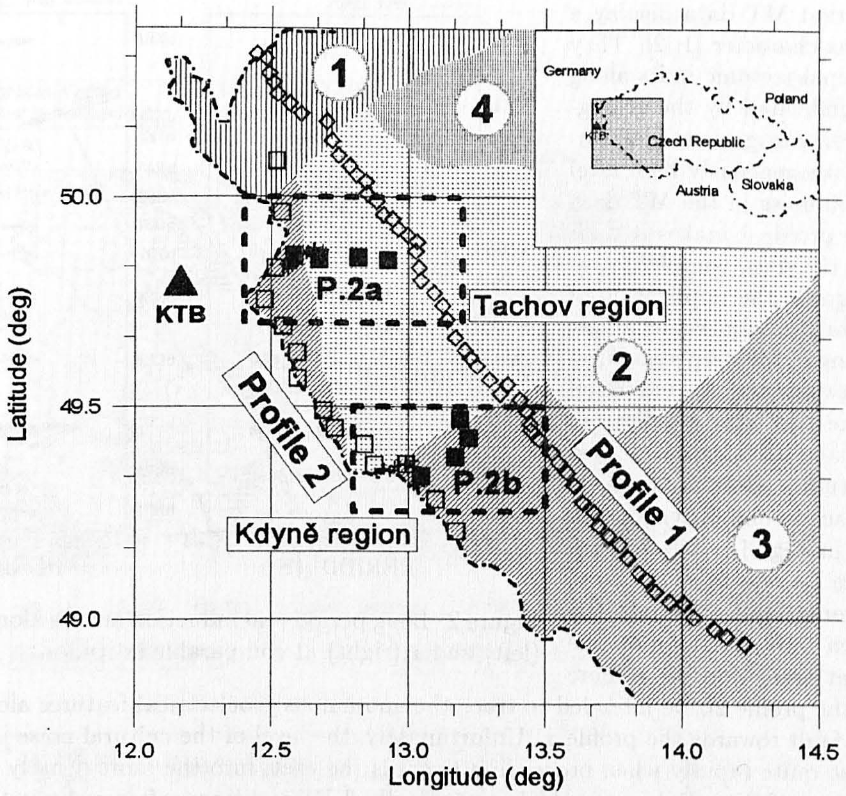


Figure 1: Layout of the AMT/MT/MV profiles in West Bohemia. In the background the principal geological units of the western part of the Bohemian Massif are shown: 1—Saxothuringicum, 2—Teplá-Barrandien Proterozoicum, 3—Moldanubicum, 4—Cretaceous.

1. The long period MT/MV data along the profile 2 display striking similarity with the analogous data obtained in the close vicinity of the KTB area [5, 6], with induction arrows directed predominantly to the south and large anisotropy of the MT impedances, indicating the direction of the highest conductivity to be NW-SE to NNW-SSE.

2. The deep over-regional E-W striking structure is characterized by a decreasing induction effect towards the south, resulting either from a gradually decreasing conductance of that structure, or from its abrupt termination somewhere to the north of the profile. To fit the MT phases along the profile, the former model of the over-regional structure is preferred, with the regional conductor represented by a relatively thin conductive layer, with gradually decreasing conductance towards the south, at middle crustal depths.

3. The large anisotropy of the MT impedances may be a combined effect of a real macro-anisotropy of the crustal layers, in the sense of the Eisel's conductive dykes in ZEV [5], and the static distortions of the MT curves.

4. Over the southern section of the profile a sudden drop of the resistivities is indicated, geologically attributed to the area where the Bohemian Quartz Lode from the north and the Central Bohemian deep fault from the NE cross one another.

The MT/MV data from the profile 1 indicate a much more complex pattern of geoelectrical changes along the traverse. Already a simple look at the long period real induction arrows for the two profiles at comparable latitudes (Fig. 2) reveals the substantial differences between the structures. While the real induction arrows along the profile 2 show a homogeneous southward orientation along the whole profile and for all the period range considered, with a slightly expressed tendency of rotating from the east in the northern part of the profile to the west in its southern section, the arrows along the profile 1 indicate a strong influence of numerous local distorters, and fit into the over-regional pattern only at long periods, specifically greater than 300 s.

The long period MT data display a similarly complex character [1, 2]. They reflect the principal tectonic units along the traverse as indicated by the geological and seismic investigations [2]. Unfortunately, a homogeneously high level of the civilization noise in the MT data along the whole profile 1 makes it difficult to exhaust the data completely, in particular as regards the application of the decomposition techniques and a more detailed modelling of the deep structure.

In the last two years the induction studies along the two basic profiles described above have been supplemented with two local studies situated in the regions near to Tachov and Kdyně, (profiles 2a and 2b in Fig. 1, respectively). With the profile 2a, we tried to cross the West Bohemian fault zone into the Teplá-Barrandien unit and to map the character of that transition on a more local scale. By the profile 2b we intended to trace the anomalous geoelectrical features along the Central Bohemian deep fault towards the profile 1. Unfortunately, the level of the cultural noise in the MT data seems to increase quite rapidly when proceeding towards the east, into the more densely populated and industrialized areas of West Bohemia, which, in typically 3-D conditions, often reduces the possibilities of the interpretation to only a qualitative level.

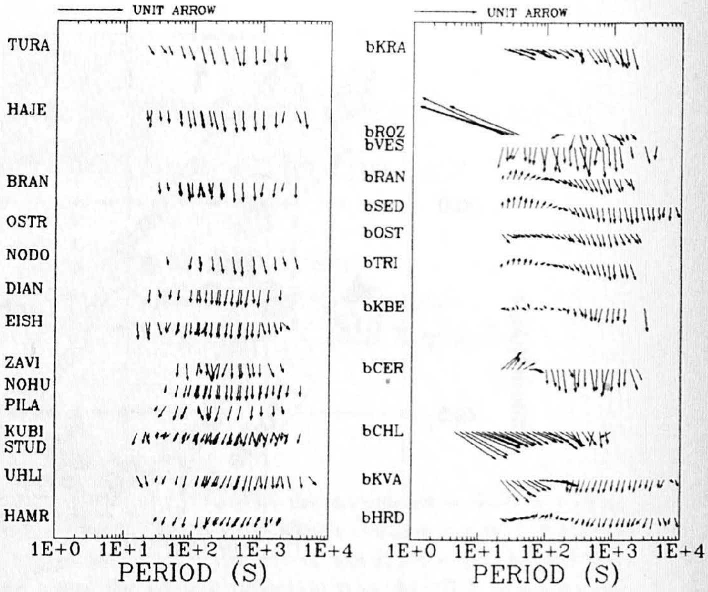


Figure 2: Long period real induction arrows along the profiles 2 (left) and 1 (right) at comparable latitudes.

2 Local induction studies in the Tachov region

The profile 2a consists of 4 long period MT/MV stations, measured by the Geophysical Institute Prague in 1994, arranged so as to cross the West Bohemian fault zone in the E-W direction (Fig. 3) and to reach the corresponding stations on the profile 1. The profile 2a represents a direct continuation of the detailed AMT profile measured by the Italian staffs in the area north of Tachov in 1993.

Geologically, the area of the profile 2a represents a transition zone between the Bohemian Forest Mts., the Bor Massif of the West Bohemian Pluton, and the Teplá-Barrandien Proterozoic unit. The region is marked by two significant fault zones—the Tachov fault, considered a seismoactive fault, and the Mariánské Lázně fault. From the north the body of the Mariánské Lázně ultrabasic complex extends into the area involved.

The analysis of the MT data along the profile 2a clearly shows the serious increase of the noise level towards the east, as already mentioned earlier. In Fig. 4, the classical MT error parameter, $\Delta = \sqrt{\delta Z_{xy}^2 + \delta Z_{yx}^2}/|Z_{xy} - Z_{yx}|$, is plotted for the MT curves from the profile. The plots demonstrate that the data errors go hardly ever under the higher 'classical' noise limit ($\Delta = 0.1$), recommended by Bahr [8] for the classical MT analysis to give reliable results, let alone under the severer error limit required by the decomposition analysis ($\Delta = 0.05$). This fact must be borne in mind whenever the results presented in what follows are assessed, as most of the conclusions made here have been hypothetized from the conformity of the estimated parameters across certain period ranges rather than based on statistically significant single-period results.

The first step of the interpretation consisted in the analysis of the classical MT parameters and the directional characteristics of the geoelectrical structure along the profile. The previous AMT measurements had already indicated that there is sudden change of the principal Swift's direction when W-E crossing the line coincident approximately with the Tachov fault, or its continuation to the north. To the west of that line the orientation of the polar impedance diagrams is, according to their major axes, predominantly SW-NE to SSW-NNE, whereas to the east of the dividing line it is SE-NW to SSE-NNW. The contour plot of the Swift's direction along the profile 2a for both the AMT and long period MT data in Fig. 5 shows clearly that the SE-NW orientation of the impedance diagrams extends all over the

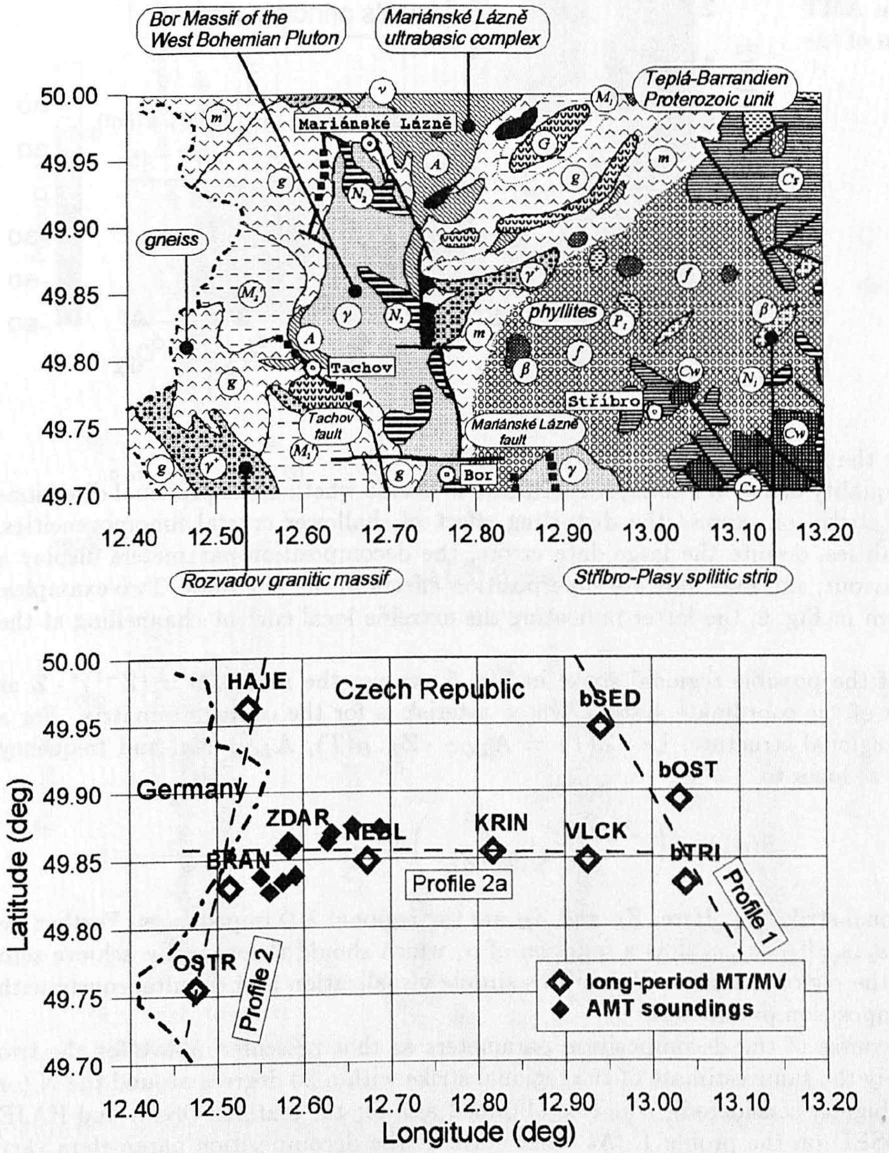


Figure 3: Geological map of the area of the AMT/MT/MV measurements in the Tachov region [7], with the principal geological units shown, and the layout of the profile 2a along with the nearby stations from the basic regional profiles 1 and 2.

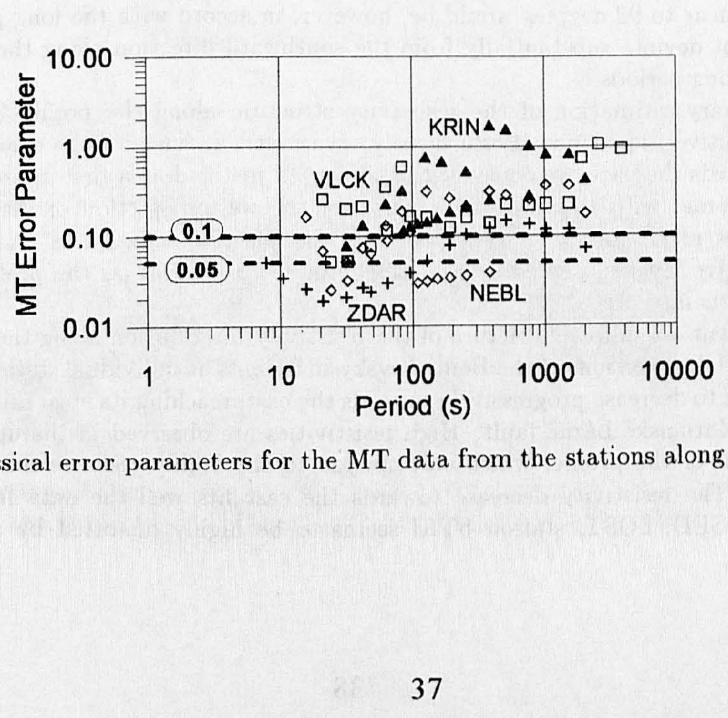


Figure 4: Classical error parameters for the MT data from the stations along the profile 2a.

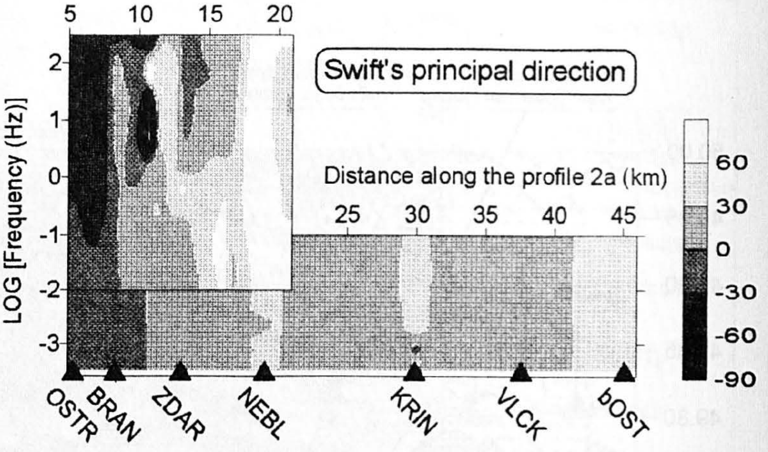


Figure 5: Contour plot of the Swift's principal direction along the profile 2a for both the AMT and MT data as a function of the period.

profile, and is preserved at the nearby stations from the profile 1 as well.

Considering the worse quality of the MT data, it is difficult to decide whether the principal directions reflect the true structurel strike, or express the distorting effect of shallower crustal inhomogeneities. Nevertheless, at some localities, despite the large data errors, the decomposition parameters display a reasonably consistent behaviour, and may indicate superposition effects in the MT data. Two examples, NEBL and bTRI, are shown in Fig. 6, the latter indicating the extreme local current channelling at the locality bTRI.

For the visualization of the possible regional strike in Fig. 6, we use the matrix $\mathbf{S} = (\mathbf{Z}^{-1})^* \cdot \mathbf{Z}$ as a function of the direction of the coordinate system, where asterisk is for the conjugate matrix. For a composed 3-D local/2-D regional structure, i.e. $\mathbf{Z}(T) = \mathbf{A}_{LOC} \cdot \mathbf{Z}_{2-D}(T)$, $\mathbf{A}_{LOC}$ real and frequency independent, the matrix $\mathbf{S}$ reduces to

$$\mathbf{S}(\alpha_R) = \begin{pmatrix} Z_H/Z_E^* & 0 \\ 0 & Z_E/Z_H^* \end{pmatrix}$$

in the direction of the regional strike α_R. Here, Z_E and Z_H are the regional 2-D impedances. Further we use the form $s(\alpha) = |1 - |s_{xx}s_{yy}|| + |s_{xy}s_{yx}|$ as a function of α, which should theoretically achieve zero value for $\alpha = \alpha_R$, i.e. for the regional strike. We use this simple visualization tool simultaneously with the analysis of other decomposition parameters.

A similarly consistent course of the decomposition parameters as that presented above for the two stations, with approximately the same estimate of the regional strike within 20 degrees around the N (or E, with the 90 degrees ambiguity considered), could be obtained also for the stations OSTR and HAJE on the profile 2, and for bSED on the profile 1. At other stations the decomposition parameters vary largely, and do not allow us to make any conclusion as regards a possible regional strike. The existence of a regional strike near to 90 degrees would be, however, in accord with the long period real induction arrows, which do not deviate substantially from the southward direction along the whole profile 2a, in particular for very long periods.

For the preliminary estimation of the resistivity structure along the profile 2a, we used the 1-D inversion of the effective impedance (Berdichevsky invariant). In view of the decreasing anisotropy of the MT curves towards the east, we consider this approach justified as a first approximation. The only obvious problem we met with this procedure was over the western section of the profile, where large MT anisotropy takes place, and *yx*-curves dominate the effective impedance. As a consequence, the thin crustal conductive layer, observed systematically in the *xy*-curves on the profile 2, vanishes if the impedance invariant is interpreted.

In Fig. 7 we present a qualitative picture of the resistivity distribution along the profile 2a, obtained by interpolating the 1-D inversions of the Berdichevsky invariants at individual stations across the profile. The resistivity seems to decrease progressively towards the east, reaching its local minimum at the station KRIN near to the Mariánské Lázně fault. High resistivities are observed in the upper crust below the whole central section of the profile, which corresponds to the highly resistive formations of the West Bohemian pluton. The resistivity decrease towards the east fits well the data from the broad band profile 1 (stations bSED, bOST, station bTRI seems to be highly distorted by a local channelling),

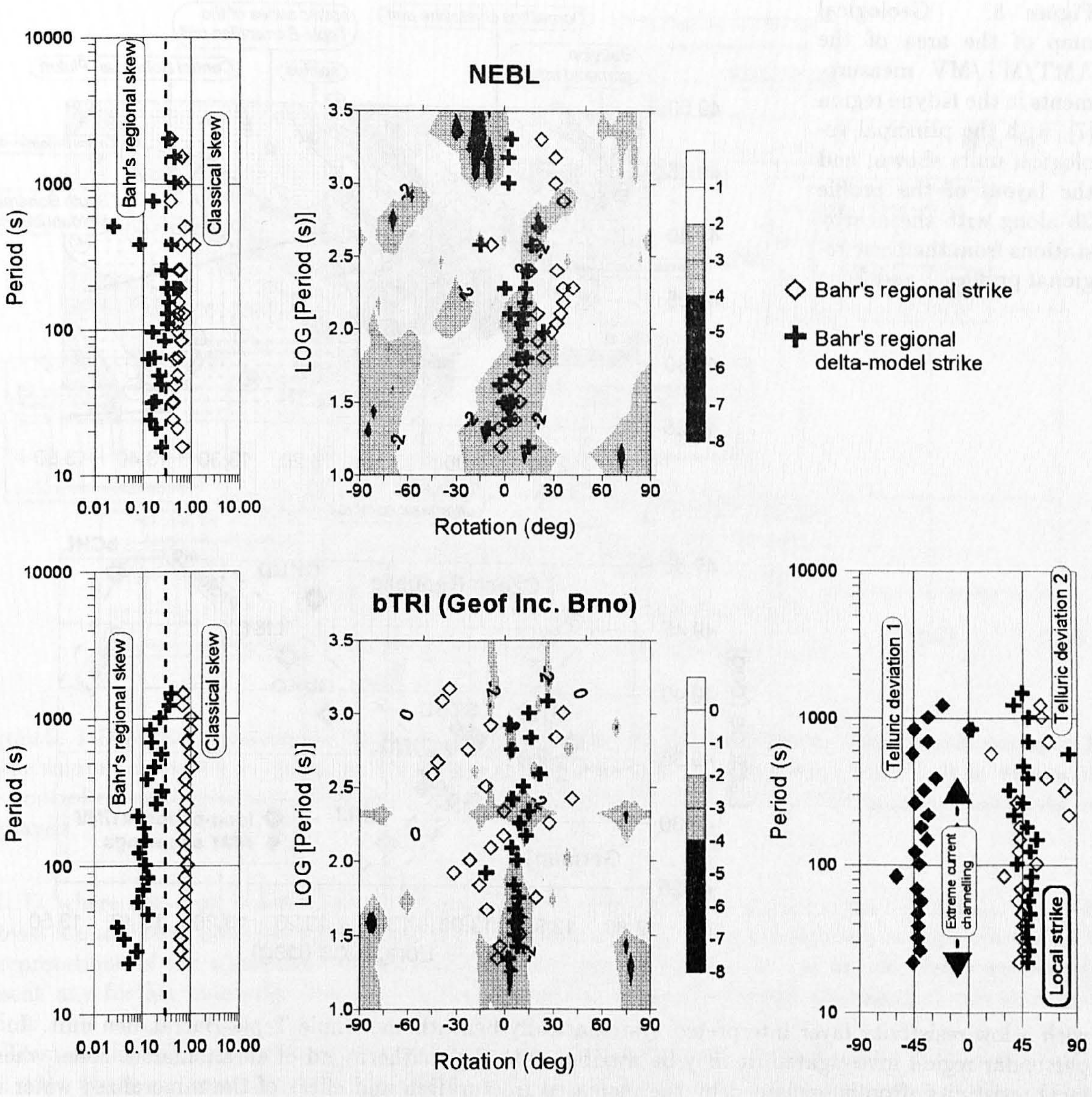


Figure 6: Decomposition parameters and estimates of the regional strike for two MT stations, NEBL and bTRI, from the area of the profile 2a.

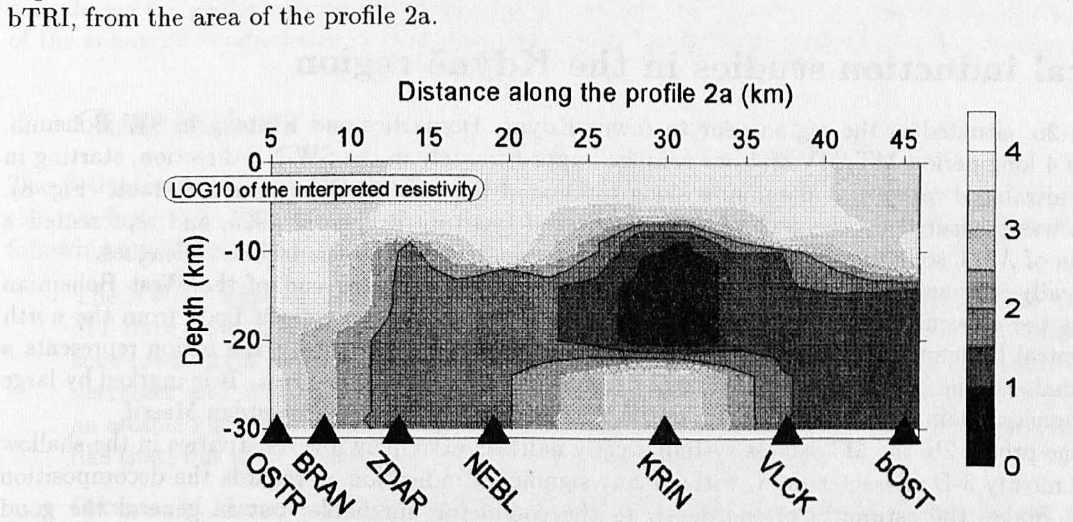
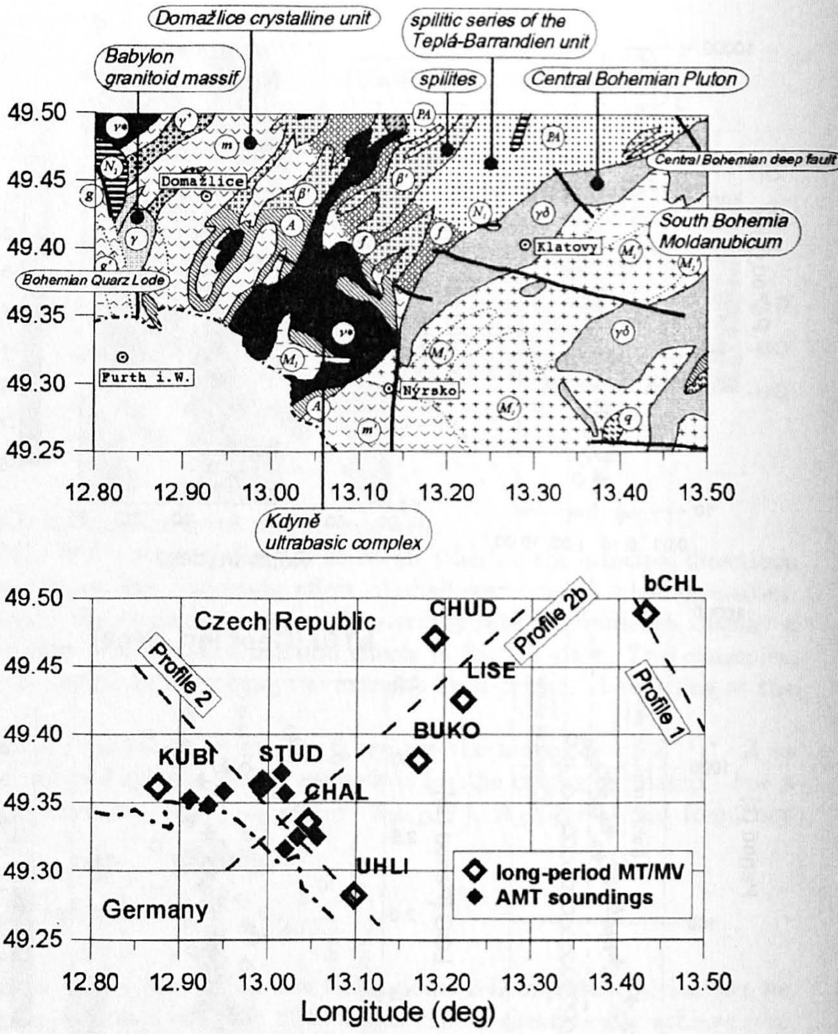


Figure 7: Qualitative picture of the resistivity distribution along the profile 2a obtained by interpolating the 1-D inversions of the Berdichevsky determinant at individual stations. Effects of distortions are not considered.

Figure 8: Geological map of the area of the AMT/MT/MV measurements in the Kdyně region [7], with the principal geological units shown, and the layout of the profile 2b along with the nearby stations from the basic regional profiles 1 and 2.



with a low resistivity layer interpreted systematically beneath the whole Teplá-Barrandien unit. In the particular region investigated, it may be attributed to the southern end of an anomalous zone, where a local resistivity drop is explained by the increased fracturation and effect of the mineralized water in a disturbed zone extending as far as the Konstantinovy Lázně spa (see zone P.2a in Fig. 10).

3 Local induction studies in the Kdyně region

The profile 2b, situated in the region near to towns Kdyně, Domažlice and Klatovy in SW Bohemia, consisted of 4 long period MT/MV stations arranged approximately in the SW-NE direction, starting in the Kdyně ultrabasic complex and running along the line of the Central Bohemian deep fault (Fig. 8). The profile was measured by the staff of the Geophysical Institute Prague in 1995, and represented a continuation of AMT soundings performed earlier in the area involved by the Italian colleagues.

Geologically, the area of the profile 2b is situated near the southern end of the West Bohemian paleorift, at the crossing of two prominent tectonic lines—the Bohemian Quartz Lode from the north and the Central Bohemian deep fault (suture zone) from the NE. Geophysically, the region represents a highly anomalous zone, with indications of large density contrasts within the crust. It is marked by large positive magnetic anomalies arranged along a SW-NE line running into the Bohemian Massif.

Along the profile 2b, the MT curves systematically indicate extremely low resistivities in the shallow crust. The mostly 3-D character data, without any significant indication as regards the decomposition possiblities, makes the estimates of the depth to the conductor unreliable, but in general the good conductor seems to emerge towards the east, from depths of about 10 km below the western section of the area to less than 1 km below the easternmost stations. Extreme situation is observed at the station

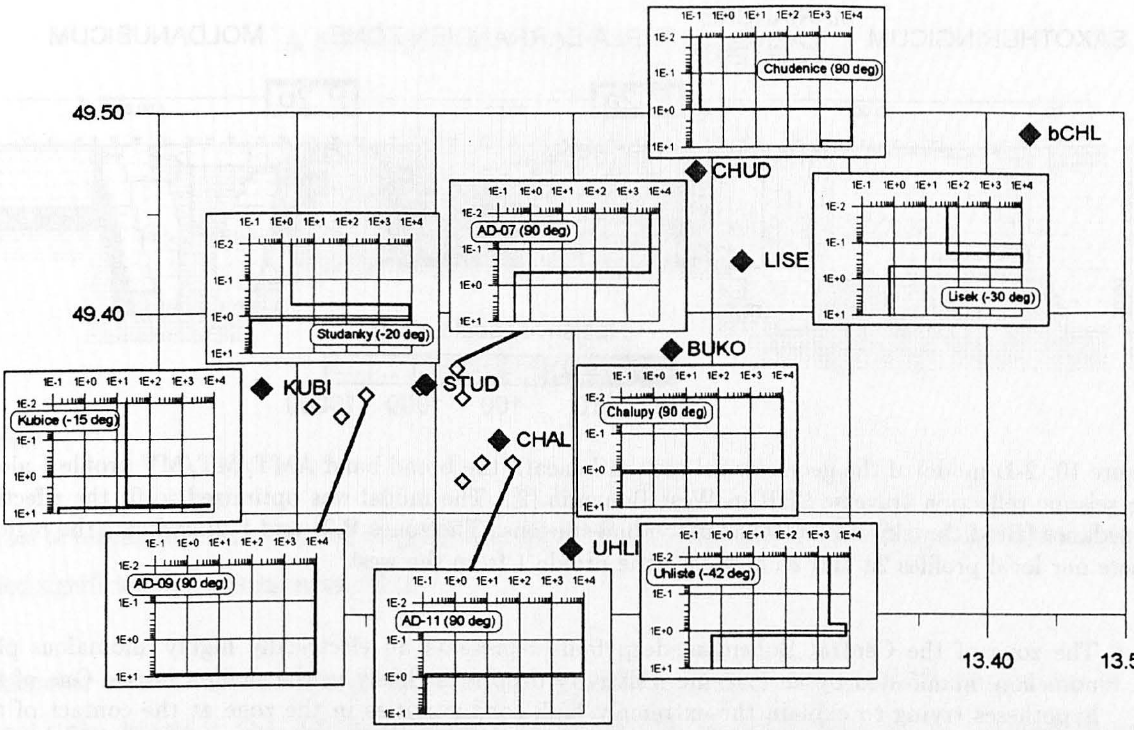


Figure 9: 1-D geoelectrical models for the stations within the Kdyně local region. The models correspond to the minimum resistivity curves at the individual stations. The inversion was carried out by means of the controlled random search procedure. Only the model with the best fit to the experimental data is displayed.

CHUD, where apparent resistivities less than 1 Ωm were obtained over a wide range of periods. To give at least a qualitative idea about the resistivity distribution within the area involved, we present the 1-D interpretations of the minimum MT curves at selected stations in Fig. 9. At the moment, we cannot present any further consistent results of a more complex, multidimensional modelling of this intricate region.

Towards the NE, the profile 2b approaches the zone P.2b of the broad band profile 1 (station bCHL, Fig. 10), where a resistivity drop is observed as well, attributed to the contact zone of the Teplá-Barrandien unit with the Central Bohemian pluton and the South Bohemia Moldanubicum. In [2], considering the geological and seismic results, the authors suggest a hypothesis as regards the mechanism of the enhanced conductivity in that zone. We repeat briefly their main ideas in the conclusion.

4 Conclusions

The preliminary analysis of the MT data from the two profiles 2a and 2b, arranged in the area between the two basic NW-SE profiles 1 and 2 above the western margin of the Bohemian Massif, allows the following qualitative conclusions to be made:

- The NW-SE apparent electrical anisotropy, observed generally along the profile 2, as well as in the MT data close to the KTB area, seems to be interrupted when crossing the West Bohemian fault zone towards the east. Along the profile 2a, further to the east of this line, the impedance anisotropy decreases and changes to almost NE-SW. Relaxation of the impedance diagrams at the contact of an anisotropic structure and an isotropic medium might qualitatively explain the directional change like that, but more modelling is required to assess this hypothesis.

- Decrease of the resistivities is indicated when proceeding into the Teplá-Barrandien zone, which fits the results from the profile 1 where a continuous, highly conductive layer is interpreted in the upper crust beneath that unit [2].

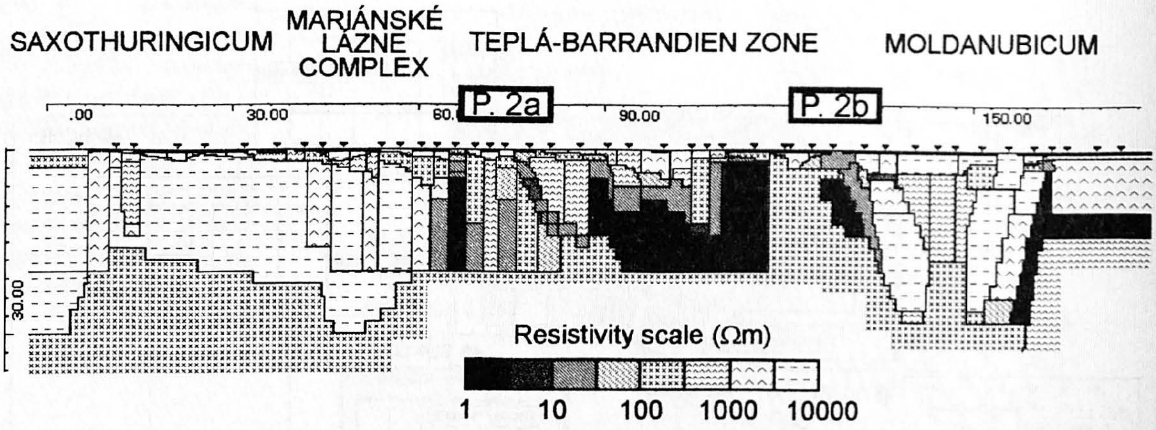


Figure 10: 2-D model of the geoelectrical section beneath the broad band AMT/MT/MV profile 1 along the seismic reflection traverse 9HR in West Bohemia [2]. The model was optimized to fit the effective impedance (Berdichevsky invariant) at individual stations. The zones P.2a and P.2b indicate the regions where our local profiles 2a and 2b approach the profile 1 from the west.

- The zone of the Central Bohemian deep fault represents an electrically highly anomalous phenomenon, manifested by an extreme resistivity drop most likely in the shallow crust. One of the hypotheses trying to explain the extremely high conductivities in the zone at the contact of the Teplá-Barrandien Protorozoicum and the South Bohemia Moldanubicum assumes the presence of highly altered spilites. This alteration gives rise to the fine-grained pyrhotite and pyrite, which, together with fracturation, substantially increases the rock conductivity [2].
- Unfortunately, the fact that the level of the cultural noise in the MT data increases progressively towards the east must also be considered to be one of the general conclusions of the induction experiments in the western part of the Bohemian Massif.

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