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ŽĎARKY-PSTRĄŻNA DOME: A STRIKE-SLIP FAULT-RELATED STRUCTURE AT THE EASTERN TERMINATION OF THE POŘÍČÍ-HRONOV FAULT ZONE (SUDETES)

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ABSTRACT
The trans-border area of the Sudetes between Žďarky and Pstrążna has attracted Prussian/German, Austrian, Czech and Polish geologists since the middle of the 19th century. The history of mapping of this area reflects the scientific development of geological centres in Berlin, Vienna, Prague and Wrocław. This paper presents a description of the oldest geological maps of Lower Silesia in the context of changing knowledge on the Carboniferous and Cretaceous stratigraphy and on the tectonics of the region. On the basis of DEM and field studies the author presents his own geological map of the area of the Pstrążna Elevation together with a description of the local structural geology. A regional structural model is suggested, that explains all the local elevations as having developed in response to a dextral strike-slip activity of the Žďarky-Jakubowice Fault during late Tertiary to Recent times, at an eastern extension of the Poříčí-Hronov Fault Zone.

KEYWORDS: Sudetes, strike-sip fult, upper Cretaceous

INTRODUCTION

The vicinity of Pstrążna in the Sudetes constitutes geologically important area for several reasons. Firstly, because since the 19th century small though easily accessible coal seams were excavated and the village of Pstrążna (German: *Straußenei*) became a miners' settlement. At present, several backfield drifts, some possessing mining documentation, still occur over this former mining field. Secondly, this area is situated at the border of three major regional geological units – the **Intrasudetic Synclinorium** (**ISS**), the **Kudowa Massif** (**KM**) and the so called **Kudowa Trough** (**KT**) (**Fig. 1**) – as well as at the termination of one of the major dislocation zones in the Sudetes – the **Poříčí-Hronov Fault Zone** (**PHFZ**). The latter zone, according to some researchers, has more than a regional significance, being a border between large regional tectono-stratigraphical units, so called terranes – the Bohemian and Saxothuringian (cf. Aleksandrowski and Mazur, 2002). The Pstrążna area constitutes an integral part of the ISS; nevertheless due to its peripheral location, this area was mostly ignored and only cursorily dealt in studies devoted principally to adjacent units. This also concerns mapping works, which are described in their historical aspect in the first part of this paper. In the second part, the results of the present author's detailed geological mapping and structural observations are presented.

The area of study is situated in the Middle Sudetes, approximately 3 km north of the centre of Kudowa Zdrój, at the foot of the **Góry Stołowe Mts**. (**GS**). The mapping area is limited by the following geographical coordinates: **50º28'58" in the north**, **50º27'38" in the south, 16º14'33" in the west** and **16º16'33" in the east**. It is the only locality in the south-eastern part of the **ISS** where granitoids, amphibolites, mica schists of its basement crop out (Gierwielaniec, 1965; Żelaźniewicz, 1977a and b), whereas Carboniferous rocks constituting the infill of the **ISS** are exposed only over a small area (Petrascheck, 1904a, 1910 and 1922; Berg, 1925; Hynie, 1949; Dziedzic, 1957 and 1961; Gierwielaniec, 1965; Bossowski and Ihnatowicz 1994a and b).

The tectonic boundaries between the crystalline and sedimentary rocks and between Carboniferous and Cretaceous rocks are of particular significance. In the vicinity of Žďarky such boundaries have been directly documented in mine drifts. Tectonic contacts were also identified near Pstrążna, where in a shaft (*Wilhelminen Schacht*) tectonic boundary of Carboniferous and Cretaceous had been described, and where reverse stratigraphical sequence had been postulated (see e.g. Weithofer, 1897; Petrascheck, 1904a and b, 1933; Schmidt, 1904; Schmidt et al., 1905; Hynie, 1949). In places, without any justification, the boundary between the Carboniferous and the Cretaceous was interpreted as an overthrust

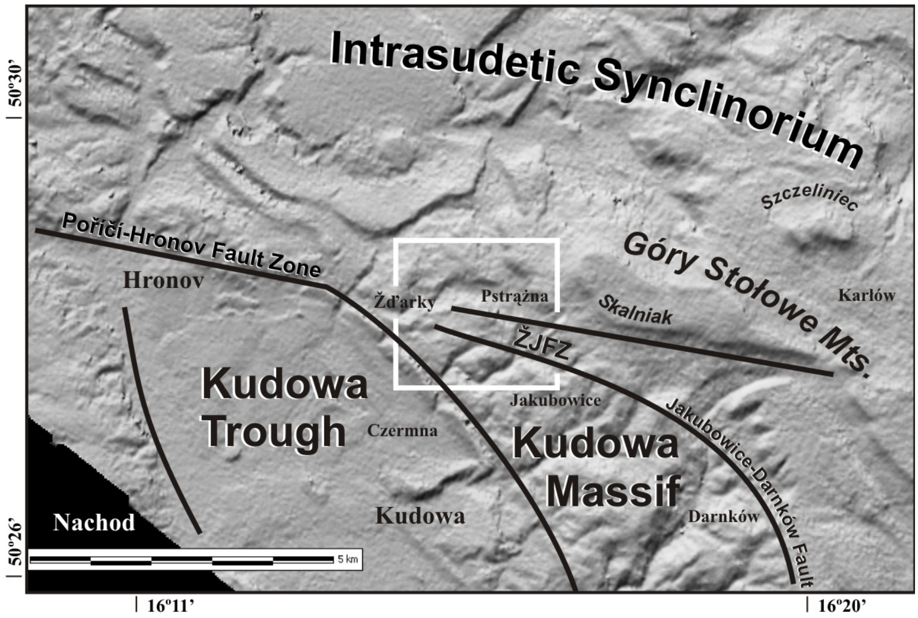

Fig. 1 Location scheme of the Pstrążna surrounding area (white square – the area imaged in Figure 6).

(see Gierwielaniec and Radwański, 1955) what in consequence became a basis for some compilations (Čech and Gawlikowska, 1999), or even of structural models of the Middle Sudetes (Cymerman, 2004).

LITHOLOGY AND THE AGE OF ROCKS

Four rock groups occur in the area of Pstrążna: (1) metamorphic rocks of the **Orlica Complex**, (2) granitoids and gabbroids of the **Kudowa Massif** (Żelaźniewicz, 1977a and b), (3) uppermost Carboniferous sediments and (4) late Cretaceous sediments of the **Bohemian Basin**. The first group is represented by mica schists and phyllites. They are probably of Pre (?)Cambrian/Lower Ordovician age, as radiometric Rb/Sr method points to 494 ± 19 Ma (phyllites) and 588 ± 25 Ma (mica schists) ages (Bachliński, 2002). The granites occur as intrusive bodies of various dimensions within the metamorphic envelope and they are jointly referred to as the **Kudowa-Olešnice Granitoid Massif**. The petrography and structural relations between these rocks were described by, among others, Żelaźniewicz (1977a and b). It is confirmed by two groups of radiometric ages of these rocks – 400-380 Ma and 320-341 Ma, respectively (Domečka and Opletal, 1974; Bachliński, 2002).

The history of description and attempts at stratigraphical division of the Carboniferous sedimentary rocks from the area of Pstrążna date back to the beginning of the 20th century (e.g.: Weithofer, 1897; Flegel et al., 1904; Schmidt, 1904; Dathe and Petrascheck, 1913; Petrascheck, 1922). Out of necessity, they referred to lithostratigraphical division of the well recognized coal mining fields of the **ISS** in the area of Žacleř to the south-west and in the Wałbrzych-Nowa Ruda coal-basin to the north-east (Schütze, 1882; Schmidt, 1904; Herbing, 1904; Berg, 1925; Hynie, 1949; Dziedzic, 1957 and 1961; Tasler et al., 1979; Nemec et al., 1982; Bossowski and Ihnatowicz, 1994a). There were only few attempts at palaeontological (palaeobotanical) classification and correlation of these sediments (Stur, 1885 and 1887; Schmidt, 1904; Herbing, 1904; Němejc, 1933, 1953 and 1958; Górecka-Nowak, 1995; Górecka-Nowak and Majewska, 2002). The lithostratigraphical subdivision which can be directly applied to sedimentary rocks occurring in the vicinity of Pstrążna and which refers both to local and to regional lithological units is shown in **Figure 2**.

The Carboniferous sequence starts with residual soils of saprolite type, covering the crystalline bedrocks, which locally occur *in situ* or have been deposited close to the site of their origin (August and Wojewoda, 2005). They have probably formed in the Westphalian B and C (ca. 313-311 Ma). The lowermost sediments *sensu stricto* are represented by the **Dolsk-Žďarky Mb.,** corresponding to the Westphalian C (about 311-309 Ma) (Němejc, 1933 and 1958). These are predominantly various conglomerates of moderately rounded and dominantly granitic and schists pebbles, as well as sandstones and mudstones with intercalations of coal (**Figs. 3a and 3b)**. The sediments constitute the topmost part of the **Žacleř Formation** (German: *Schatzlarer Schichten,* the name first used by Stur in 1874). They are overlain by a series of poorly sorted sediments, dominantly conglomeratic, which represent the Westphalian D to the Stephanian A (ca. 307-298 Ma).

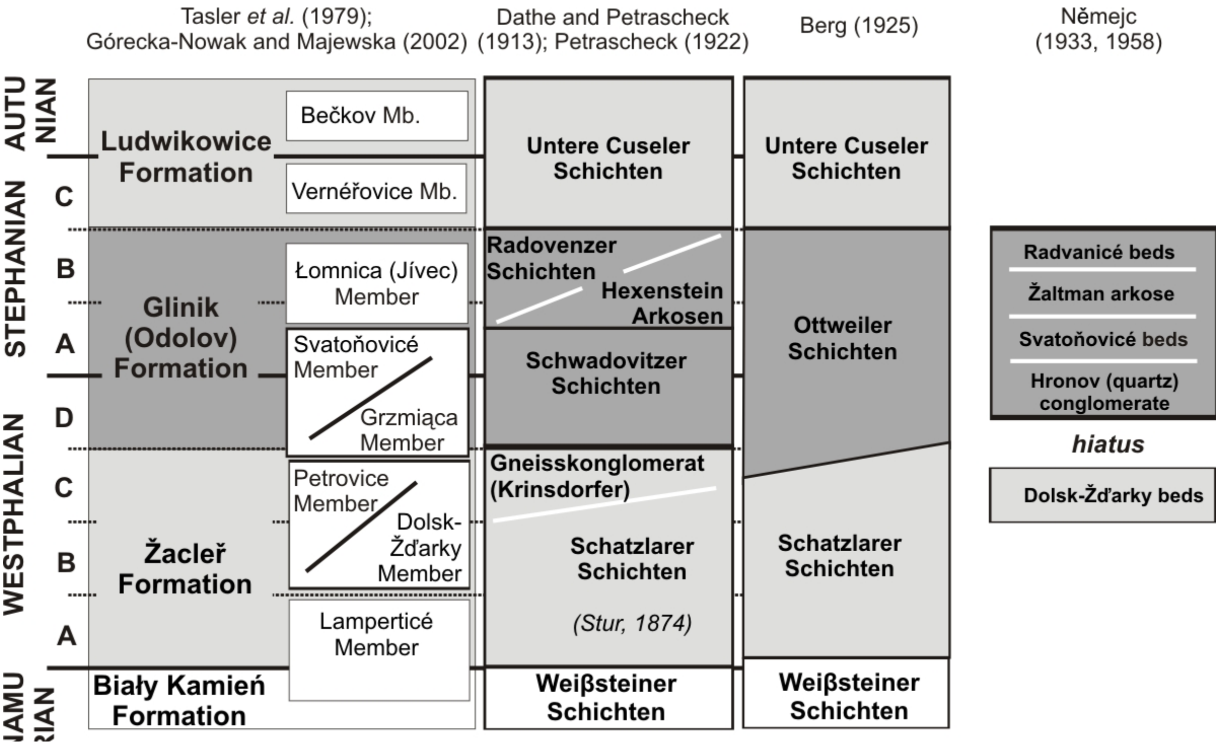

Fig. 2 Stratigraphic subdivisions of the uppermost Carboniferous in the intrasudetic province according to various authors.

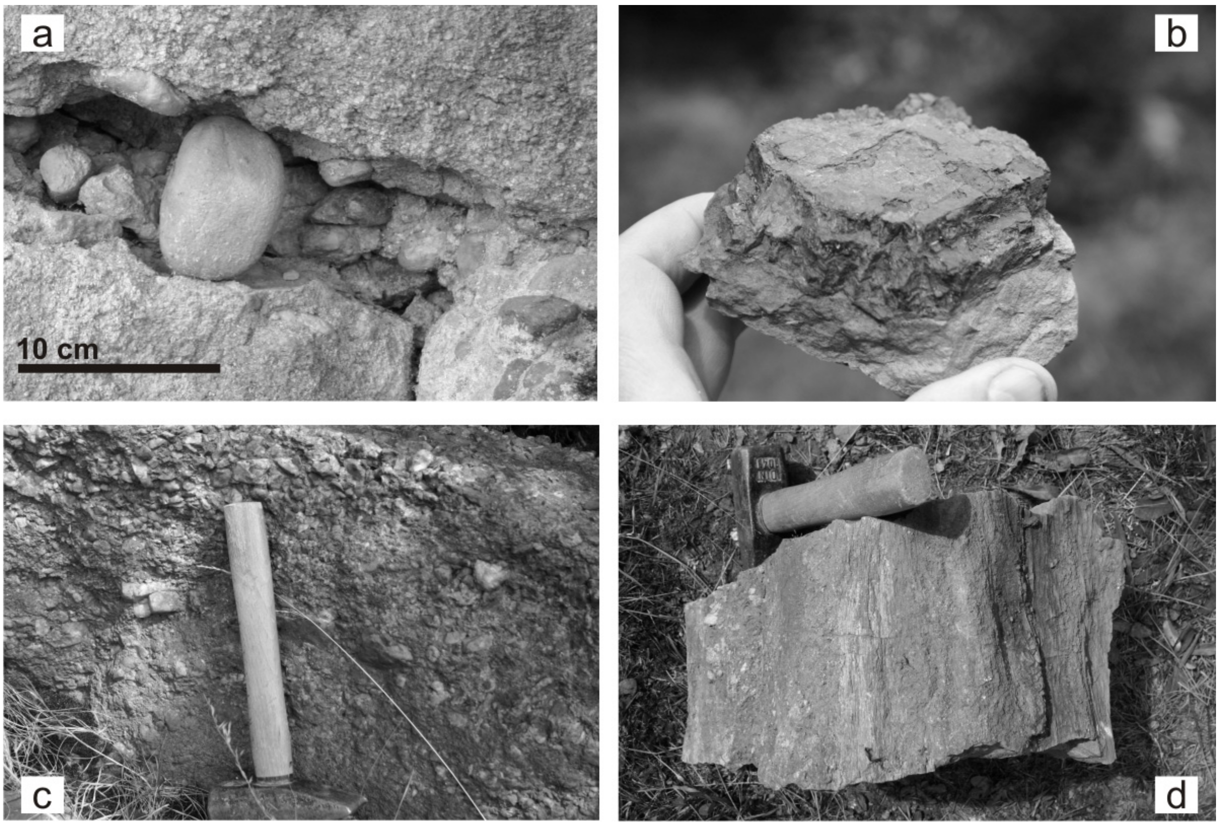

Fig. 3 Uppermost Carboniferous deposits in the vicinity of Pstrążna: a - Dolsk-Žďarky Mb. (Westphalian C); b - coal intercalation; c - Svatoňovice Mb. (Stephanian A); d - silicified wood.

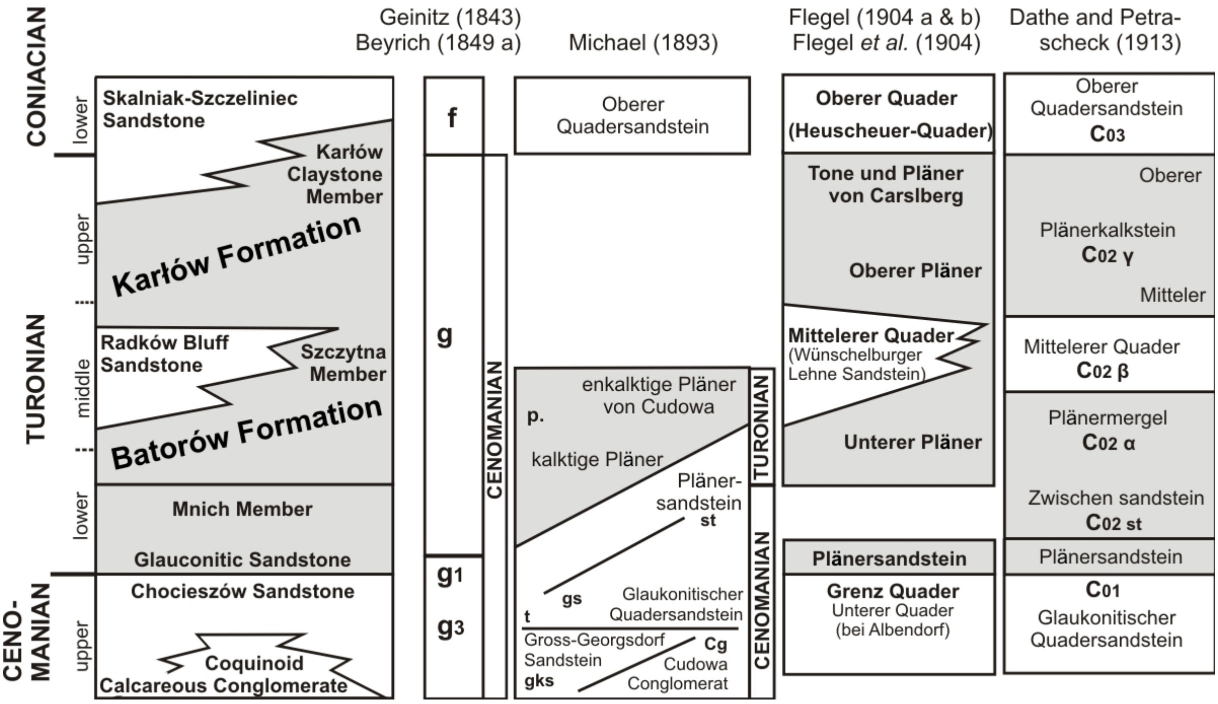

Fig. 4 Stratigraphic subdivisions of the Cretaceous in the area of Pstrążna in relation to divisions used on older geological maps (explanation of symbols in text).

This series begins with quartz conglomerate at the bottom (so called **Hronov Conglomerate**), which, together with the overlying conglomeratic sandstone and mudstone (**Svatoňovice Mb.**), form the lower part of the **Glinik (Odolov) Formation** (**Figs. 4c** and **4d)**. The Carboniferous deposits from the vicinity of Pstrążna in older divisions and on older maps are referred to as the **Ottweiler** (German: *Ottweiler Schichten* – the name first applied by Dathe, 1903). The boundary between the deposits of the Žacleř and Glinik (Odolov) Formations is marked by paraconformity corresponding to the non-deposition period at the turn of the Westphalian C and D (about 308-309 Ma) (Němejc, 1933 and 1958).

Upper Cretaceous deposits in the area of Pstrążna are included by some researchers into the sedimentary-volcanic succession of the **ISS**, however they do not correspond with either basin or structural patterns of this unit but they fit the palaeogeographical pattern of the Bohemian Basin (Wojewoda, 1986, 1997 and 2003; Jerzykiewicz and Wojewoda, 1986; Wojewoda et al., 1997; Don and Wojewoda, 2004 and 2005). The lithology of the Cretaceous deposits, as well as their distribution have been recognized already in the 19th century (Raumer, 1819; Zobel and Carnall, 1831 and 1832; Geinitz, 1843 and 1848; Goeppert, 1848; Beyrich, 1849a and b, 1854; Beyrich et al., 1867; Michael, 1893). Binding up to date (with minor changes, **Fig. 4**) lithostratigraphical scheme of the Sudetic Cretaceous based on *Inoceramus sp*., has been established at the turn of the 19th and 20th centuries (Michael, 1893; Flegel, 1904a and b; Flegel et al., 1904).

The Cretaceous sequence in the area of Pstrążna begins with poorly sorted, locally conglomeratic sandstone, regarded as the Upper Cenomanian (*Actinocamax Plenus* zone). The sandstone is locally intensely calcareous and contain abundant bivalve shells (coquinoid conglomeratic sandstones). Since the time of their discovery and assessment of their transregional extent they are referred to as the (Lower) Jointed Sandstones, due to their distinct, orthogonal system of jointing (German term *Quadersandstein* was first applied to them by Karl von Raumer in 1819, who referred to the sandstones occurring in the **GS**). Locally, at the contact with the crystalline bedrock, medium- to fine-grained sandstones and calcareous mudstones of the **Batorów Formation** occur, representing the Lower and Middle Turonian (*I. labiatus*, *I. lamarcki*). These sediments, in the area between Jakubowice, Czermna and Pstrążna, were referred to as *Pläner* by Raumer (1819). This rock series begins with medium-grained, well sorted sandstone, first described by Zobel and Carnall (1831 and 1832) as *Plänersandstein.* The thickness of the Cretaceous cover in the area of Pstrążna is strongly reduced being 30 m on average. Only at the outskirts of the studied area, its thickness increases to approx. 40 m in borehole Pstrążna-2 borehole, and approx. 230 m in borehole Bukovina, (see also **Fig. 6**).

THE HISTORY OF GEOLOGICAL MAPPING OF THE VICINITY OF PSTRĄŻNA

The area of Pstrążna has always been a subject of controversy among geologists due to its historical trans-border location. This locality since long has attracted fans of the landscape of Góry Stołowe (**GS**), the more so that it also became an important balneological health resort. Both aspects resulted in imaging of the area on maps since long ago, on geological maps inclusively. The history of the geological mapping in question locality is worth presenting, especially as it illustrates the progress in mapping of the whole Sudetes.

The oldest attempt at presenting the geological structure of the Sudetes on a map was made by Leopold von Buch in 1796 on his Mineralogical Map of Silesia at the scale of 1:500000. The map was enclosed in a book describing his journey across Silesia (Buch, 1802). The **Góry Stołowe Mts** were schematically marked on this map with their highest peak Szczeliniec (German: *Heuscheuer*) as an area of sandstone occurrence, and the vicinity of Pstrążna was shown as the northern termination of the Góry Bystrzyckie Mts. (German: *Habelswerder Gebirge*) within the schists outcrop area (German: *Glimmerschiefer*). In 1818 Karl von Raumer made the first proper geological reconnaissance map of the Sudetes at the scale of 1:178600 (Raumer, 1819). On this map, for the first time, outcrop zones of the Carboniferous and Cretaceous were schematically depicted. This oldest, 'heroic' period of geological mapping of the Sudetes was crowned with sheets of a reconnaissance map of the Sudetes at the scale of 1:188000 made in 1827 by Zobel and Carnall (1831 and 1832), Carnall (1832).

The successive period of detailed geological mapping in the strict sense was initiated by the sheet Duszniki (German: *Reinerz*) elaborated by Ernst H. Beyrich between 1841 and 1865 and issued as a series of 5 sheets (Geological Map of the Sudetes, 1:75000 scale; Beyrich, 1849a and b, 1854; Beyrich et. al., 1867; **Fig. 5**). This map was preceded by a geological sketch-map by Beyrich, enclosed in his work in 1854, which contained no altitude contour lines. and the topography image limited to dash and shadow pattern, which only schematically presented major positive forms of the surface. The boundaries between all the rock varieties were marked as non-tectonic. There are two WNW-ESE-trending faults shown on the map. First of them, of longer extent, is located close to the southern boundary of the Carboniferous outcrops and the other, remarkably shorter, close to their eastern border. Interestingly, at the continuation of the latter fault towards the east, the boundary of the Carboniferous and the Cretaceous is distinctly offset. Some details from Beyrich et al. (1867) map do not reappear on later maps. This happens e.g. with the idea that the Carboniferous outcrops from the area of Pstrążna make up a continuous belt reaching up to the vicinity of Hronov to the west or the already mentioned outcrop of the volcanic rocks.

Almost at the same time, in 1847-1860, 17 sheets of a geological map of the Czech territory were prepared at the scale of 1:144000 under supervision of Johann Jokély. One of the sheets included the vicinities of Nachod and Žďarky (sheet Broumov; Jokély and Wolf, 1861). In 1893 Richard Michael wrote a pioneering paper devoted to the geological structure of the Kudowa Trough area. One of figures attached to this article (Tab. V), was a geological map at the scale of 1:50000, which, together with accompanying cross-sections, ranged up to the vicinity of Pstrążna. The lithostratigraphic units of the Cretaceous as established by Michael, were successively accepted by most authors of the maps produced later and remained valid until now with only minor changes. In the vicinity of Pstrążna, Michael marked out on his map undivided Carboniferous and the galuconite-bearing Lower Jointed Sandstone (*Glaukonit-spongitenreicher Quadersendstein,* g_s) dated as the Cenomanian. According to Michael, these rock units are not separated by, but rather overlie an unconformity on top of mica schists and the Kudowa granite. In comparison to later maps, the structural pattern on Michael's map is surprisingly simple, what is confirmed by cross-sections. In the area of Pstrążna no tectonic phenomena are marked.

In 1897 Anton K. Weithofer wrote a paper about the geology of the southern outskirts of the **Intrasudetic Synclinorium** (issued in 1898) with an attached geological map at the scale of 1:100 000 that included a small part of the Žďarky area. Together with the map he also published 5 cross-sections perpendicular to the Pořiči-Hronov Fault Zone (it is in this paper that the name of *Parschnitz-Hronower Bruch* appears for the first time). In the vicinity of Žďarky, westwards of Pstrążna, Weithofer marked Carboniferous outcrop zone, entirely enclosed within undivided Cretaceous deposits. However, the most important detail of Weithofer's work is the part relating to the description of a fault zone documented in the Wilhelmina's shaft. This author quotes an account of a mining engineer, Nowak, and of a mine surveyor, Irrmann, stating that a fault zone separates the Cretaceous from the overlying Žacleř Beds (Weithofer, 1897, p. 470). This suggests that the fault was of reverse type and that thrusting of the Carboniferous over the Cretaceous took place at the western outskirts of the Carboniferous outcrops near Pstrążna.

In 1904 K. Flegel, J. Herbing and A. Schmidt elaborated a geological map of the **ISS** at the scale of 1:75 000, which also reached up to the area of Pstrążna (**Fig. 5**). All the Cretaceous units distinguished on this map, although in different places, are shown as lying unconformably over the Carboniferous. In comparison to the older maps, this one contains newely recorded tectonic features. The

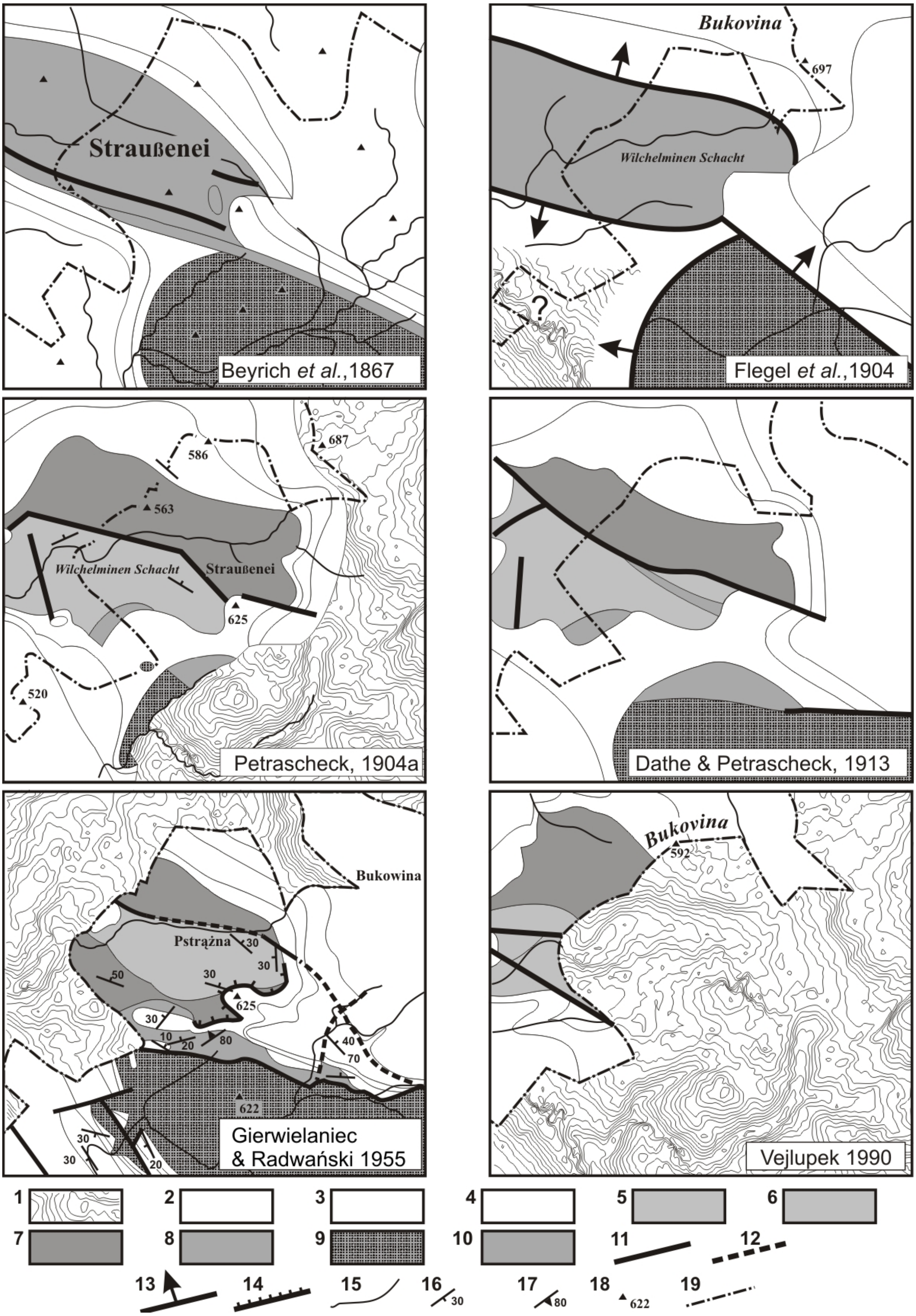

Fig. 5 Fragments of the most important and commented geological maps of the Pstrążna area.
Explanations: 1 – 20 m contour interval on the area not presented on the map; 2 – middle Turonian; 3 – lower Turonian; 4 – upper Cenomanian; 5 – uppermost Carboniferous (undivided); 6 – Svatoňovice Mb. (Stephanian); 7 - Dolsk-Žďarky Mb. (Westphalian); 8 – volcanic rocks; 9 – granite; 10 – mica schists; 11 – evidenced fault; 12 – presumed fault; 13 – inclined fault plane (arrow indicates dip direction); 14 – thrust plane; 15 – contour line; 16 – bedding; 17 – foliation; 18 – peaks; 19 – state boundary.

authors apparently were very blunt in clearly showing the faults and interpreting their kinematics; they placed arrows along the fault lines to show which fault sides were downthrown. The map picture of the Pstrążna area shows two uplifted blocks separated by normal faults. The first block is constituted by E-W-elongated zone of Carboniferous exposure, the other one by **Kudowa Massif (KM)** in the southeast. The Carboniferous strata, as presented on this map in the central part of the Carboniferous outcrop zone (the area between Svatoňovice and Žacleř), show consistent dip towards the NNE. In 1904 Flegel supplemented the map with a paper. The outcrops of the Carboniferous are referred to there as the "**Hronov-Pstrążna Carboniferous Structural Elevation**" (German: *Karbonscholle von Hronov-Straußenei*), and the fault bounding this Elevation from the north is named the "**Pstrążna Fault**" (German: *Straußenei Sprung*). The north-eastern and south-western faults bounding the **KM** were referred to by Flegel as the "**Duszniki Springs Fault**" and the "**Kudowa Fault**" respectively.

Still in the year of publishing the map, Flegel et al. (1904) met serious criticism. In 1904 Walter Petrascheck published a paper on the geology of the area between Nachod and Žďarky, which contained a 1:50000 map covering the area from Hronov to Pstrążna (**Fig. 5**). This more detailed map of better resolution, as compared to previous ones, brought substantial changes in the area's structural interpretation. What distinguishes this map from previous maps is that the boundaries between the Carboniferous and the Cretaceous formations, except in one place near to in the vicinity of the Pstrążnica Hill, nowhere are along faults. The Pstrążna Fault occupies the central position within the Carboniferous outcrop zone and simultaneously it defines a contact between the Svatoňovice Beds at the northern and the Žacleř Beds at its southern side. The fault which had a substantial importance on the map by Weithofer (1897), has only minor significance on the map by Petrascheck. The mapping work of Petrascheck was crowned with a map at the scale of 1:100000 elaborated together with Ernst Dathe and published in 1913 (**Fig. 5**).

After the World War II the German part of the Sudetes became Polish territory. The Polish Geological Survey launched a project of reambulation of German maps and of re-mapping of most sheets, resulting in the Detailed Geological Map of the Sudetes at the scale of 1:25000. The area of Pstrążna was shown on sheet Jeleniów by J. Gierwielaniec and S. Radwański published by the Polish Geological Institute in 1955 (**Fig. 5**). According to this map, the Pstrążnica Hill (625 m a.s.l.) consists of Cretaceous deposits and across its slope the above mentioned thrust should strike – the Carboniferous sandstones and conglomerates should be thrust over the Cretaceous sandstones. This is either an error in mapping or a mistake in edition, as such a spatial occurrence is impossible. There are numerous examples of incorrect measurements. For example in the western part of the Carboniferous rocks outcrops which outcrop in a forest road is totally different to that marked on the map. Because this place is well exposed and there are many rocks accessible to measurements, one can assume that since 1955 the situation has not significantly changed. Alike puzzling are some measurements of the Cretaceous sandstone bedding, e.g. the one born in the road north of Czartowski Kamień, which is completely inconsistent to that marked on the map. The dip of the sandstones does not exceed 25^{o} in this area.

On the Czech territory, the vicinity of Nachod-Žďarky was imaged by M. Vejlupek in 1990 on the sheet Náchod (Geologická Mapa ČR) at 1:50000 scale (**Fig. 5**). The author scrupulously distinguished all litostratigraphical units. Within the Carboniferous Westphalian B and C (*žacléřské souvrství, petrovické vrství*) and Stephanian B (*odolovské souvrství*) were differentiated. Within the Cretaceous transgressive conglomerates and glauconitic sandstones of the Upper Cenomanian and the Lower Turonian age (*perucko-korycčanské* and *bělohorské souvrství*), as well as mudstones and calcareous sandstones (*jizerské souvrství*) of the Middle Turonian age were distinguished. Few structural facts are worth mentioning. Firstly, the Carboniferous formations are surrounded by the Cretaceous formation. Secondly, the boundaries between the Carboniferous and the Cretaceous almost everywhere are non-tectonic and are of unconformity type. Thirdly, both the Carboniferous and the Cretaceous formations border with the crystalline rock along fault planes. Fourthly, the bedding within the Cretaceous dips towards NNE north of the Carboniferous formations and towards SSW south of them. Fifthly, as indicated by the superposition of the Carboniferous formations and their younging towards NE, these beds are isoclinally dipping in that direction. Most important dislocations are represented by faults striking WNW-ESE, which separate sedimentary formations from crystalline rocks of the **KM** to the south.

SELECTED STRUCTURAL FEATURES IN THE AREA OF PSTRĄŻNA

The phenomena presented below on the map and the cross sections (**Fig. 6**) are imaged on a hypsometric surface made on the basis of high resolution radar images (SRTM 30 m x 30 m). The accepted working contour interval was 2 m (!) and the interval on the hypsometric basis is 10 m. Structural features identified in the field were localized with GPS **Meridian Color Magellan** and than were positioned with an accuracy of 0.001'' and about 1.5 m. Therefore the error of imaging in the area of mapping does not exceed 0.005 %. Regional structural surfaces were constructed with use of **MICRODEM** software elaborated by Prof. Peter Guth from the Oceanography Department (U.S. Naval Academy).

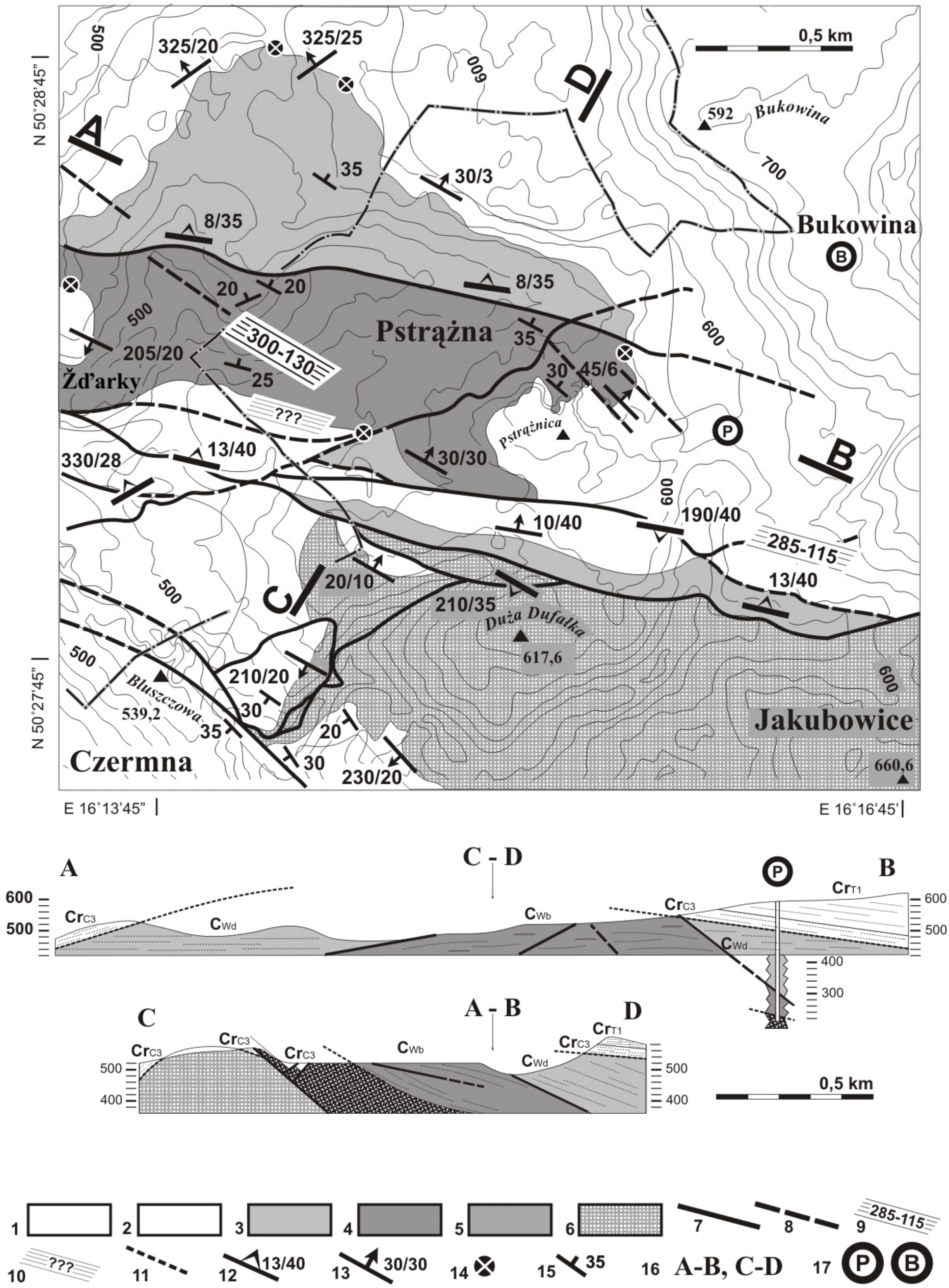

Fig. 6 Simplified geological map of the Pstrążna vicinity.
Explanations: 1 – lower Turonian; 2 – upper Cenomanian; 3 – Svatoňovice Mb. (Stephanian A); 4 – Dolsk-Žďarky Mb. (Westphalian C); 5 – mica schists; 6 – granitoides; 7 – evidenced fault; 8 – presumed fault; 9 – evidenced shear zone; 10 – presumed shear zone; 11 – unconformity; 12 – fault plane orientation; 13 – unconformity plane orientation; 14 – extent boundaries of the unconformity plane of same inclination; 15 – bedding; 16 - A-B and C-D cross-section lines; 17 - the Pstrążna borehole (P) and Bukowina borehole (B) location.

EXPOSURES

In the area of Pstrążna the occurrence of lithological varieties as far evidenced by mapping was confirmed, despite the volcanic rocks (cf. **Fig. 5**). It may be that they are hidden under rock waste from the spoil banks on the southern slope of the Pstrążnik Creek. The outcrops of sedimentary formations were marked on the map (**Fig. 6**) accordingly with the modern lithostratigraphical schemes (see **Figs. 3 and 5**).

All Cretaceous deposits occurring directly in the area of Pstrążna are encountered as the Cenomanian. These are coarse-grained sandstones, locally conglomeratic and calcareous-glauconitic which continuously grade upwards into fine-grained calc-siliceous sandstones, also with glauconite and with significant content of sponge parts (so called spongiolites). In the north of the area (vicinity of Bukowina) and in the east (vicinity of Jakubowice) fine-grained sandstones and calcareous mudstones (heterolithic series) occur, which are encountered to the lower and middle Turonian.

There are no Cretaceous *in situ* exposures directly in the vicinity of Pstrążna. Therefore their occurrence and character of their base surface can be only concluded from intersection. Having the occurrence of low angle thrusts excluded, the Cretaceous overlies unconformably the basement built of Carboniferous rocks. The unconformity surface is radially inclined in all directions at an angle ranging from 20º (in the west and south) to 15º (in the north) and 6º (in the east) relative to the Carboniferous outcrops (**Fig. 6**). Higher inclination (about 20º) this boundary surface depicts under an isolated occurrence of the Cretaceous overlying the Kudowa granite (north of Czermna) and along mica schists outcrops between the Pstrążna and Jakubowice (about 40º), what is confirmed by direct measurements of bedding orientation in existing rock exposures. It is worth mentioning that the isolated Cretaceous outcrop in the western part of the area discovered by Weithofer (1897) and then marked on the map and widely commented by Petrascheck (1904) and Schmidt et al. (1905) results from an intersection effect of the inclination of the unconformity surface between the Carboniferous and the Cretaceous at 20º towards 205º. The Cenomanian deposits border along a fault with mica schists or Carboniferous rocks south of the Pstrążnica Hill, and the Turonian deposits with s or granite south-east of Pstrążna (**Fig. 6**) (cf. Petrascheck, 1904a and b; Schmidt et al., 1904; Gierwielaniec and Radwański, 1955; Gierwielaniec, 1965). The bedding of the Cretaceous deposits consistently dips towards NNE along the latter boundary, however nowhere the dip exceeds 20º (!), what is evidenced in exposures.

The Carboniferous outcrop has a rectangular shape in a plane view with the sides of about 1.5 x 0.8 km. There are numerous natural exposures of Carboniferous rocks in the direct vicinity of Pstrążna as well as mine drifts, some of which possess documented profiles (Weithofer, 1897; Schmidt et al., 1905). Most of the exposures occur at the southern slope of the Pstrążnica hill, but they also occur in roads and streams close to the Polish and Czech state border. Few of the exposures are located on the northern slope of Bukowina Hill and in the Pstrążnik Creek bed.

The Carboniferous deposits are inclined towards the north-west (western part of the outcrop) and towards the north-east (central and eastern parts of the outcrop) at an angle from 15º in the south to about 35º in the north of the area (**Fig. 6**). The boundaries of the outcrop almost everywhere are determined by the unconformity with the Cretaceous (as above). The only exception is represented by the southern border of the outcrop. The Carboniferous borders with mica schists along fault lines SW of the Pstrążnica Hill and with the Cretaceous along the Pstrążnica Creek valley. The southern part of the outcrop is built of Dolsk-Žďarky Mb. (cf. Němejc, 1933 and 1958) belonging to the Žacleř Formation and encountered into the Westphalian B and C. The northern part of the outcrop is built of Svatoňovice Mb. (cf. Němejc, 1933 and 1958) belonging to Glinik (Odolov) Formation (cf. Tàsler et al., 1979) and encountered into the Stephanian A. The Carboniferous outcrops is divided into two parts by almost latitudinal Pstrążna Fault line.

Mica schists occur exclusively in the south of the area, where they border everywhere along faults with the Kudowa granite. Despite the lack of exposures, which might directly document the nature of the contact of the schist with the sedimentary rocks, it can be assumed with high probability that south of Pstrążna these boundaries represent unconformity surface. Indirectly it is indicated by low angles of inclination of this boundaries, determined based on intersection – up to 30º for the contact with the Carboniferous and only 10º for the contact with the Cretaceous (**Fig. 6**). The foliation in the schist is generally concordant with that marked on the map Jeleniów (Gierwielaniec and Radański, 1955), and only the orientation of foliation situated in the diverge of the Czermnica valley and ascribed as bedding (?) is probably an editorial error.

TECTONIC FEATURES

The most important dislocation zone in the vicinity of Pstrążna is represented by the zone separating the Carboniferous and Cretaceous sediments from the crystalline rocks of **KM** the **KT**. So far the zone was usually marked as a single fault. Since the work by Weithofer (1897), the western part of this zone is referred as "**Poříčí-Hronov Fault**" (German: *Parschnitz-Hronower Bruch*). The eastern part of this zone Gierwielaniec (1965) referred as "**Žďarky-Darnków Dislocation**". This zone, which in fact comprises numerous faults, both normal and reverse, of general strike WNW-ESE, extends between Žd'arky in the west and Jakubowice in the east. The biggest extent and most constant direction (13˚/40˚) within this zone has a normal fault, which separates the granitoids of the **KM** from mica schists in the east and the Carboniferous from the Cretaceous rocks in the west of the area (**Fig. 6**). The only evidenced reverse fault (190˚/40˚) which occurs a bit northern and separates the Cretaceous and the Carboniferous from mica schists has a local character (**Fig. 6**). Close to this fault, within the outcrops of the Turonian, SE of Congress Centre in Pstrążna, a 150-m-wide zone of vertical fractures striking 285˚-115˚ occurs (**Fig. 7a**). Judging from the measurements and descriptions in archive works (Petrascheck, 1904a; Schmidt et al., 1905; Gierwielaniec and Radwański, 1955; Gierwielaniec, 1965) the joints occurring in this area were misinterpreted as bedding of the mudstone-sandstone deposits, which in fact dips there towards NE at an angle of 15˚. Moreover, direct kinematic indications on the joint surfaces (slickenlines and microsteps) allow to determine the direction of the displacement in this locality as dextral strike-slip. It is worth to stress that at the continuation of this zone towards the west, numerous blocks of sandstone occur in the soil with distinct slickenlines on slickenside surfaces perpendicular to the bedding planes. Slickenlines are always almost parallel to the bedding. Thus, if they derive directly from the basement, their presence in the fault zone between Žd'arky and Jakubowice, together with the evidence of shearing in the east of the zone, indicate strike-slip character of this fault zone.

The second according to importance and extent fault is the Pstrążna Fault (Petrascheck, 1904a; Flegel, 1904a and b; Schmidt et al., 1905; Gierwielaniec, 1965). Most probably this is a singular surface dipping at 35˚ towards 8˚ (**Fig. 6**). The fault can be cartographically determined as certain only within the Carboniferous outcrops, where it separates deposits of the Glinik and the Žacleř Formations. Its descriptions from a mine drift, provided that they concern consistently the same fault, exclude each other. Weithofer (1897, p. 470) states that "in the shaft, at a depth of about 50 m, the fault dips towards NE" and that "the Carboniferous is thrust over the Cretaceous along this fault towards the south". Radically different situation is presented by Flegel (1904a, p. 151, 1904b p. 139), which on the basis of Axel Schmidt (1904) and "*obersteiger*" Hoffmann direct observations writes - "at a distance of about 250 m from the entrance to the drift the rocks are cut by a fault striking WNW-ESE, along which the Carboniferous deposits are thrust towards NNE over the Cenomanian sandstone". Yet another situation is stated by Petrascheck (1904a) in his critical work on the geology of that region. In his opinion, provided that the location of the fault in the drift made by Weithofer (1897) is correct, therefore it is not the Pstrążna Fault, but completely different one, which he actually marked in the sketch attached to his work (**Fig. 2**, p. 537). Regarding the fault described by Flegel (1904a and b), Petrascheck (1904a, p. 537) also recognized that this can not be the same fault as the Pstrążna Fault as drawn on the map by Schmidt et al. (1904) and that the description does not concern a fault but the unconformity between the Carboniferous and the Cretaceous.

The fault with orientation 330˚/28˚ can be determined as certain only in places where it marks the boundary between the Cretaceous and mica schists and within the Carboniferous outcrops. Taking into account the offset of the Carboniferous and the Cretaceous outcrops along this fault, this is a normal fault with the north-west limb downthrown. As it results from the construction, the fault throw is about 8 m. Obliquely at the same angle relative the Pstrążna Fault and the ŽJFZ but in the opposite direction dip presumable faults striking approximately 310º-130º (**Fig. 6**). Probably to these faults the system of vertical joints (shear cleavage) in the central part of the Carboniferous outcrops is related (40º/80º-90º) (**Fig. 7b**). Presumably faults belonging to this system are also responsible for nearly 100 m offset of the Carboniferous and the Cretaceous boundary (e.g. directly north of Pstrążnica Hill, **Fig. 6**). Because this contact is parallel to the fault, the offset can be only (!) explained by dextral strike-slip horizontal displacement.

BASAL SURFACE OF THE CRETACEOUS SEDIMENTS

Both in the area of **ISS** and within recent outcrops of Cretaceous formations in the area of **KT** facies changes in the Cretaceous result directly from palaeotopography. In the late Cenomanian southern part of the present day **ISS** and **KT** were submerged at initial stage of transgression. The main coastline of that sea correlated with north-eastern part of the synclinorium. At that time, two distinct elevations were present in the south – the present day area of **KM** and connected massifs of Nove Mésto and Orlica. Their occurrence is evidenced by the oldest Cretaceous sediments (area of Czermna, Jakubowice, Lewin Kłodzki and Spalona) – coquinoid conglomerate that consists of typical storm shell debris – or absence of the Upper Cenomanian (Nove Mésto, Olešnice, Zieleniec) (Mostowice and Duszniki map segment). The unification of the palaeogeographical scheme took place in the early Turonian, after all the area under consideration became submerged. Since that time the sediments were supplied to the Intra Sudetic Basin from the north and the architecture of Cretaceous sediments consistently indicates that scheme of regression (Wojewoda, 1986; Jerzykiewicz and Wojewoda, 1986; Rotnicka, 1999 and 2004).

The basal surface of the Cretaceous shown in **Figure 8a** is reconstructed basing on more than 30 boreholes, geophysical data and detailed geological mapping. This surface corresponds only in general

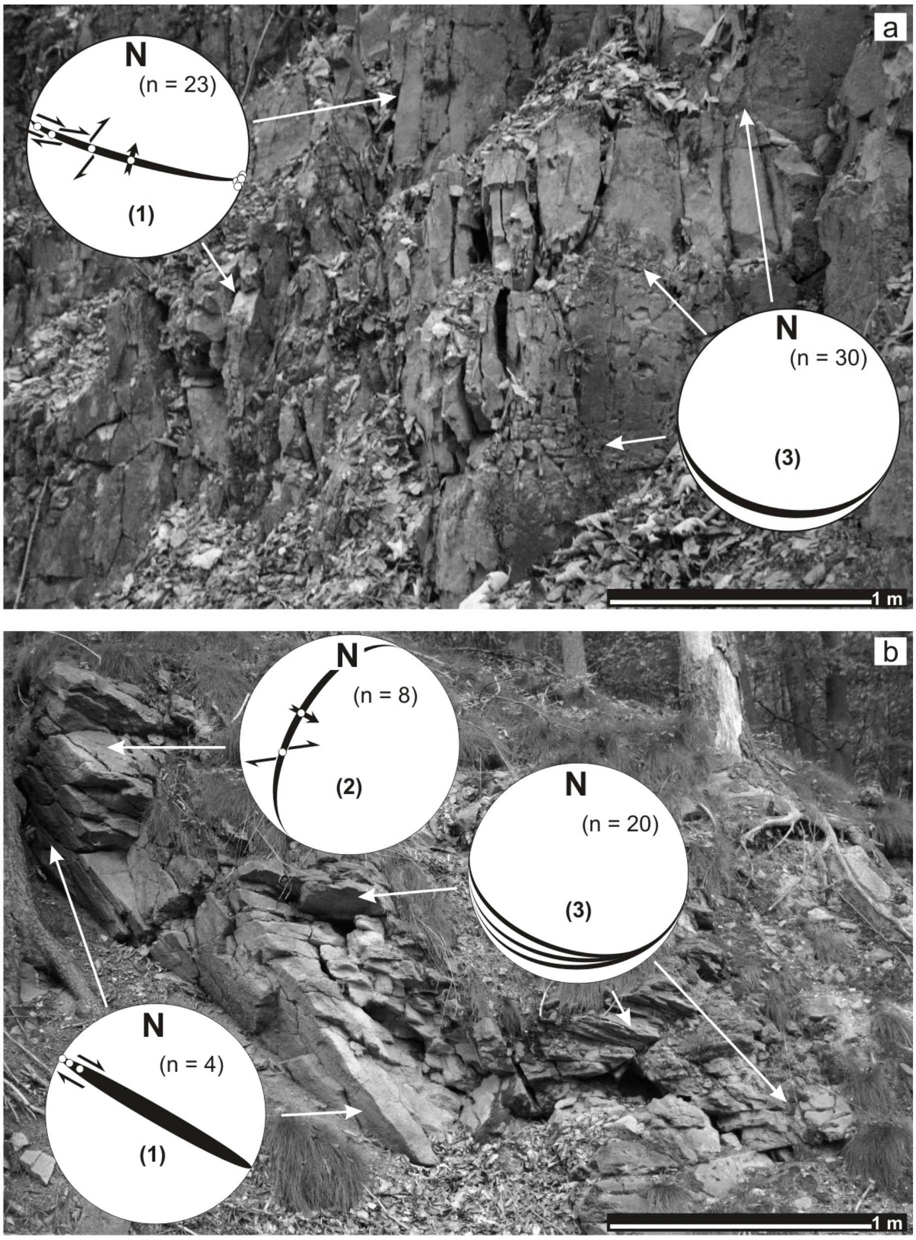

Fig. 7 Cretaceous (a) and Carboniferous (b) rocks outcropping in shear zones with the bedding and cleavage indicated on the diagrams (in parenthesis number of measurement).

scope to the above described scheme of evolution. Some elements of the surface can be regarded as relics of the pre-transgression landscape, as for example a distinct valley that is reflected SE of Pstrążna. The valley narrows southwards, then in continues as modern river valley over the area of **MK**, and then it terminates on the **KT** marginal fault and is not visible further to the south of the reconstructed relief of the base of the Cretaceous in **KT**.

Two distinct areas – **KT** in the south and a prominent elevation trending SW-NE between Jakubowice and Pasterka – do not manifest themselves in facies distribution of the Turonian sediments. Relative height difference equal to more than 500 m and more that 100 m, respectively, and they are surely higher than estimated highest depth of the sea basin in the Turonian. Therefore, the elevation of the basal Cretaceous surface in those regions most probably results from a post-depositional tectonics.

The gravimetric imaging of the area of Pstrążna is very suggestive (**Fig. 8b**). The gravity anomalies after Bouguer reduction equal to -10 to +5 mgl and they show a regular zonal arrangement, being elongated in 283˚-113˚ direction (Cholewicka and Farbisz, 1997). Local lows and highs situated alternately on both sides of a line that correlates

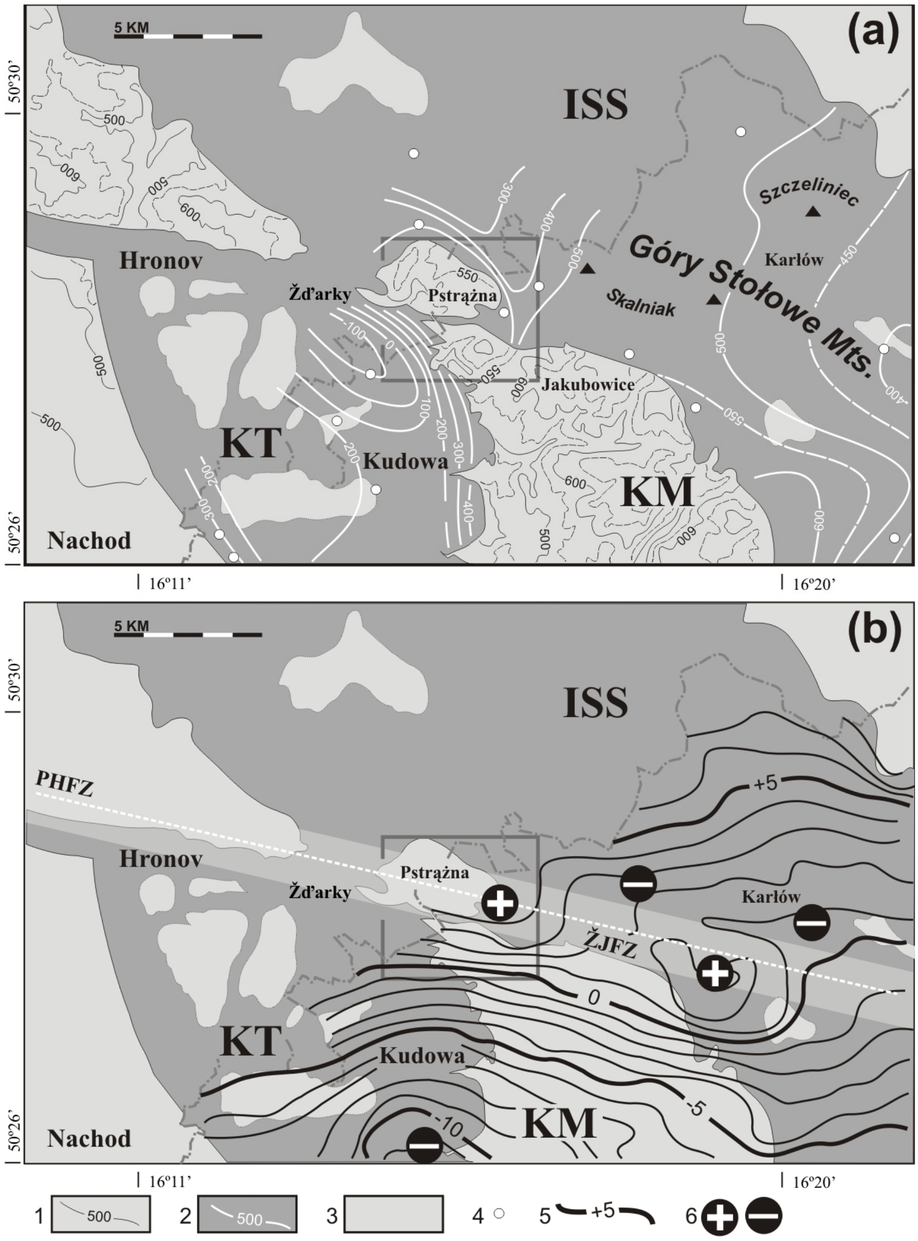

Fig. 8 Simplified image of the Cretaceous basal surface (a) and gravity anomalies after Bouguer reduction (b) of the Pstrążna surrounding area.
Explanations: 1 - 50 m hipsometric contour intervals; 2 - 100 m contour intervals of the Cretaceous basal surface; 3 – Tertiary-to Recent sediments; 4 – boreholes; 5 - 1 mgl intervals of gravity anomalies; 6 - gravimetric anomalies peaks.

with **PHFZ** are sharply outlined (**Fig. 8b**). Such a distribution of gravimetric anomalies can imply for alternate occurrence of elevations and depressions of deeper basement along the **PHFZ**, and certainly indicates that this zone extends over the **GS**, that were considered as relatively stable and tectonically low-active region of the Sudetes.

DISCUSSION AND CONCLUSIONS

The geological structure (**Figs. 6 and 7**) and gravimetric features (**Fig. 8b**) of the area of Pstrążna presented above, can be conceived altogether in a consistent structural model of this region (**Fig. 9**). The model takes into account both the structural features and modern state of knowledge on the age of deposits. This model results from precise spatial location of the phenomena, what was not quite possible so far.

Two distinct structural elevations are distinguishable in the area of Pstrążna – the **Pstrążna Elevation** (**PE**) and the **Kudowa Elevation** (**KE**). They are separated by a dislocation zone consisting of numerous normal or reverse faults. An immanent feature of this zone is structural disintegration and

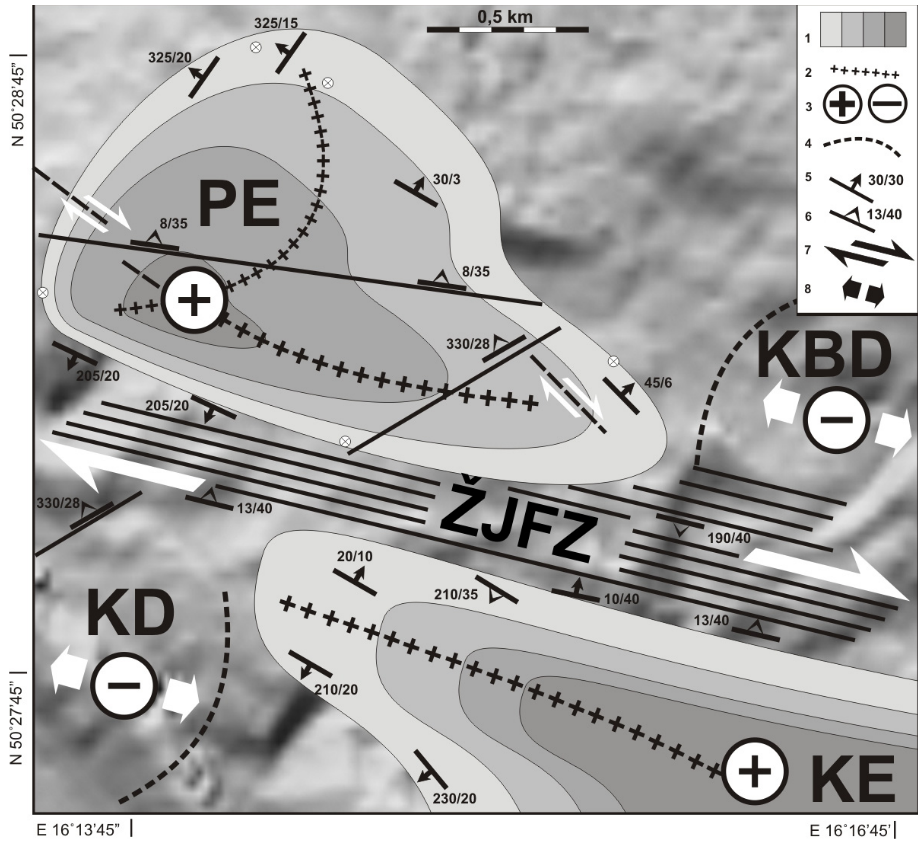

Fig. 9 Structural model of the area of Pstrążna (image at a level of about 600 m a.s.l.).
Explanations: 1 – 25 m contour intervals; 2 – axes of elevations; 3 – central points of the elevations and depressions; 4 – presumable normal listric faults; 5 – unconformities; 6 – fault planes; 7 – presumable direction of strike slip; 8 – presumable extensional zones; **PE** – Pstrążna Elevation; **KE** – Kudowa Elevation; **KBD** – Karłów-Batorów Depression; **KD** – Kudowa Depression; **ŽJFZ –** Žďarky-Jakubowice Fault Zone.

common occurrence of structures indicating dominantly dextral dislocation with significant horizontal component of the movement. The most characteristic phenomenon is shear slaty cleavage, which so far was often misinterpreted as bedding in sedimentary rocks. The **Žďarky-Jakubowice Fault Zone** (**ŽJFZ**) constitutes the eastern extension of the Pořiči-Hronov Fault Zone. On the opposite side relative to **ŽJFZ** the elevations are assisted by tectonic depressions – the **Kudowa Depression** (**KD**) in the west and the **Karłów-Batorów Depression** (**KBD**) in the east.

The **PE** and **KE**, despite distinct differences, depict some structural similarity. Their boundaries neighbouring with **ŽJFZ** are of fault type and steeply inclined, while the opposite boundaries dip more gently and the sedimentary covers form fault-forced folds. Also the shape outline of both elevations relative **ŽJFZ** is similar. This is not decisive about their genetic connection of those three structures but it suggests such a possibility.

Considering the altitude of the basement in the depressions (from about -100 to 50 m a.s.l. respectively), relative vertical amplitude of the displacement along **ŽJFZ** certainly exceeds 600 m. Horizontal displacement along **ŽJFZ** is difficult to assess. While the dextral displacement seems certain, its amplitude is not possible to be determined. Some indication can be obtained from the assessment of the component of the horizontal displacement parallel to **ŽJFZ** on the area of **PE**. Based on the offset of the Carboniferous and the Cretaceous contacts along the faults trending 310º-130º and considering possible fold shortening in the elevation areas, this component can be assessed most certainly as 100 m according to the Carboniferous outcrops.

Structural depressions and elevations are well known and recognized since long in the strike-slip zones (see e.g. Allen and Allen, 1990). Their mutual position results from a general scheme of spatial distribution of deformation relative the main stress axes, which in relation to real basins developed in strike-slip zones, as well as in analogue models, were clearly presented e.g. by Christie-Blick and Biddle (1985), Neugebauer (1995). Experimental modelling leads to generation of elevations and depressions possessing similar shape and position as those described above (**Fig. 9**). It concerns also numerical models (see Gölke et al., 1994), as well as analogue models (Sims et al., 1999). Asymmetry is a typical feature of such elevations – steep, fault boundaries on the strike-slip zone side and isoclinal (oroclinal) outer ones, and a characteristic triangular outline. Typical features of depressions are their elongated outline and oblique orientation of their axis relative the surface of the main strike-slip fault. It is worth stressing that experimental features obtained by finite elements method by Gölke et al. (1994) for a normal-slip fault are identical regarding the shape and outline to the situation observed in the area of Pstrążna shown in **Figure 7** (Gölke et al., 1994, Figs. 3 and 4) and simultaneously they indicate dextral slip along **ŽJFZ**.

Shear zones, manifested by the presence of slaty cleavage typically develop in strike-slip zones and they often develop also in sediments overlying active strike-slip discontinuity in their central, axial part (e.g. Burks and Mosher, 1996; Salvini et al., 1999; Wilkins et al., 2001; Shipon and Cowie, 2001; Flodin and Aydin, 2004). Cleavage surfaces are either vertical and parallel or oblique to the main plane of the slip (strike-slip faults) or oblique to that plane (dip-slip and reverse-slip faults). Whereas cleavage planes in the Carboniferous formation NW of Pstrążna (**Figs. 6 and 7b**) point to strike-slip nature of the shear zone, the shear zone in the Cretaceous formation east of Pstrążna can be linked with a dip-slip fault in the basement (**Figs. 6 and 7a**).

Sediments overlying active strike-slip discontinuities are often faulted and folded, and the strikes of both the faults and fold axes are oblique to the main fault plane, accordingly to the Riedel's shear (1929). Complementary faults in the overlying deposits are usually normal (Neugebauer, 1995; Sims et al., 1999) and only at zones of local transpression they may also have a reverse character Wakabayashi et al., 2004). It is worth stressing that such faults – provided that the interpretations on maps by Gierwielaniec and Radwański (1955) and Cymerman (2004) are untrue – do not occur in the area of Pstrążna. The rocks within the fault zone can also be faulted and folded, however their orientation is parallel to the main fault slip plane. These can be both normal and reverse faults, and the domination of one of the types determines the nature of the zone (Harding, 1985). Co-existence within the **ŽJFZ** of parallel to each other normal faults, which are dominant, and a reverse fault (190˚/40˚, see **Figs. 6 and 9**), are typical of a flower structure, which is regarded as characteristic deformational style for dip-slip fault zones (cf. Naylor et al., 1986). Dextral strike-slip character of **ŽJFZ** is confirmed also by dextral strike-slip faults striking 300-329º (**Fig. 9**) (Wojewoda, 2007c, cf. Abbate et al., 1995; Zhang et al., 1995).

The **PE** as a regional structure was described by Petrascheck (1904a and b) and Flegel (1904a and b). Yet both authors recognize it as a part of a larger, elongated parallel to **ŽJFZ** regional structure, which they refer as the Hronov-Pstrążna Carboniferous Elevation or Horst (German: *Karbonscholle (Längshorst) von Hronov-Straußenei*). The range of it they, however, extend further to the east, up to the furthermost Carboniferous outcrops at the north-eastern border of the **KE**. This concept can not be maintained for several reasons. Firstly, if the Carboniferous formation had constituted elongated, uprised horst, the style of tectonic deformation would have to be at least partly symmetric relative the axis of such a horst. And this is not the case, as the Carboniferous formation constitutes a homocline along the whole south-western boundary of the **ISS**. This means that the tectonic style of the Carboniferous reflects the stage of uprise of the south-western margin of the **ISS**. This uprising had to begun in the Westphalian C and D, as the Žacleř Fm. contain redeposited material of metamorphic rock soils *Krinsdorfer Gneisskonglomerat*, *sensu* Dathe and Petrascheck, 1913; Petrascheck, 1922) and the Hronov Quartz Conglomerate (see Němejc, 1933 and 1958). In the Stephanian and the Autunian the rate of denudation increased, which is indicated by the unconformity surface at the contact with the Westphalian, poorly sorted deposits and distinctly lower accumulation potential of the area (relatively low thickness and numerous erosional surfaces in the deposits of the Svatoňovice Mb.). The denudation had to reach the Kudowa granite massif, as first clasts of this rock occur within these beds. It is worth adding that the uprising of the southern margin of the Intrasudetic Basin was assisted by intense volcanism within the Basin (Awdankiewicz, 1999).

A new palaeotopografic pattern concerns the Saxonian deposits, which unconformably overlie both the Carboniferous formations and the crystalline basement. Deformation of those deposits are of local character and they relate to the zones of local troughs and tectonically formed basins (August and Wojewoda, 2005, Wojewoda, 2006, 2007a and b; Blecha et al., 2008; Burliga et al., 2008; Wojewoda and Burliga, 2008).

In the Late Cenomanian, during and after the transgression, the whole area of the **KE** (and perhaps the whole area of the modern Góry Orlickie Mts. as well), including the Carboniferous and the Permian, constituted a morphological structural elevation – probably the denudation relics of the structural elevation form the time of the Stephanian-Autunian, partly destroyed between the Saxonian and the Early Cretaceous. The presence of such an elevation is evidenced by deposits typical of the surge zone (Michael, 1893) occurring in places which were located 25-50 km away from the that-time shoreline (area of modern Wzgórza Ścinawskie Hills) (see Don and Wojewoda, 2005). An important, although indirect implication on post-Cretaceous morphological inversion derives from the morphology of the basal Cretaceous surface (**Fig. 8a**).

Therefore the name of the Pstrążna Elevation refers first of all to the style of deformation of the Cretaceous formations. And these depict an inclination outwards of the Carboniferous outcrops, forming, thus, a structural dome – brachyanticline (see **Figs. 6 and 9**). This structure had developed in the post-Cretaceous, and its development only slightly modified the older structural pattern of oroclinal setting of the Carboniferous formations (north-western dips of beds in the western part of the Carboniferous outcrops).

It is not clear when exactly the **PE** had developed. It is separated by **ŽJFZ** to the south from the **KT**. The last one is in turn open to the south, where since the Neogene-to-Recent alluvial sediments from the eroded **KM** have accumulated. And although it can not be straightforwardly proved, just the late Tertiary seems to be the period of the tectonic troughs of Kudowa and Žernov (the **Nachod Basin** *sensu* Wojewoda, 2007a and b initial development.

The brachyanticlinal pattern of the Pstrążna dome, due to the lack of cartographical evidence of formerly supposed „thrusts", must meet another explanation than a regional compression. Moreover, the author does not find proofs which could exclude the possibility of complementary and even synchronous development of the **Pstrążna Elevation, Kudowa Elevation, Karłów-Batorów Depression, Kudowa Depression and Žďarky-Jakubowice Fault Zone**. Their mutual arrangement, their outline and subordinary structural features (faults, shear zones) indicate that they all could develop as conjugated structures over a regional strike-slip discontinuity. The features imaged on a structural model (**Fig. 9**), as well as those described above in the paper, allow, in the author's opinion, to assent the **PE** and the **ŽJFZ** as features originated over and within the strike-slip zone, and the tectonic depressions of Kudowa and Karłów-Batorów as two pull-apart basins conjugated with the zone.

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