TECTONIC PATTERN OF THE HRONOV-POŘÍČÍ TROUGH AS SEEN FROM POLE-DIPOLE GEOELECTRICAL MEASUREMENTS

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(*Received* January 2008, *accepted* April 2008)

ABSTRACT
The Hronov-Poříčí Trough represents the easternmost part of the Trutnov-Náchod Depression. The NW–SE striking structure was formed due to the post-Cretaceous flexural folding and is filled with the Upper Cretaceous sediments. Both the NE and SW margins of the trough are bounded by flexures with the Upper Cretaceous strata dipping 40–60° towards the axis of the trough. The NE flexure is situated close to the parallel Hronov-Poříčí Fault Zone. Up to now, it is not fully known, in what extent the normal faulting was involved in the evolution of the structure. From the geomorphological point of view, the normal fault constraints of the trough seem to be acceptable, as the surface topography of its present margins exhibit many signs typical for fault scarps. However, the existence of a fault system bounding all round the Hronov-Poříčí Trough has not been proved by any geological research. Hence the geophysical research was carried out on both sides of the NW part of the trough to support one of these hypothesis. Five geoelectrical profiles were measured in the area and the fault system was proved on the NE side of the trough. On the SW boundary the fault system was not found. Thus it seems, that the NE boundary is controlled by fault tectonics, whereas the SW boundary is rather formed by a simple flexure.

KEYWORDS: Hronov-Poříčí Trough, Hronov-Poříčí Fault Zone, electric resistivity measurements, geomorphology, normal faulting

1. INTRODUCTION

The broader area of the Hronov-Poříčí Fault Zone (HPFZ) is characterised by significantly increased tectonic activity. It belongs to a larger seismoactive zone on the NE margin of the Bohemian Massif, which is approximately 40-60 km wide and 150 km long and comprises a number of NW–SE and NNW–SSE-striking faults. This zone forms a SE termination of the important central European tectonic structure – the Elbe Fault system (EFS). In comparison with the well known West Bohemia/Vogtland seismoactive region (see e.g. Bankwitz et al., 2003), the seismoactive region of the SE termination of the EFS is characterized by less frequent occurrence of seismic events. Smaller earthquake swarms in this area were reported by Špaček et al. (2006) from Jeseníky Mts., but these micro-swarms do not number more than 50 weak events ($M \leq 1.3$). The strongest earthquakes occurred on the NW margin of this seismoactive region and are connected with movements along the HPFZ (Kárník et al., 1984; Procházková et al., 1986; Schenk et al., 1989).

HPFZ is a system of parallel fractures, dividing two important structural units – the Intra-Sudetic Basin and the Krkonoše Piedmont Basin (Fig. 1). The NW–SE-striking fault zone is approximately 40 km long and up to 500 m wide. It is bounded by the Vrchlabí Fault in the north and by the Nová Paka Fault in the south. Both E–W-striking faults are supposed to be sinistral strike slips (Schenk et al., 1989). The contemporary HPFZ is a result of complicated and long-lasting evolution, which began in the late Paleozoic. Since then, several tectonic phases have taken place. The fault zone has been successively developed from an asymmetric anticline, whose steeply inclined SW arm was axially disrupted due to the regional compression by a reverse fault (Tásler, 1979). Along this fault the NE block was relatively uplifted. The main reverse fault is accompanied by numerous parallel or oblique high-angle dislocations.

The relatively frequent local seismic activity is a proof of the present-day mobility of the HPFZ. The strongest historical earthquake of January 10, 1901 reached the magnitude of 4.6 and was felt over an area of 50,000 km^2 (Woldřich, 1901). The isoseists of local earthquakes are elongated mostly NW–SE, parallel to the orientation of the HPFZ. The depth of foci is mostly between 5 and 15 km (Schenk et al., 1989). A possible explanation of the present mobility of the HPFZ was given by Schenk et al. (1989). According to this local geodynamic model, the HPFZ as a reverse fault balances the compression caused by the movements along the Nová Paka and Vrchlabí Faults, bounding the HPFZ in the north and south. This

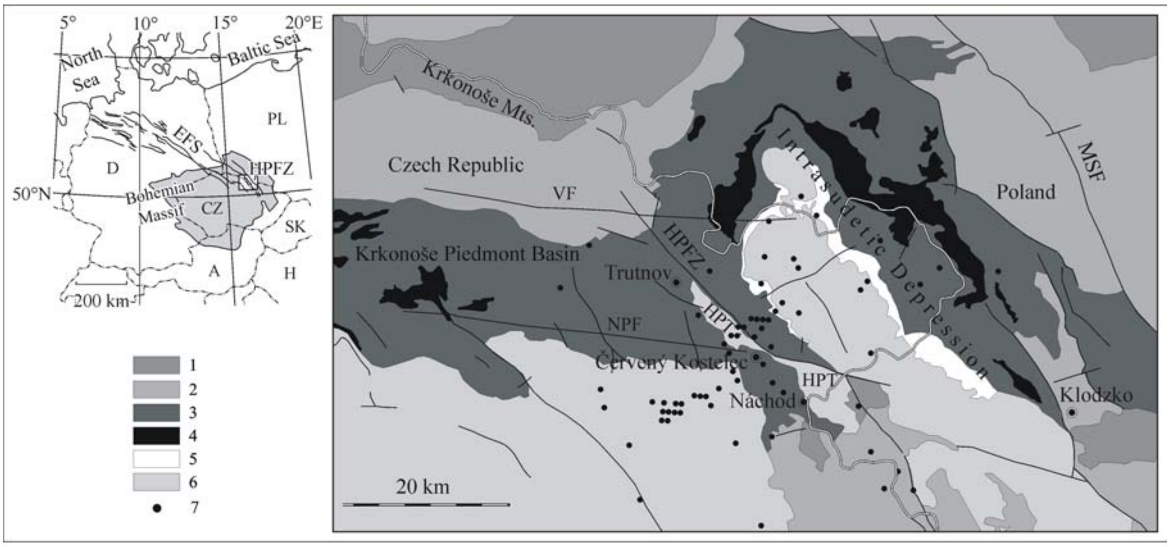

Fig. 1 Geology and tectonics of the study area (after Biely et al., 1968; Scheck et al., 2002; Cymerman, 2004). 1 – plutonic rocks (granites, granodiorites), 2 – metamorphites (gneisses, schists, granulites, migmatites), 3 – Permian and Carboniferous sediments, 4 – Permian volcanics, 5 – Triassic sediments, 6 – Cretaceous sediments, 7 – epicentres of seismic events recorded from 1985 to 2005 (after Catalogue of regional seismic events, published by the Geophysical Institute AS CR at http://web.ig.cas.cz/en/seismic-service/catalogs-of-regional-seismic-events/). HPFZ – Hronov-Poříčí Fault Zone, HPT – Hronov-Poříčí Trough, VF – Vrchlabí Fault, NPF – Nová Paka Fault, MSF – Marginal Sudetic Fault, EFS – Elbe Fault System (see the small-scale map in the upper left corner).

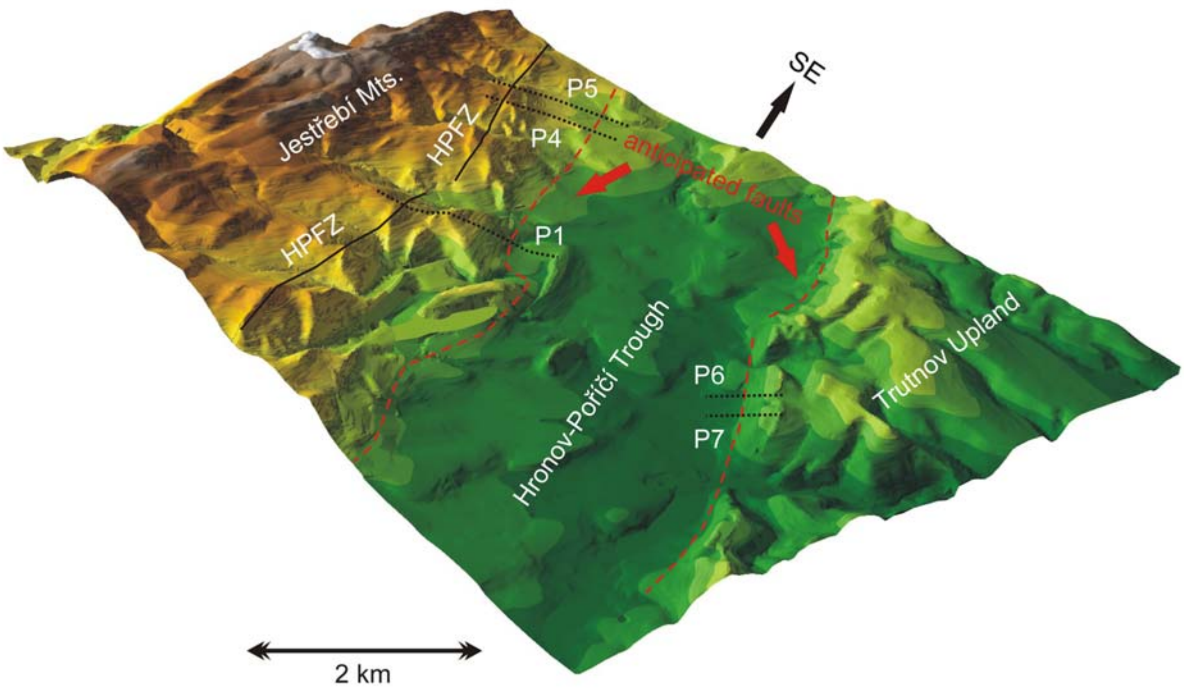

Fig. 2 Digital elevation model of the studied part of the Hronov-Poříčí Trough with depiction of anticipated normal faults. HPFZ – Hronov-Poříčí Fault Zone, P1–P7 – measured profiles.

presumption is supported by the analyses of repeated triangulation and precise levelling performed in the broader vicinity of the HPFZ by Vyskočil (1988) or using GPS survey by Kontny (2004).

In the present study we focus on the area of so called Hronov-Poříčí Trough (HPT – see Fig. 1 and Fig. 2) which represents a neotectonic basin structure adjacent to the HPFZ. The NW–SE striking HPT was formed due to the post-Cretaceous flexural folding and is filled with the Upper Cretaceous sediments. The both NE and SW margins are bounded by flexures with the Upper Cretaceous strata dipping 40–60° towards the axis of the trough. The NE flexure is situated close to the parallel Hronov-Poříčí Fault Zone (HPFZ). Up to now, it is not fully known, in what extent the normal faulting was involved in the evolution of the structure, especially in its NW part situated between towns of Trutnov and Červený Kostelec (see Figs. 1 and 2). From the geomorphological point of view, the tectonic constraints of the trough seem to be acceptable, as the surface topography of its present margins exhibit many signs typical for fault scarps (see section 2, bellow). However, the existence of a fault system bounding the HPT all along its circuit has not been proved by any geological research – it is very difficult to map layer boundaries in this area, because the terrain lacks outcrops and the individual rocks are hard to distinguish when weathered. In order to resolve this ambiguity five geoelectrical profiles were measured and interpreted in the area of presumed normal faults.

2. GEOMORPHOLOGICAL BACKGROUND

The HPT as a tectonic depression is situated between relatively uplifted geomorphological units – the Jestřebí Mts. on the NE and the Trutnov Upland and Červený Kostelec Upland on the SW (see Fig. 2). Surface topography of the trough is characterized by smooth relief on Upper Cretaceous deposits and occurrence of flat floored and shallow valleys of water streams. The depression is bounded against the relatively uplifted surroundings by steep rectilinear slopes (see Fig. 2). Morphologically the most apparent is the NE boundary fixed to the marginal scarp of the Jestřebí Mts.

The both marginal slopes of the HPT are fixed on the flexures, originated during Tertiary. Dips of the strata reach up to 60°. According to Tásler (1979), the flexures are accompanied with normal faults in some places. Nevertheless, normal faults bounding the HPT in its NW part are not recorded at any published geological maps (see e.g. Svoboda and Chaloupský, 1961; Vejlupek, ed. 1990; Cymerman, 2004). These faults however, may be anticipated based on the surface topography.

Both marginal slopes of the HPT exhibit some signs typical for fault scarps, like relatively straight mountain front, presence of triangular facets (on the marginal scarp of the Jestřebí Mts.), or the distinct change of the slope, with no relation to the change of the basement lithology. Based on geomorphologic mapping, Demek (1992) considers the NE and SW marginal scarps of the HPT to be combined fault scarps. The surface trace of the main reverse fault of the HPFZ is running in the NW–SE direction in the lower part of the SW hillside of the Jestřebí Mts (see Fig. 2). In general, it is morphologically much less distinct than the supposed normal faults bounding the Jestřebí Mts. along its foothill (see Fig. 2). We can give two reasons for the less distinct morphological manifestation of the reverse fault:

a) According to Tásler (1979) normal faults in the area of the HPFZ represent younger tectonic elements; i.e. younger normal faults are morphologically more distinct than the older reverse fault.
b) Denudation of the less resistant aleuropelites of the Svatoňovice series cropping upslope the reverse fault is faster, which results in degradation of landforms determined by its presence. From the geomorphological point of view, the HPT represents relatively young element.

The study of drainage network evolution and perturbations in fluvial terraces in broader area of HPT revealed tectonic movements along normal faults dating back to Pliocene/Pleistocene to Early Pleistocene (see, e.g., Stejskal et al., 2006). We assume that the young tectonic movements were the most remarkable within the NW part of the HPT and the along the Úpa River valley adjacent to SW part of the HPT. The disturbance of flight of the oldest (Miocene to Pliocene) Úpa River terraces, which reaches up to 30 m gives the evidence of tectonic movements occurring in Pliocene/Pleistocene (Král, 1949). The Pleistocene tectonic movements can be assumed based on situation of the Úpa River valley and the HPT. Spatial position of the Early Quaternary fluvial terraces (level 1 – praegünz and level 2 – günz) reveals that then the Úpa River flew close to the present margin of the HPT at higher altitude than the bottom of the trough is today. Excluding the possibility of Early Quaternary co-existence of the shallow Úpa River valley flowing within the higher relief of the Trutnov Upland close to the adjacent much lower lying HPT, it can be assumed that the present altitudinal differences of the Trutnov Upland and the HPT must have taken place after the deposition of the oldest Quaternary fluvial terraces of the Úpa River. Quaternary subsidence of the HPT in the SW must have been slow enough to be compensated by erosion of the Rtyňka Brook, which flows through the marginal slope towards the higher relief of the Trutnov Upland. Deeply incised valley of the Rtyňka Brook (up to 80 m) is therefore considered to be antecedent one (see Fig. 3).

In order to assess the rate of recent to present day tectonic movements along the margins of the HPT we

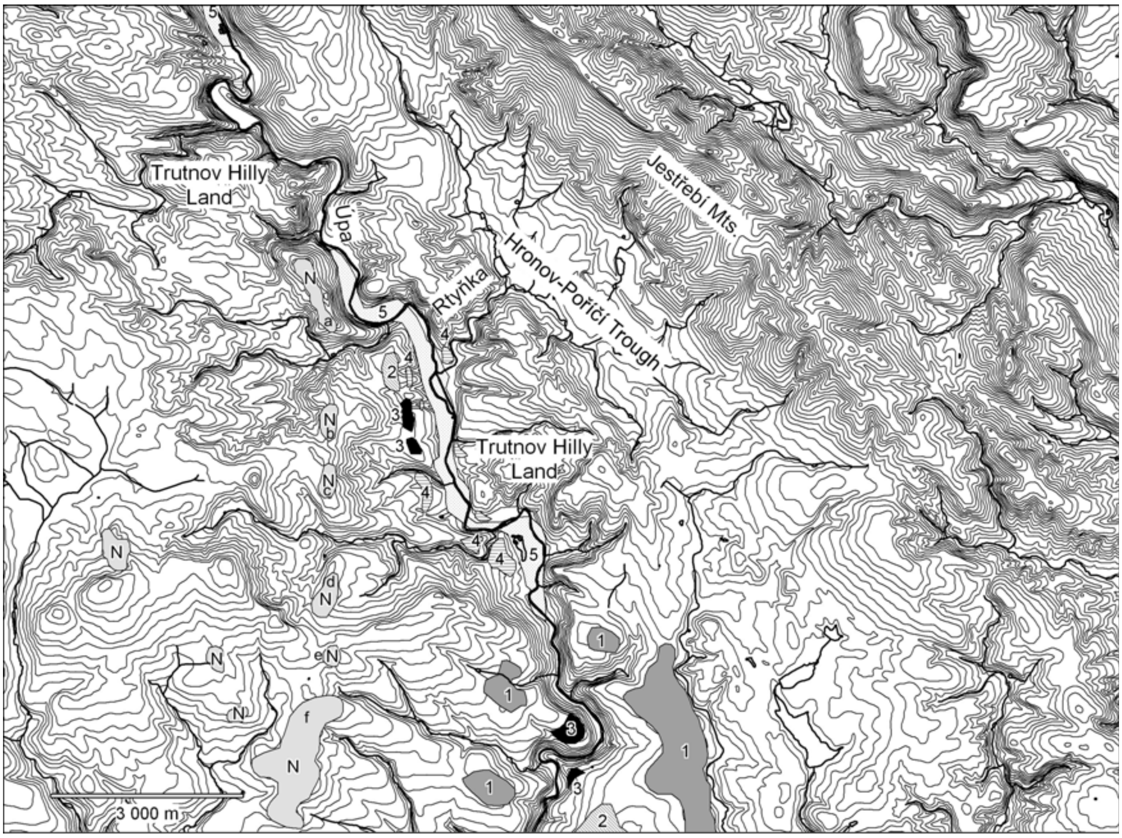

Fig. 3 Fluvial terraces and surface topography in the area of the Rtyňka valley. Contour lines spacing – 5 m. Fluvial terraces after Král (1949). N – Neogene (Miocene – Pliocene), 1 – Praegünz, 2 – Günz, 3 – Mindel, 4 – Riss, 5 – Würm (gravels of the valley floor).

used a simple morphometric parameter – *mountain front sinuosity index, Smf* (Bull and Mc Fadden, 1977), calculated as:

$$Smf = Lmf/Ls$$

where *Lmf* is the length of the mountain front measured along the foot of the mountain range at the pronounced break of slope, and *Ls* is the straight-line length of the mountain front. In general, mountain fronts associated with active uplift are relatively straight, with low values of *Smf*, usually very close to 1.0. For slightly active and inactive regions the *Smf* values tend to be close to 2 or higher.

We derived the *Smf* index for the SW marginal scarp of the Jestřebí Mts which we suppose to be fixed to the anticipated normal fault parallel to the main reverse fault of the HPFZ (see also Stejskal et al., 2006). The *Smf* index was derived separately for three different parts of the Jestřebí Mts. from topographic maps in scale 1:25 000, with contour-lines spacing 5 m (see Fig. 4). The *Smf* is of the lowest value within the NW part (*Smf* = 1.26) and the central part of the Jestřebí Mts. (*Smf* = 1.25). Mountain front measured along the foot of the SE part (east of the Metuje River valley) shows rather higher sinuosity – *Smf* = 1.59. All above stated *Smf* values are rather higher than those typical for areas of significant recent tectonic movements, where the *Smf* is often lower than 1.05 (Burbank and Anderson, 2001). These results correspond to the general conception about low present-day tectonic activity within the Bohemian Massif. On the other hand, the resulting *Smf* values seem to reflect the different degree of the rate of relative subsidence of the HPT in its different parts adjacent to the Jestřebí Mts. Based on the *Smf* values we suppose that NW part of the HPT adjacent to the NW and the central part of Jestřebí Mts. is subjected to the most active tectonic deformation. We therefore carried out the electric resistivity measurements along five profiles in this part of the Trough, in order to verify the anticipated normal faults.

3. ELECTRIC RESISTIVITY MEASUREMENTS

3.1. *METHOD DESCRIPTION*

As was stated before, the individual beds of Cretaceous sediments in the area of the HPT are lithologically very similar. Hence, it is difficult to distinguish particular faults by means of geological mapping. But the fault zones differs in certain physical parameters from the surrounding rocks and it became natural to employ geophysical methods to solve the problem.

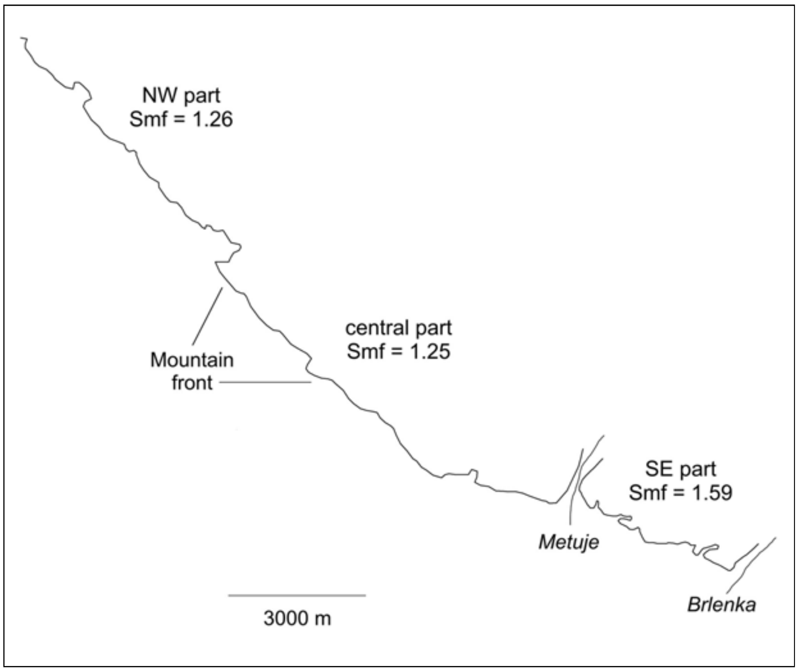

Fig. 4 The mountain front sinuosity calculated for three different parts of the SW marginal scarp of the Jestřebí Mts.

In general, the fault zones are characterised by increased grade of weathering and thus they contain larger amount of conductive clay particles than the surrounding rocks. Consequently they reveal itself as zones of increased conductivity. Hence, among the wide range of available geophysical methods, most often the geoelectrical ones are used for mapping of faults. From the assortment of geoelectrical methods the pole-dipole and very low frequencies (VLF) methods have been selected. To support the results of geoelectrical methods by some different method also the measurements of soil-gas radon concentrations were carried out. The fractured areas, as the faults are, allows penetration of radon from bedrock. Hence the concentration of radon in the soil-gas increases within the fractured areas.

However, during our measurements only the pole-dipole method led to usable results. The VLF method failed due to the lack of suitable long wave transmitters. The measurements of soil-gas radon concentrations also were not successful due to high clay content in the soil. Consequently, the measured results are unreliable due to the problems with soil-gas sampling. Thus the interpretation and following text will deal only with results of the pole-dipole method.

The pole-dipole method was carried out in the configuration A40M10N of the forward dipole and in the same configuration for the reverse dipole – M10N40B. The approximate depth of penetration of this particular configuration is about 30 metres. This depth is sufficient for filtering out of small-scale near-surface inhomogeneities and the conductive zones detected should be larger and deeper zones of tectonic significance.

3.2. MEASURED PROFILES

In total five profiles, crossing both the anticipated faults and the main reverse fault of the HPFZ, were measured at three sites on both sides of the NW part of the HPT (see Fig. 2). A short description of measurement sites is given bellow:

Measurement site 1 was situated N of Rtyně v Podkrkonoší on the marginal scarp of the Jestřebí Mts. One profile (P1) of 1300 m length, crossing the outcrops of Permo-Carboniferous and Upper Cretaceous rocks, was measured.

Measurement site 2 was situated E of Rtyně v Podkrkonoší approximately 2.5 km SE from Measurement site 1. Two parallel profiles – P4 and P5 – of 650 m and 550 m length respectively were measured. Both profiles crossed both Permo-Carboniferous and Upper Cretaceous strata.

Measurement site 3 was situated on the SW marginal scarp of the HPT, east of Úpice. Two parallel profiles – P6 (400 m) and P7 (360 m) – crossing predominantly Upper Cretaceous layers were measured.

3.3. RESULTS

Measured resistivity curves were interpreted with respect to the geological situation and results of previous geological and geophysical studies in the area (e. g. Andres, 1966; Guenther et al., 1964; Jelen, 1957). The rocks with the lowest resistivities on the profiles are the Cretaceous marlites, Triassic sandstones and heavily weathered arkoses of Permian age – all with high content of clay particles. Their apparent resistivities are in the order of the first tens of Ωm. The rocks with the highest resistivities are the Cretaceous sandstones and spiculites and on some places also the Permian conglomerates and volcanic rocks. They have apparent resistivities about 100 Ωm. The fault zones, due to the higher degree of weathering in comparison with surrounding rocks, are the most conductive features (about 10 Ωm) on the profiles and hence reveal themselves as conductors.

Profile 1 starts in the layers of middle Cretaceous marlites and goes through the Cretaceous lithological sequence down to the Permian sediments. On the station 1.835 km profile enters the layer of Cretaceous spiculites – sediments more resistant to weathering than marlites and hence the resistivities are increasing here. On station 2.65 km the spiculites are replaced with a bed of Cretaceous sandstones (Peruc-Korycany formation – first bed of the Cretaceous transgression) with high apparent resistivities (about 100 Ωm). The Cretaceous sediments are transgressive on the sediments of the Permian age – sandstones and arkoses on the station 2.31 km. They are heavily weathered and clayey and hence the apparent resistivities decreases down to the value of about 40 Ωm. There seems to be a lithological boundary on the station 2.4 km. In the area affected by very low apparent resistivities of the Hronov-Poříčí Fault Zone (2.49–2.65 km), described further, the Permian arkoses are exchanged with Carboniferous coal layers (about the station 2.57 km). The sedimentation of coal layers was typical for this area – gradual change of sedimentation from conglomerates to coal followed by break in the succession and then the whole sequence is repeated again and again. This sedimentation pattern was disrupted twice by volcanic eruptions – the two layers of alkaline volcanics with increased values of apparent resistivities on stations 2.87–2.89 and 2.91–2.93 km. Individual layers are assigned and labelled in Figure 5.

The profile crosses two distinct conductive zones. The first one located about the station 2.03 km. Unfortunately this conductive zone is too small-scale to be the searched fault and it seems to be only a lower order fracture. The searched fault zone might be situated somewhere in the area obscured by the railway. About the station 2.57 km the profile crosses the other highly conductive zone – the Hronov-Poříčí Fault Zone (2.49–2.65 km).

Profiles 4 and 5 crosses the Cretaceous sedimentary sequence and ends in the upper Permian conglomerates (Fig. 6). They begin again in the beds of middle Cretaceous sediments – the middle Turonian siltstones (Jizera formation). They have relatively high values of apparent resistivities – about 60 Ωm – a consequence of high content of quartz grains. The siltstones are exchanged with marlites (upper part of the Bílá Hora formation) on station 465 m on profile 4 and 588 m on profile 5 and the apparent resistivities decreases down to 20 Ωm. On the stations 695 m (profile 4) and 775 m (profile 5) are swapped again for siltstones (lower part of the Bílá Hora formation) – apparent resistivities about 40 Ωm. On station 740 m on profile 4 and 830 m on profile 5 the siltstones changes to sandstones of the Peruc-Korycany formation with increased values of apparent resistivities – more than 100 Ωm. The Permo-Carboniferous sedimentary sequence begins on stations 853 m on profile 4 and 950 m on profile 5. It is represented by sandstones and arkoses of the Permian age. The Hronov-Poříčí Fault Zone (900–915 m on profile 4 and 985–1000 m on profile 5) is a border between the Permian and Carboniferous sediments. The apparent resistivities of Carboniferous sediments are similar to those of Permian layers (about 60 Ωm) and the sedimentary sequence is again the gradual change from conglomerates to coal.

The distinct conductive zones crossed by the profile are the Hronov-Poříčí Fault Zone (about the station 910 m on profile 4 and 990 m on profile 5) and the conductive zone about the station 625 m on profile 4 and 725 m on profile 5. The latter conductive zone probably represents the searched fault, along which the Jestřebí Mts. were uplifted and the HPT subsided.

Profiles 6 and 7, located on the SW margin of the HPT starts in the layer of upper Permian arkoses, crosses the Triassic sandstones end ends in sediments of the Cretaceous age (Figs. 7 and 8). However, from the resistivity curves no distinct conductive zone seems to be present. This was further affirmed by resistivity modelling (Fig. 8). The RES2DMOD program by M. H. Loke was used to compute synthetic resistivity curves.

The profiles start in the upper Permian arkoses (resistivity about 80 Ωm) and the sedimentation continues (undisrupted) to the lower Triassic sandstones (station 30 m on profile 6) with resistivities about 30 Ωm. On the station 100 m on profile 6 the lower Triassic sandstones are swapped for the transgressive Cenomanian sandstones – the Peruc-Korycany formation. These sandstones are sandstones with large quartz particles and low amount of matrix which lead to high values of resistivities – 150 Ωm. On the station 130 m on profile 6 they are turning to marlites and siltstones with resistivities about 30 Ωm. About the station 220 m on profile 6 begins bed of the lower Turonian marlites with even lower values of resistivities – 15 Ωm. And on the station 320 m on profile 6 the resistivities decreases again as the profile crosses the Quaternary fluvial sediments with resistivities as low as 10 Ωm. All layers, except the Quaternary ones, are tilted to NE (to the centre of the trough), the tilt decreasing in direction to the centre of the trough.

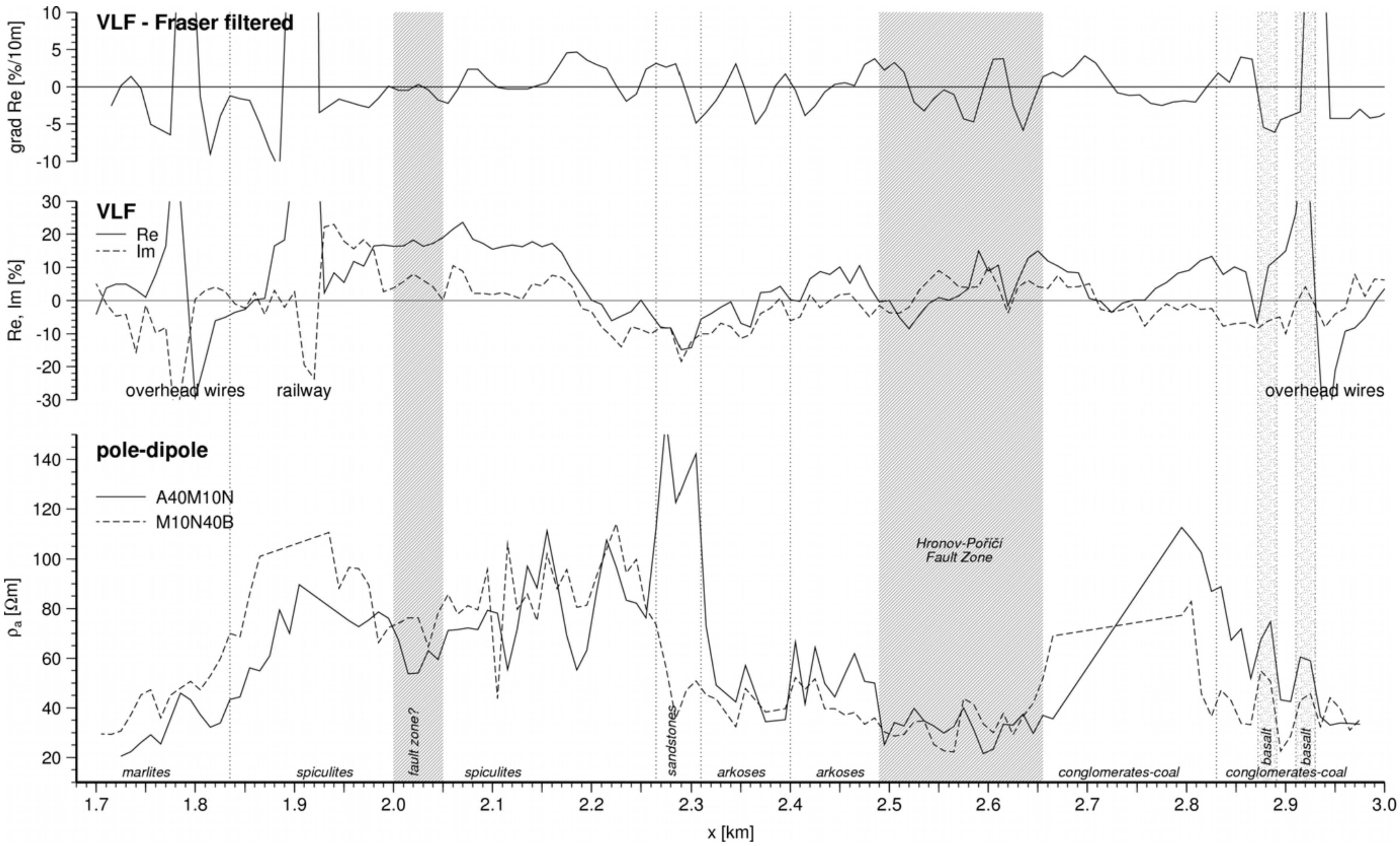

Fig. 5 Interpreted curves from the VLF method and pole-dipole method on profile 1. The weathered Createaceous marlites and Permian arkoses have low resistivities due to the high clay content and thus they create resistivity minima. The conductive zone about the station 2.05 km seems to represent the searched fault but may be as well artefact of the nearby railway.

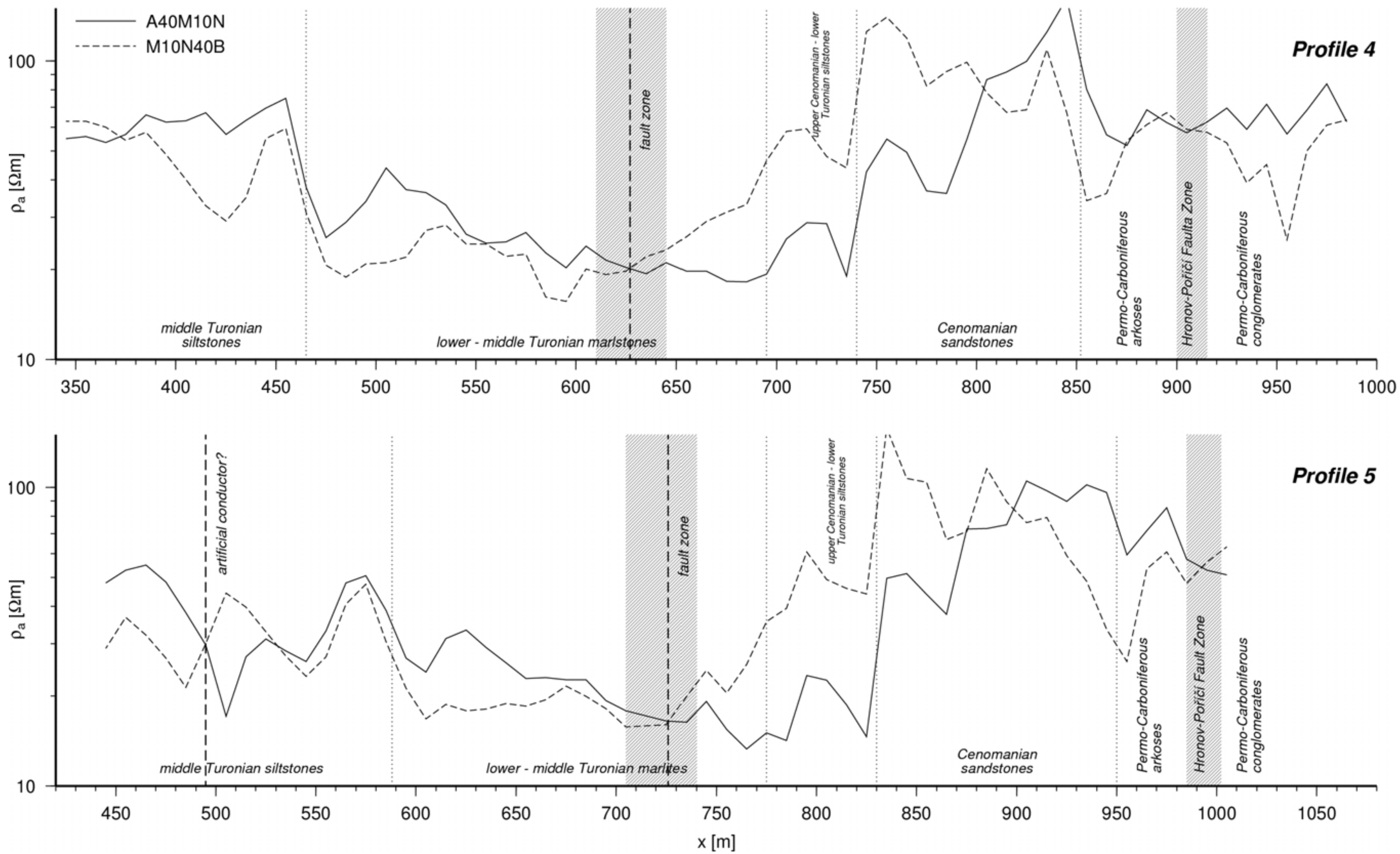

Fig. 6 Interpreted apparent resistivity curves from the pole-dipole measurements on profiles 4 and 5. The conductor on the station 625 m on profile 4 and 725 m on profile 5 represents the searched fault along which the Hronov-Poříčí Trough subsided and the Jestřebí Mts. were uplifted.

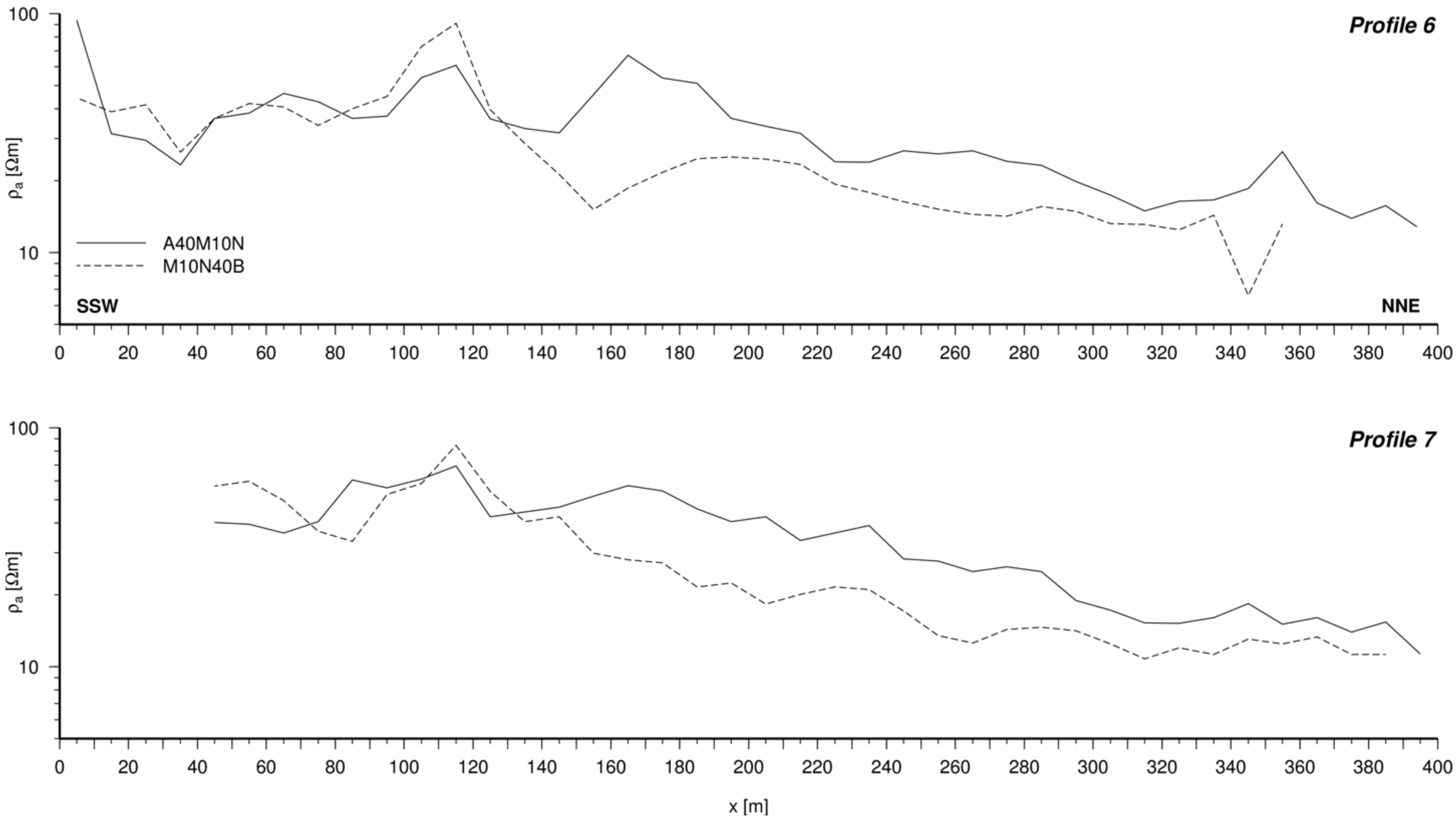

Fig. 7 Measured apparent resistivity curves for the pole-dipole method on profiles 6 and 7. No fault seems to be crossed by the profiles.

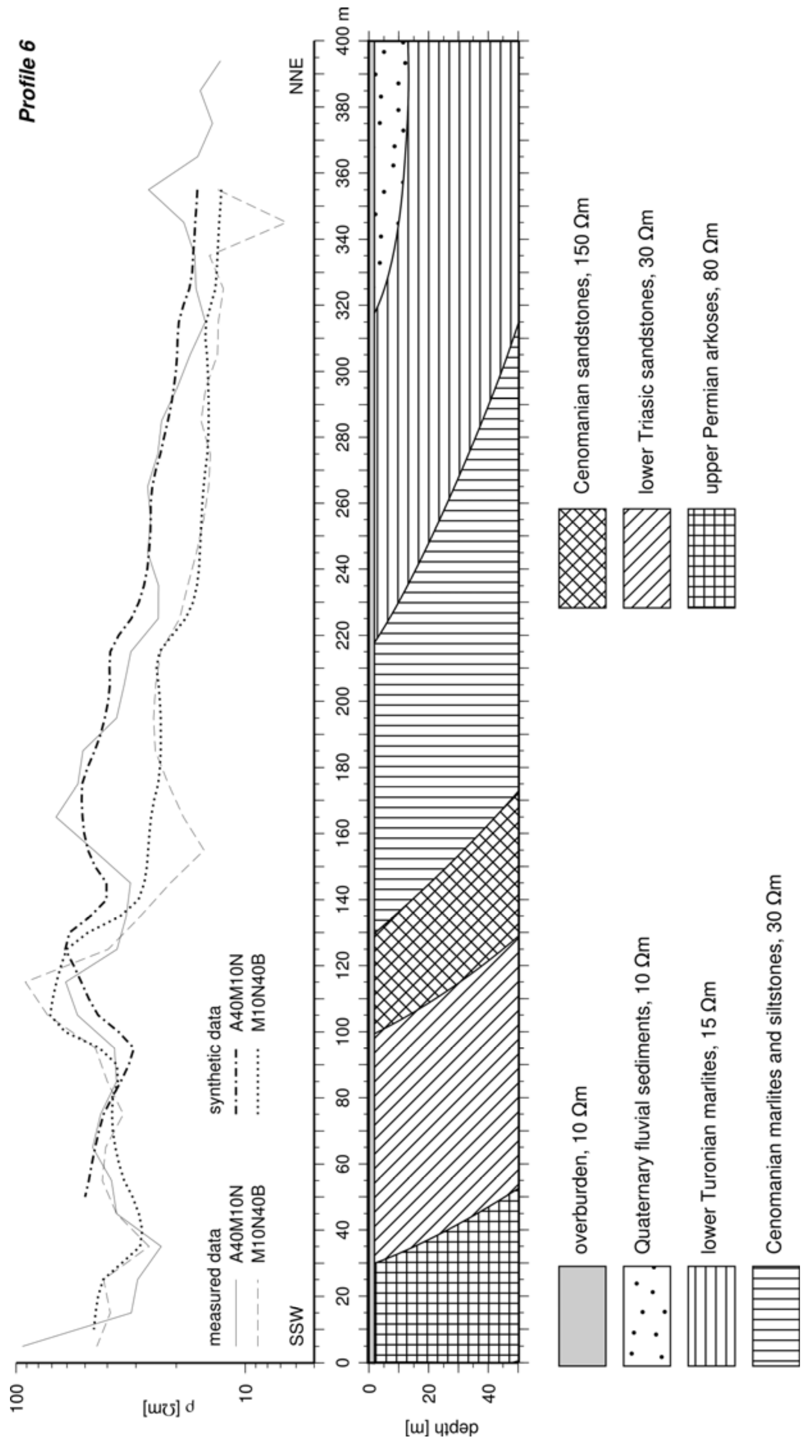

Fig. 8 Geoelectrical model for profile 6 – SW margin of the Hronov-Poříčí Trough. No fault was detected and hence the margin is modelled as a simple flexure structure.

4. DISCUSSION

Based on the results of resistivity measurements we suppose that the NE margin of the studied part of the HPT is controlled by a normal fault parallel to the main reverse fault of the HPFZ. The position of this fault is corresponding to the foothill of the Jestřebí Mts. On the other hand, the SW margin of the HPT does not seem to be determined by a normal fault and it rather seems to be fixed to a simple flexure structure.

From the geomorphological point of view, the new information about the tectonics of the HPT enables to classify its marginal scarps as structural on SW and fault scarp on NE. Thus the Pliocene to Quaternary subsidence of the HPT was driven both by normal faulting (along the NE margin) and flexural deformation (along the SW margin). The present day seismic activity gives the evidence for ongoing tectonic movements in the area of the HPT.

5. CONCLUSIONS

The electric resistivity measurements using pole-dipole method were carried out along five profiles crossing the anticipated normal faults bounding the NW part of the HPT between the towns of Trutnov and Červený Kostelec. The results confirmed our previous hypothesis on the presence of normal fault bounding the HPT against the Jestřebí Mts. on the NE. In contrast, the normal fault which we suppose to bound the SW margin of the HPT was not found. We therefore conclude that the Pliocene to Quaternary subsidence of the HPT results from both the normal faulting and flexural deformation.

ACKNOWLEDGEMENT

This study has been supported by the Czech Science Foundation (Grant No. 205/05/H020) and by the Research Plan of the Institute of Rock Structure and Mechanics, AS CR, v. v. i., No. A VOZ30460519.

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