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DIGITAL ELEVATION MODEL OF THE CRYSTALLINE BASEMENT AND PERMO-CARBONIFEROUS SURFACE (BOHEMIAN MASSIF, NE PART OF THE CZECH REPUBLIC)

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ABSTRACT
Permo-Carboniferous and Cretaceous sediments cover the main tectonostratigraphic units of the crystalline basement in NE Bohemia. Within the activities of "Research Centre for Advanced remedial Technologies and Processes" the Czech Geological Survey revises the boreholes and geophysical investigations in the Bohemian Cretaceous Basin and adjacent areas. One part of the research is a compilation of pre-Cretaceous relief of the basement including the crystalline basement and Permo-Carboniferous relief. The digital elevation model uses all boreholes from the Czech Geological Survey-Geofond database, previous geophysical interpretation and the recent surface of the individual geological units defined from detailed geological mapping. The final model reflects well the evolution and recent position of several tectonic blocks and subsequent reprocessing of the information about basement rocks enables compilation of the ´solid´ geological map.

KEYWORDS: boreholes, seismic research, vertical electrical sounding, elevation model, crystalline basement, geological units

1. INTRODUCTION

The crystalline basement of the NE part of Bohemian Massif is largely concealed beneath Cretaceous sediments and the Permo-Carboniferous volcano-sedimentary complex (Fig. 1). The crystalline rocks crop out in the Karkonosze-Jizera Massif and Góry Sowie Block on the north and Orlice-Sněžník Block on the east. The basement of the Bohemian Cretaceous Basin and basement of the Permo-Carboniferous volcano-sedimentary complex are known only from boreholes.

Petrascheck (1944) published first summarizing study of the basement of Cretaceous sediments in the Bohemian Massif. Intensive research of the Bohemian Cretaceous Basin (**BCB**) has been started since the 50s of the 20th century along with the exploration for mineral deposits. Pouba et al. compiled in 1959 the first solid geological map. Vachtl in 1965 and Malkovský et al. in 1974 published the results of exploration work carried out in the 60s and 70s that involved a large quantity of deeper structural boreholes and geophysical survey. The surface of the basement was interpreted from the seismic refraction profiles above all in the central part of the BCB (e.g. Hrách, 1970; Cidlinský at al., 1974) accompanied with an extensive vertical electric sounding near Poděbrady, Chlumec nad Cidlinou and Lázně Bělohrad (e.g. Cidlinský at al., 1974; Svoboda and Zaw, 1984). The map published by Suk-Ďurica et al. in 1991 is derived from deep borehole data and geophysical interpretation and provides information on thicknesses of Permo-Carboniferous sequences.

Cretaceous sediments cover the studied area in the environs of Jaroměř and are part of the Bohemian Cretaceous Basin, they also occur near Police nad Metují and belong to the Czech portion of the Intra-Sudetic Synclinorium (*sensu* Oberc, 1977). Permian and Carboniferous rocks lie nearly everywhere in their footwall.

Two boreholes that reached the crystalline basement were situated in the Krkonoše Piedmont Basin (Prosečné Pé-1 1750 m) and in the Intra-Sudetic Synclinorium (Broumov Br-1 2628,5 m). Seismic survey was conducted across the Poříčí-Hronov Fault Zone and in the Intra-Sudetic Synclinorium (**ISS**) near Broumov. The refraction profiles (Bayer et al. 1961) were interpreted only partly, owing to unfavourable physical properties (subvertical seismic boundary). The reflection profiles gave better results – one was run across the central part of the Poříčí-Hronov Fault Zone and two close to Broumov to acquire data for the planned Br-1 deep borehole (Cidlinský et al., 1966; Fejfar et al., 1982).

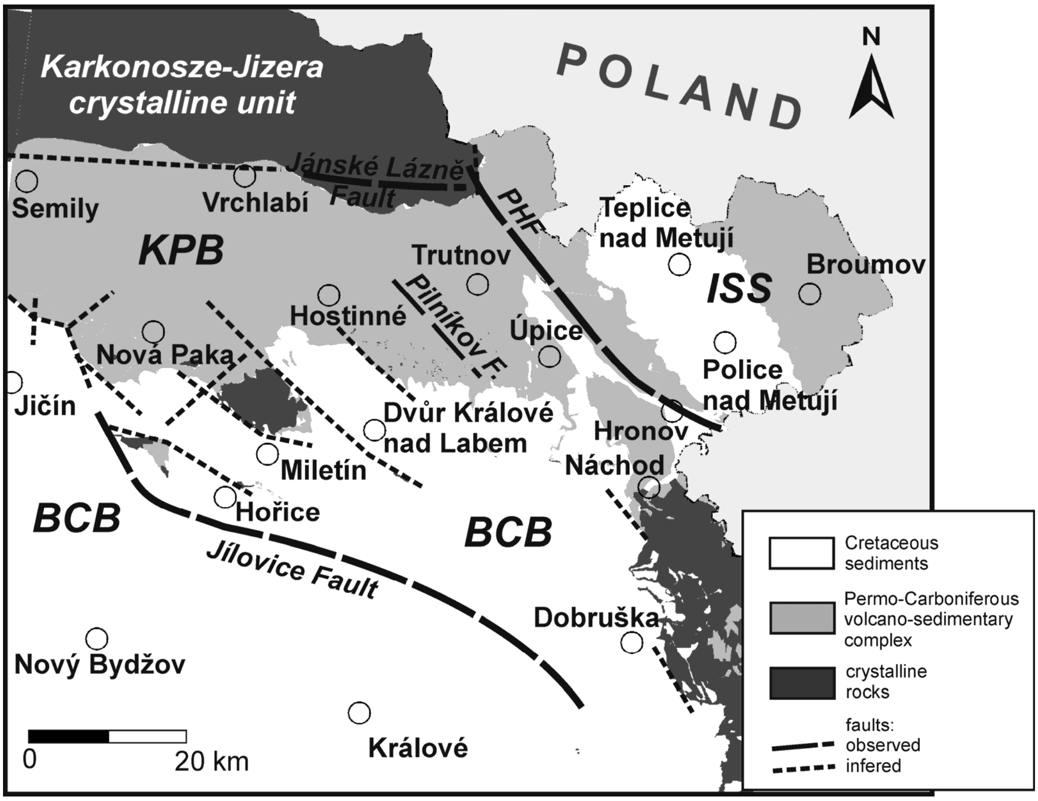

Fig. 1 Geological scheme of the NE Bohemia.

2. DATABASE AND METHODS

The borehole database of the Czech Geological Survey – Geofond was used for the compilation of 3D model of the crystalline basement and the surface of the Permo-Carboniferous volcano-sedimentary complex in the Krkonoše Piedmont Basin and Czech part of the Intra-Sudetic Synclinorium. The modelled surface was established for every individual borehole (altitude, rock type, geological unit) and filed to the 3D model database. In total, 5.064 boreholes for the Permo-Carboniferous surface and 11.195 boreholes for the crystalline basement were used.

The previous geophysical data (seismic data and the vertical electric sounding data) were used in the territory with sporadic borehole coverage. The re-entry reprocessing was necessary for the identification of the crystalline basement depth (digitization of the coordinates of the measurement points, verification of the results – seismic velocity and apparent resistivity). Finally, we loaded 777 entries to the crystalline basement model database.

The data of the digital elevation model of the recent relief at a scale of 1 : 25.000 were used for the area, where the Permo-Carboniferous volcano-sedimentary complex or the crystalline basement crop out recently.

The final database contains over 683.000 entries for the Permo-Carboniferous surface and 635.000 entries for the relief of the crystalline basement in NE Bohemia (Fig. 2).

The software of the Golden Software Inc. was used for the 3D modelling (program Surfer 8). XYZ data of the final 3D model were interpolated into a 500 m x 500 m spaced grid (used method of gridding: kriging).

3. DISCUSSION AND RESULTS

The final 3D models (Figs. 3 and 4) represent a significant contribution to the knowledge of tectonic evolution of the crystalline basement and sedimentary sequences of the NE part of the Bohemian Massif. Combination of the modelled surface together with the recent relief provides an integrated view on the position of geological units beneath their sedimentary cover. In general, Permo-Carboniferous and Cretaceous rocks cover the crystalline basement in the study area. The thickness of the cover reaches in some regions several hundreds of meters. Accuracy of the boundary line between the crystalline rocks and sediments is determined in relation to the density of geological data. High degree of geological exploration of the Czech territory has enabled to create the final 500 m x 500 m grid. Several selected areas could have been modelled even with greater accuracy (e.g. in a grid of 100 m x 100 m). The geophysical data suitably supplemented those from boreholes.

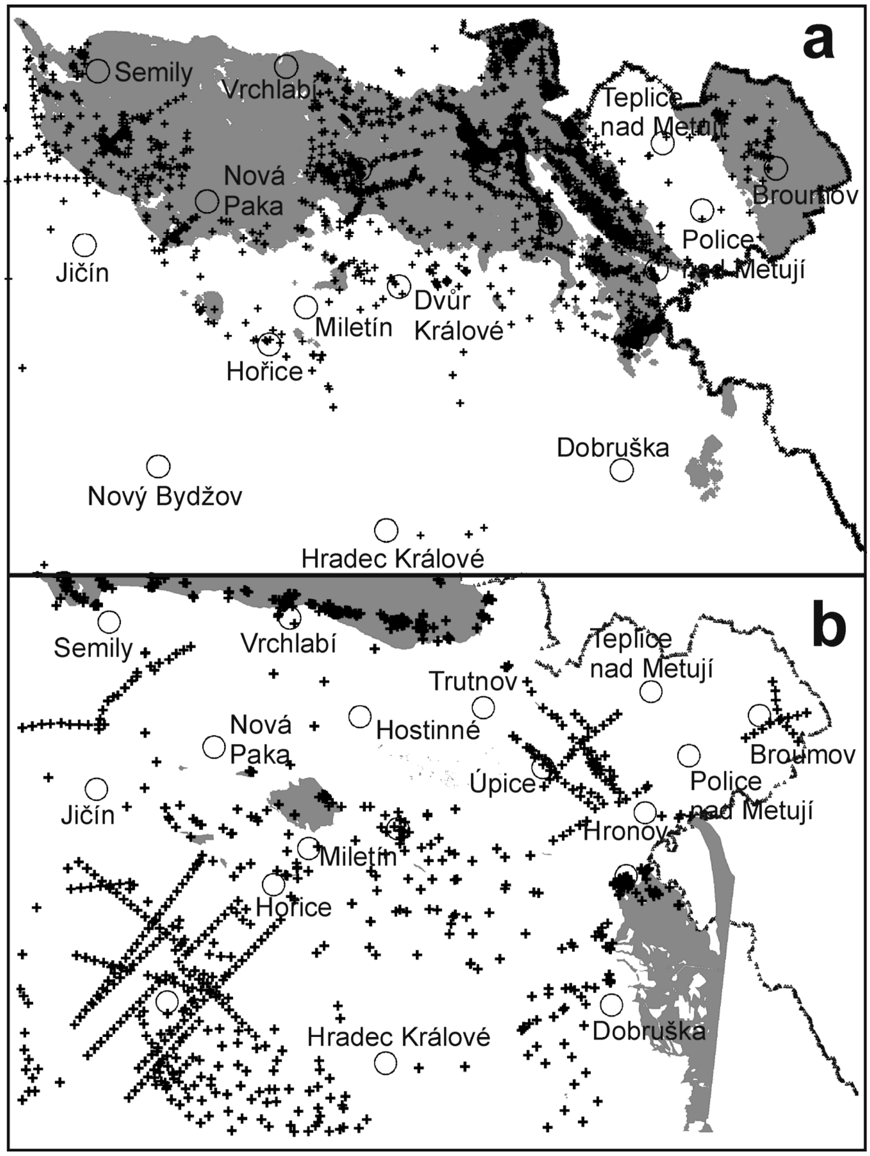

Fig. 2 (data used) a) Permo-Carboniferous surface, b) crystalline basement, (grey – present-day relief of the geological unit, black crosses – boreholes or geophysical data).

3.1. THE CRYSTALLINE BASEMENT

The boreholes to the crystalline basement covered the study area in an irregularly spaced grid. Small amount of them are located in the Krkonoše Piedmont Basin (**KPB**) and in the Intra-Sudetic Synclinorium (**ISS**), i.e. in the area of maximal thickness of the Permo-Carboniferous volcano-sedimentary complex. Geophysical data add more precision to the information about the Poříčí-Hronov Fault (**PHF**) and the Miletín syncline (south of Nová Paka).

The final 3D model of the crystalline basement (Fig. 3) reflects geological history, tectonic movements and deformation processes on the NE margin of the Bohemian Massif. The Permo-Carboniferous volcano-sedimentary complex and Cretaceous sediments cover the contact of Proterozoic and Paleozoic rocks represented by the Teplá-Barrandian Unit and Lusatia (Franke and Zelazniewicz, 2000), i.e. contacts of the Teplá-Barrandian Unit (TBU), Lusatia-Izera terrane, South-East Karkonosze terrane, Kaczawa terrane, Góry Sowie Mts.-Kłodzko terrane and Moldanubian terrane (*sensu* Mazur and Aleksandrowski, 2003), respectively. Following important fault zones accompany this boundary – a) the Intrasudetic Shear Zone or Labe/Lužice and Sudetic Fault Zone (Uličný et al., 2002; Martínek et al., 2006; Wojewoda, 2007), b) the Elbe Zone or Elbe Lineament and c) the Sudetic faults.

a) The Intrasudetic Shear Zone (**ISZ**) trending WNW-ESE forms the crystalline basement

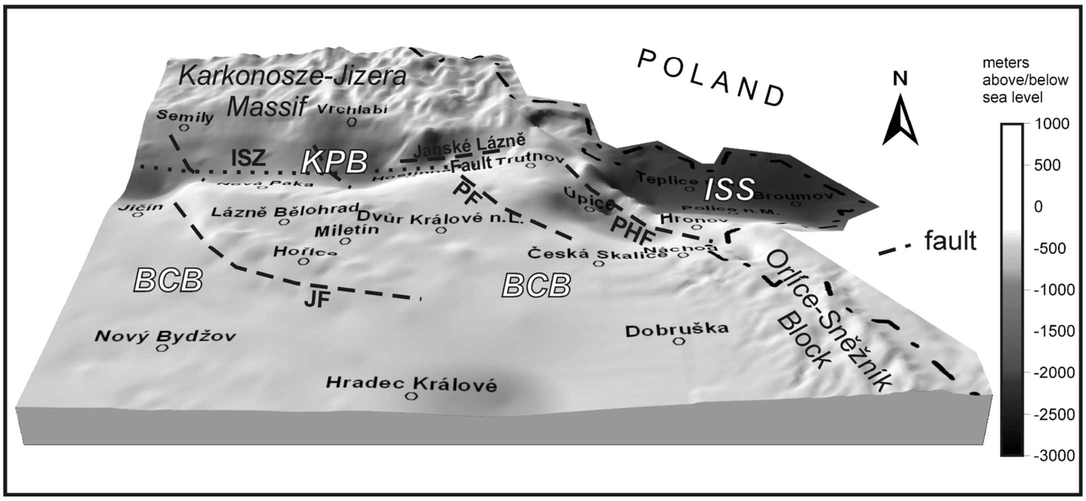

Fig. 3 Digital elevation model of the crystalline basement in NE Bohemia (double vertical exaggeration).

above all in the KPB (Autunian and Late Cenozoic times sensu Uličný et al., 2002)

b) the Elbe Zone in NW-SE direction (represented e.g. by the Jílovice Fault) bounds ridges and valleys on the NE margin of the Bohemian Cretaceous Basin (between Jičín, Hořice and Dvůr Králové nad Labem)

c) and the NNW-SSE trending faults which create a block of crystalline stretched out along the Poříčí-Hronov Fault. One of the deepest-sunken blocks of the crystalline basement is situated south of Semily and Vrchlabí in the KPB. The crystalline rocks reached by boreholes comprise low- to medium-grade metamorphosed volcano-sedimentary complexes (sericite-chlorite, sericite and graphite phyllite, metadiabase, metagabbro) on the contact between the Karkonosze-Jizera crystalline unit (Malkovský et al., 1974; Kachlík and Patočka, 1998) and the Teplá-Barrandian Unit (green schist, schist, spilite, amphibolites). This 15 km wide WNW-ESE trending zone (the Intrasudetic Shear Zone) represents probably a suture between a fragment of the Saxothuringian and the TBU (Mazur and Aleksandrowski, 2003) or more precisely contact between Early Paleozoic (Cambrian/Ordovician to the Silurian/Devonian) and Upper Proterozoic complexes. Neotectonic analysis of the morphology and of the recent geodetic measurements considers the Intrasudetic Shear Zone as „*shallow continuation of a deep strike-slip zone, which had significant influence on the rearrangement of the epivariscan cover in the Sudetes*“ (*sensu* Wojewoda, 2007).

In comparison with the previously published contour map of the crystalline basement (Malkovský at al., 1974 or Suk and Ďurica et al., 1991) the newly submitted 3D model has detected a structural high between the towns of Semily and Nová Paka and a structural low south of Vrchlabí (Fig. 3). Both can represent a dextral strike-slip movement along NNW-oriented faults accompanied by a sinistral strike-slip movement on the NNE-oriented structures (described as half-graben shape in an article of Uličný et al., 2002). Following movements along NW to NNW-striking faults (the Poříčí-Hronov Fault starting-up during the Saxonian) the Trutnov-Náchod sub-basin originated. The reactivations of NNW-trending fault system occurred during Early Jurassic on the Nová Paka anticline, Zvíčina Crystalline Unit and Pilníkov Fault (**PF**) (Martínek et al., 2006) and are documented in 3D model as ridges near Hořice, Nová Paka, Zvíčina, Dvůr Králové and Pilníkov-Hajnice and valleys represented e.g. by the Miletín syncline (Fig. 3). At present the crystalline basement outcrops on these ridges in separate tectonic windows.

A significant feature of the crystalline basement is the reactivation of existing pre-Variscan and Variscan shear zones in Cretaceous times. Along the NW-trending faults Cretaceous „basin system“ originated– with the Police Depression, Kłodzko Basin, Nysa-Králíky graben and Poříčí-Hronov trench as major structures. Uplift of the northern blocks of the Jílovice Fault (**JF**) and along the PHF is well documented in the 3D model (Fig. 3).

Another deeply subsided area is situated in the Intra-Sudetic Synclinorium. The crystalline basement has reached maximal depth near Broumov and is formed by amphibolite and metamorphosed volcanic

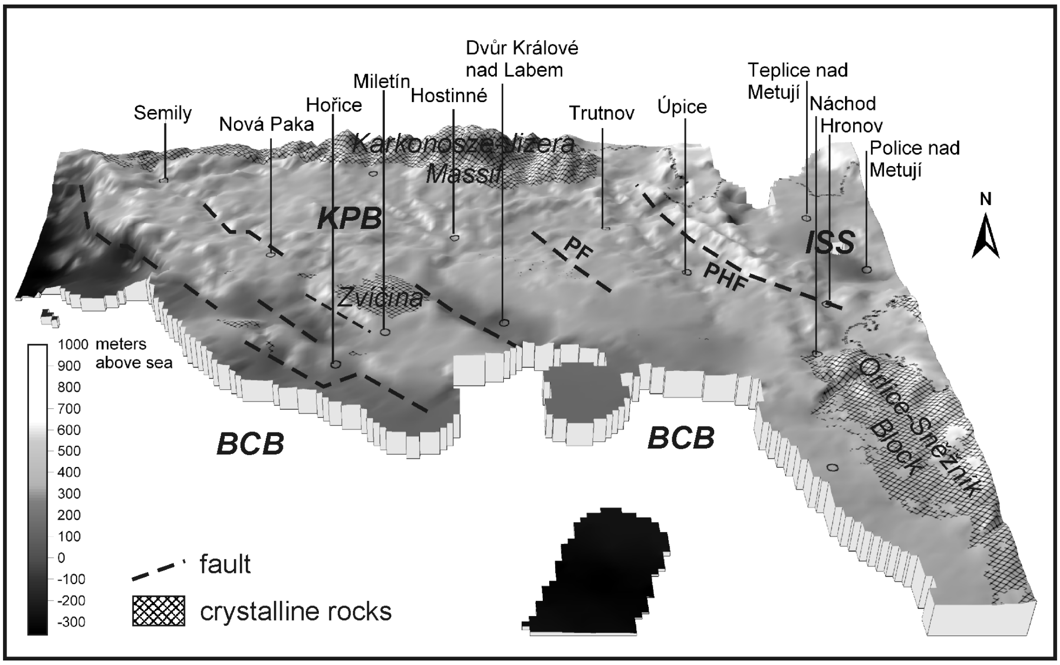

Fig. 4 Digital elevation model of the Permo-Carboniferous volcano-sedimentary complex in NE Bohemia (double vertical exaggeration).

rocks appertaining to the Leszczyniec Metavolcanics Complex of the East Karkonosze Unit (Čížek et al., 1986).

3.2. THE PERMO-CARBONIFEROUS VOLCANO-SEDIMENTARY COMPLEX

Permo-Carboniferous rocks build up a substantial part of the present-day relief in NE Bohemia, and they occur in two major areas: a) the E-W oriented Krkonoše Piedmont Basin (**KPB**) and b) the Czech part of the NW- trending Intra-Sudetic Basin (Teisseyre, 1968) or Intra-Sudetic Synclinorium (**ISS**). Both of them represent post-orogenic pull-apart, mostly limnic basins (Aleksandrowski et al., 1997; Tásler et al., 1979). The Intra-Sudetic Basin had been initiated as an intra-orogenic basin in the Lower Carboniferous (Tournaisian ?; Visean after Cháb et al., 2008) preserved on the NE margin of the Bohemian Massif and gradually changed into a large asymmetric one during Pennsylvanian and Permian times (Tásler et al., 1979). During the Lower Carboniferous – Westphalian the Plzeň-Trutnov Basin originated (it includes an area between Plzeň, Roudnice nad Labem, Česká Kamenice, Mnichovo Hradiště and Trutnov) and it represented a consequential intra-orogenic sedimentary feature, which was interconnected with the Intra-Sudetic Basin during Stephanian times. Decreasing trend in tectonic activity in the surrounding massifs caused shifting of the sedimentary area of Plzeň-Trutnov Basin farther to the S during the Westphalian D, and thus the Krkonoše-Piedmont Basin (KPB) was initiated (Tásler et al., 1979). The morphological changes starting during the Stephanian C and Autunian caused culmination of volcanic activity in this area. The movements along the NW-trending Hronov-Poříčí Fault Zone and the Pilníkov fault were initiated during Saxonian and resulted in the formation of the Trutnov-Náchod sub-basin (Martínek et al., 2006). The fault activity continued until Late Cretaceous/Paleocene times. The present-day area and shape of the basins are defined by their preserved Late Palaeozoic infill dominated by continental deposits and volcanic rocks. The sediments forming fining-upward cycles, consist of Pennsylvanian coal-bearing alluvial sequences (Valín, 1976; Nemec and Ćmiel, 1979), alluvial-plain to lacustrine deposits of the Lower Rotliegend associated with a strong volcanic activity (Mastalerz and Wojewoda, 1989; Blecha, 1992; Mastalerz and Nehyba, 1997; Awdankiewicz, 1998, 1999) and the Upper Rotliegend braided- plain to alluvial plain – alluvial fan deposits at the top (Tásler et al., 1979; Sliwiński, 1980). The following Upper Permian to lower Triassic period comprises fluvial and aeolian deposition (Lorenc and Mroczkowski, 1978; Zajíc, 1998). Saxonian to Triassic conglomerates, sandstones and mudstones are documeted only in the Trutnov-Náchod sub-basin and in the Intra-Sudetic Synclinorium (Martínek et al., 2006).

Volcanic rocks represent 10–15 % of the basin´s area (Tásler et al., 1979; Schovánková, 1985) and crop out close to the Czech-Polish border and in the western part of KPB. Two phases of volcanic activity are distinguished here: Carboniferous (Westphalian) and Permian (Autunian) respectively (Tásler et al., 1979).

Products of the Westphalian phase - andesitic lava flows, subvolcanic bodies and rhyolitic pyroclastics (Schovánková, 1985) - are concentrated in the southwestern limb of the Czech part of the Intra-Sudetic Synclinorium (Tásler et al., 1979). In the KPB minor andesitic intrusions occur in the southwestern part of the basin (Tásler et al., 1979). The second, Autunian phase can be further subdivided into 3 cycles (Kozłowski, 1958; 1963), of which each comprises andesites in the lower part and rhyolites in the upper part. In the Czech Republic, only products of 2 younger cycles are present and they are concentrated in the northeastern limb of the Intra-Sudetic Synclinorium and in the western part of the KPB. Cretaceous sediments cover the Permo-Carboniferous surface only on the NE margin of the Bohemian Cretaceous Basin (south of the Nová Paka-Hostinné-Úpice line), in the Hronov-Poříčí Trench (between Trutnov and Hronov) and in the Police Depression (in the Adršpach, Teplice nad Metují and Police nad Metují areas).

The major now existing structure is the 400 m wide zone of the Poříčí-Hronov Fault (**PHF**) stretching in NW-SE direction (Fig. 4), separating the ISS from the KPB, in which reverse faults caused displacement of 1 km (Tásler et al., 1979). Except for the major NW-SE orientation of normal and reverse faults in both basins, minor N-S structures in the ISS and E-W structures in the southern and central part of the KPB occur. The average displacement varies from 50 up to 150 m (Tásler et al., 1979). The depression on the SW of the PHF is manifested in the Permo-Carboniferous surface (Fig. 4) as a paleo-valley of the Úpa River. The Permo-Carboniferous surface is tilted to the NE and forms a structural low with two minima in the basement of the Police Depression. The first one is situated near Teplice nad Metují and the second near Police nad Metují. Borehole data from Poland are necessary for a complete compilation of the final 3D model.

The interpretation of the Permo-Carboniferous surface in the NE margin of the Cretaceous Bohemian Basin (between Jičín, Lázně Bělohrad, Dvůr Králové. L. and Náchod) is based on the available borehole data and on small tectonic windows cropping out on the surface. The faults limited isolated crystalline ridges and valleys (described above) with the relicts of the Permo-Carboniferous volcano-sedimentary complex having a few to hundreds of meters in thickness.

4. CONCLUSIONS

The digital elevation model of the crystalline basement and the model of the Permo-Carboniferous surface represent an integrated interpretation of boreholes and geophysical data enhanced by information gathered during detailed geological mapping (delimitation of the geological units forming the present-day relief). Created database can be complemented and upgraded thus adding more accuracy to the 3D models.

3D model of crystalline basement (Fig. 3) provide information about the configuration and history of the Krkonoše Piedmont Basin and the Intra-Sudetic Synclinorium, which are predominantly filled by Permo-Carboniferous volcano-sedimentary complex. The maximal depth of the Krkonoše Piedmont Basin is thought to be located south of Vrchlabí. On the north and south this structural low is constrained by steeply dipping faults in W-E direction and enclosed by NW-SE trending structural highs on the west (Semily-Nová Paka) and on the east (near Trutnov). The structural low near Úpice with the crystalline basement in the footwall represents the Trutnov-Náchod sub-basin (or Poříčí-Hronov trench) filled by the Permo-Carboniferous volcano-sedimentary complex and Cretaceous sediments. The maximal depth of the Intra-Sudetic Synclinorium is found near Broumov. The crystalline basement on the NE margin of the Bohemian Cretaceous Basin (between Jičín and Dobruška) is uplifted by about 350 m along the Jílovice Fault.

3D model of the Permo-Carboniferous volcano-sedimentary complex surface (Fig. 4) reflects Cretaceous and post-Cretaceous development of the study area. The steep slope west of the Semily-Nová Paka line represents the most distinctive morphological element in the modelled surface. The normal throw is about 500 m. This tectonic movement is a manifestation of faults connecting the Lužice and Jílovice faults. The Permo-Carboniferous volcano-sedimentary complex occurs between Hořice, Dvůr Králové nad Labem and Náchod only as isolated tectonic windows on ridges composed of crystalline. The south-situated Jílovice Fault shows the movements only in Cretaceous sediments and in the crystalline basement.

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