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NEOTECTONIC STRUCTURES OF THE UPPER SILESIAN REGION, SOUTHERN POLAND

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Abstract

Neotectonic structures of the Upper Silesia that originated during the last 5 Ma (Pliocene and Quaternary) overlap Miocene grabens and horsts of the Carpathian Foredeep. They had been reactivated in Pliocene as an effect of the young Alpine uplift of the Carpathian Foredeep. It is postulated that ice-sheet derived compaction of a thick Miocene deposits was the most significant agent of the development of neotectonic depressions. Glacioisostasy of mobile bedrock structures was presumably also an important component of vertical movements. The amplitude of neotectonic movements is estimated to 40–100 m, basing on DEM map analysis, analysis of sub-Quaternary structural maps, and the Pleistocene cover thickness. The present-day tectonic phenomena are generated by mining-induced seismicity. These are connected with stress relaxation in the deep bedrock thrust zones of the Upper Silesian Coal Basin.

Key words: neotectonic structures, glacioisostatic movements, tectonic fracture zones, induced seismicity, Carpathian Foredeep, Upper Silesian Coal Basin (USCB)

INTRODUCTION

Tectonic structures of the upper Silesian region were the object of numerous publications, presenting diversified ideas. Some authors claimed that the role of Young Alpine–Neogene tectonic movements was insignificant (Jureczka, Kotas 1985) whereas the others tried to prove intensive faulting within marine strata of the Carpathian Foredeep (Alexandrowicz 1964), as well as the presence of analogous phenomena in Quaternary sediments and landforms (Dyjor *et al.* 1978, Kotlicka 1979, 1981, Lewandowski 1995). Some present-day tectonic movements are also observed. These are connected with ongoing mining that generates induced seismicity (Idziak *et al.* 1999, Teper *et al.* 1992, Teper 1998). Diversity of the existing theories is caused in large part by differences in understanding the term "neotectonics" (*vide* Zuchiewicz 2002), and also by incorrect evaluations of the amplitude of neotectonic movements and their relation to that of the older structures of Variscan, Laramide and Miocene age. Most of these problems are attributed to a well-known, widespread phenomenon of recurrence and rejuvenation of tectonic structures (*vide* Ostaficzuk 1995).

METHODS

Analyses of thickness differentiation of Pleistocene deposits and their facies changes against the sub-Quaternary tectonic structures are the main tools in discovering young (younger than Miocene) tectonic phenomena in the Upper Silesia (Lewandowski 1995, Jura, Małolepszy 1999). Satisfactory results can be obtained from geomorphological studies based on the shadowed DEM method (cf. Ostaficzuk, 2003) (Fig. 1) and condensed countourlines method (Fig. 2). Present-day tectonic movements can be studied by precise levelling, SAR interferometry as well as by monitoring of contemporary and historic seismicity of the area (Teper 1998, Perski 1999, 2000).

Nevertheless an analysis of the sub-Quaternary surface in relation to thickness of Quaternary deposits and their facies changes remains the most unbiased criterion for estimating neotectonic subsidence, especially in the area of the Carpathian Foredeep. The sub-Quaternary surface is of erosional-depositional type, upon which however, some tectonic elements can be traced, for instance, isolated depressions situated in the zones of Neogene grabens (Figs. 3, 4).

The origin of neotectonic depressions is presumably connected with postdepositional compaction of sandy-silty Miocene strata, the thickness of which attains 300–500 m in the graben zones. The above-mentioned compaction could have been induced by ice-sheet loading, especially during the South-Polish Glaciations. The rate of compaction in Western Carpathians is estimated at 50–100 m (Oszczypko *et al.* 1993), whereas the analogous estimation for the Carpathian Foredeep is at least 20–30 m. Longitudinal profiles of solid bedrock within fossil valleys, like pre-Odra (Lewandowski 1988) and pre-Vistula (Lewandowski 2003), can also serve as a basis for subsidence assessment. The rate of Pliocene–Quaternary subsidence of the Racibórz-Oświęcim Basin is *ca.* 60–80 m (cf. Rączkowki *et al.* 1985).

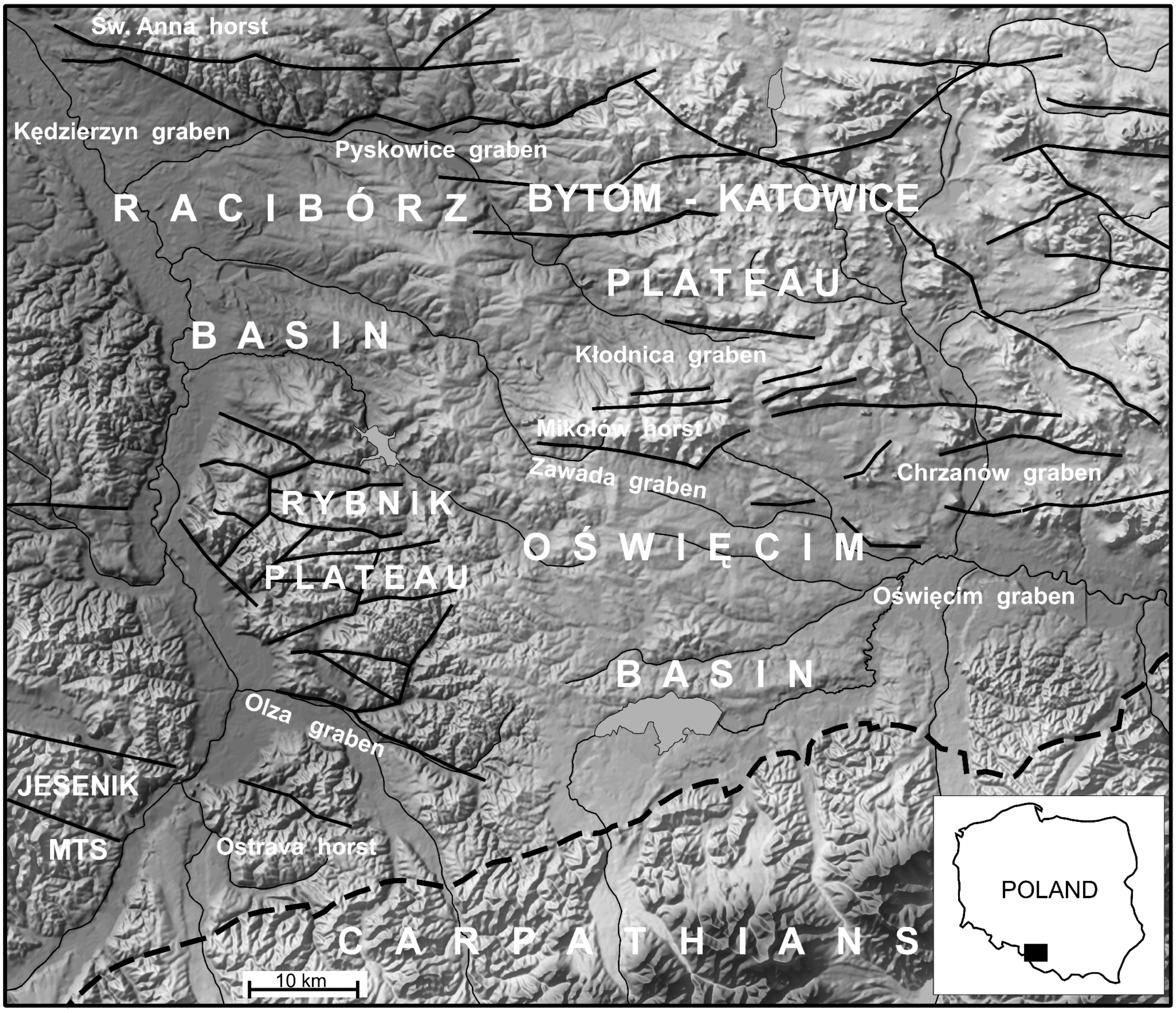

Fig. 1. Digital elevation model (DEM) of the Upper Silesian region with the main Miocene faults rejuvenated during Quaternary and Carpathian margin thrust.

MAIN NEOTECTONIC STRUCTURES

The Upper Silesia region is placed within two main structural units of the Alpine complex: the western part of the Carpathian Foredeep in the south and the Silesian-Cracow Monocline in the north. The Alpine units partly overlie the older Variscan structures: the centrally located Upper Silesian Coal Basin bordered by the Bohemian Massif in the south-west and Małopolska Massif in the north-east, together with the so-called Cracow Fold Zone (Bukowy 1974). The main fracture zone between the Silesian Coal Basin and Małopolska Massif is a sinistral strike-slip fault, an element of the Teisseyre-Tornqvist Zone (Żaba 1995).

In the interior as well as on peripheries of the Carpathian Foredeep, the W–E oriented grabens of Neogene age, rejuvenated in Quaternary, are common (Fig. 5). The Kędzierzyn, Pyskowice, Kłodnica, Zawada, Szeroka and Oświęcim grabens are the biggest (Kleczkowski *et al.* 1972, Dyjor 1987, Lewandowski 1995, 2000). Sedimentary infills of these grabens are frequently thicker than 100 m, whereas average thickness of the Pleistocene cover reaches 30–40 m in the Racibórz-Oświęcim Basin. The Kłodnica Graben in the Upper Silesian Coal Basin is one of the best-recognised neotectonic structures of this type, with nearly complete Pleistocene–Holocene sedimentary succession (Fig. 4) thicker than 100 m (Lewandowski 2000). Since the Early Pleistocene the above-mentioned grabens have served as valleys of the pre-Odra River drainage basin. West from the Cracow Upland, the Carpathian Foredeep and the Silesian and Żywiec Beskid Mts. were drained towards NW during the Pliocene and Early Pleistocene (Klimek 1972, Lewandowski 1993). The thickness of alluvial deposits within grabens is often greater than 60–80 m, whereas in the gorge-like zones the same deposits are nearly two-times thinner (Fig. 3).

The Św. Anna Mt., Mikołów, Rydułtowy, Jastrzębie and other horsts (see Fig. 5) accompany the above mentioned

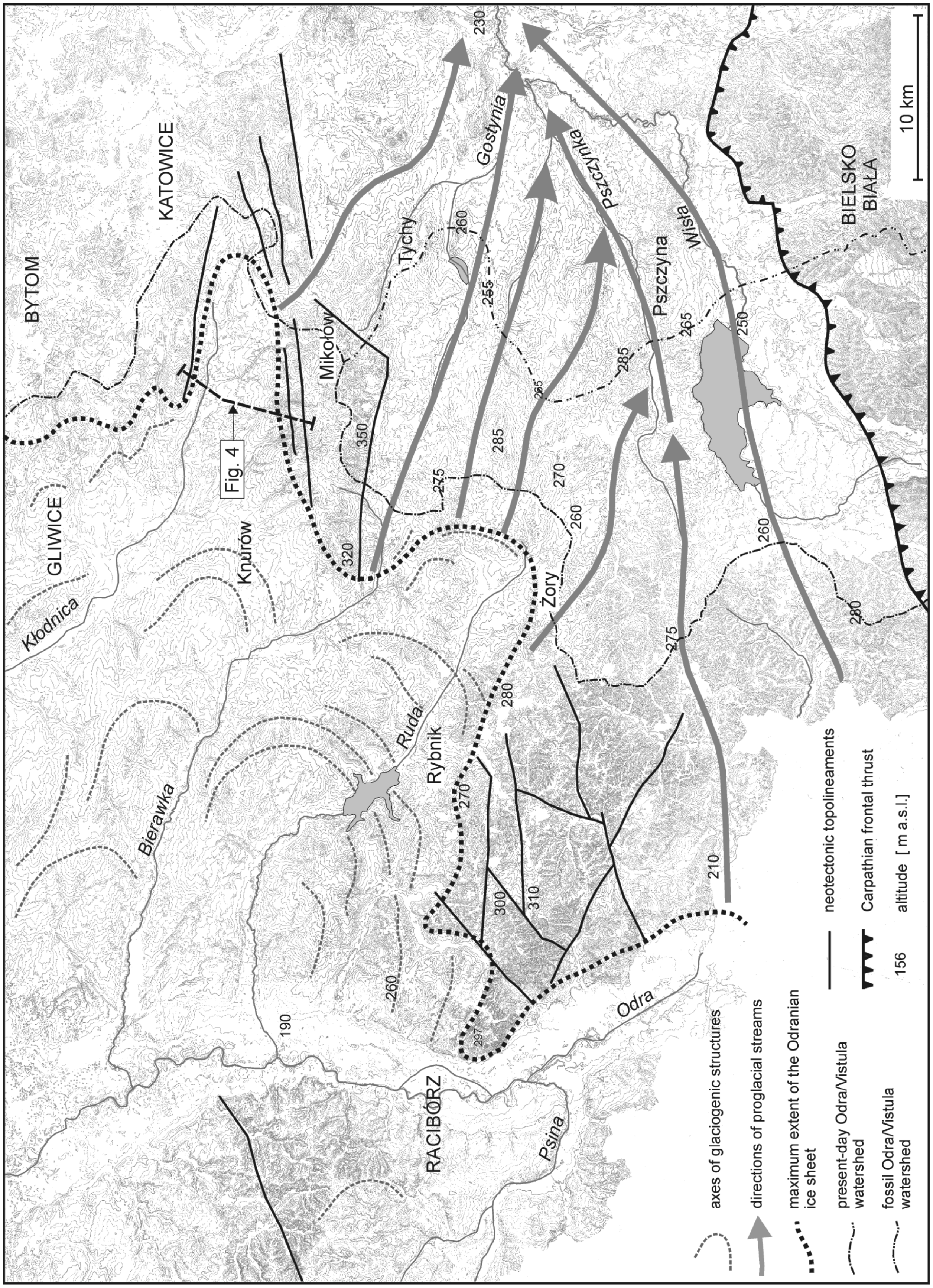

Fig. 2. Present-day Upper Silesian topography analysed by condensed countourlines method.

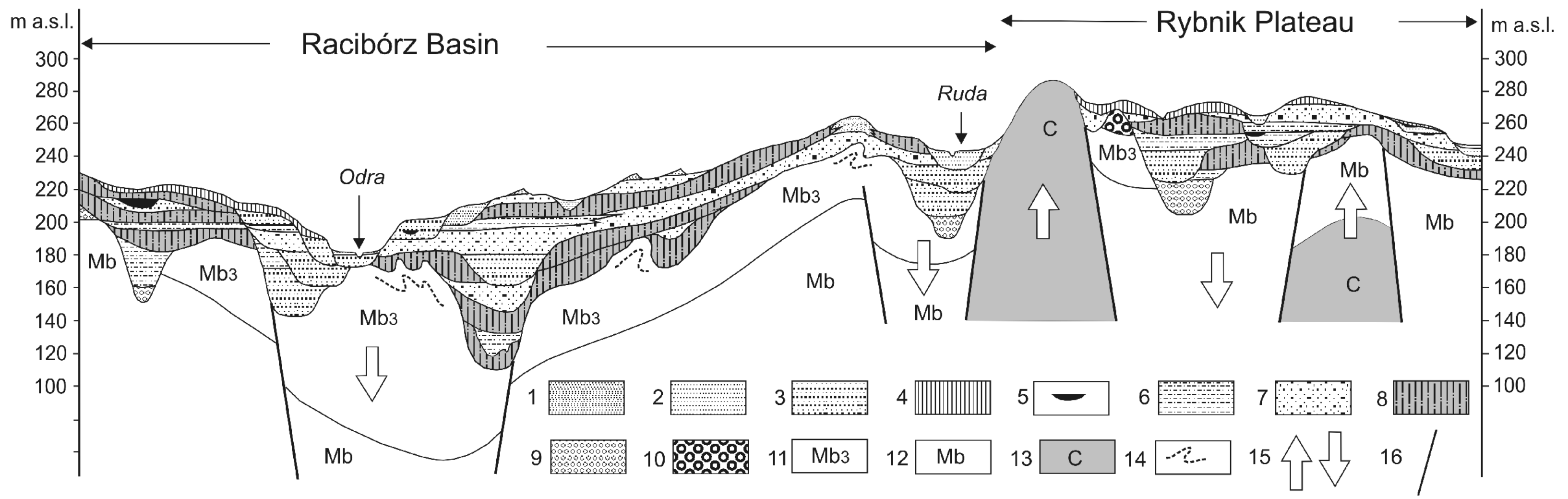

Fig. 3. Synthetic geological cross-section of the Racibórz-Oświęcim Basin and Rybnik Plateau. *1* – aeolian sands, *2* – alluvial sands, *3* – alluvial sands and gravels, *4* – loess, *5* – peat, *6* – glaciolacustrine silts and clays, *7* – glaciofluvial sands and gravels, *8* – tills, *9* – preglacial sands and gravels (Eopleistocene), *10* – Pliocene (Upper Miocene?) proluvial gravels and sands (Sośnicowice Formation), *11* – Upper Miocene clays and sands (Kędzierzyn beds), *12* – Badenian clays (mainly Gliwice beds), *13* – Carboniferous rocks, *14* – glaciotectonic deformations, *15* –neotectonic uplift and subsidence, *16* – faults.

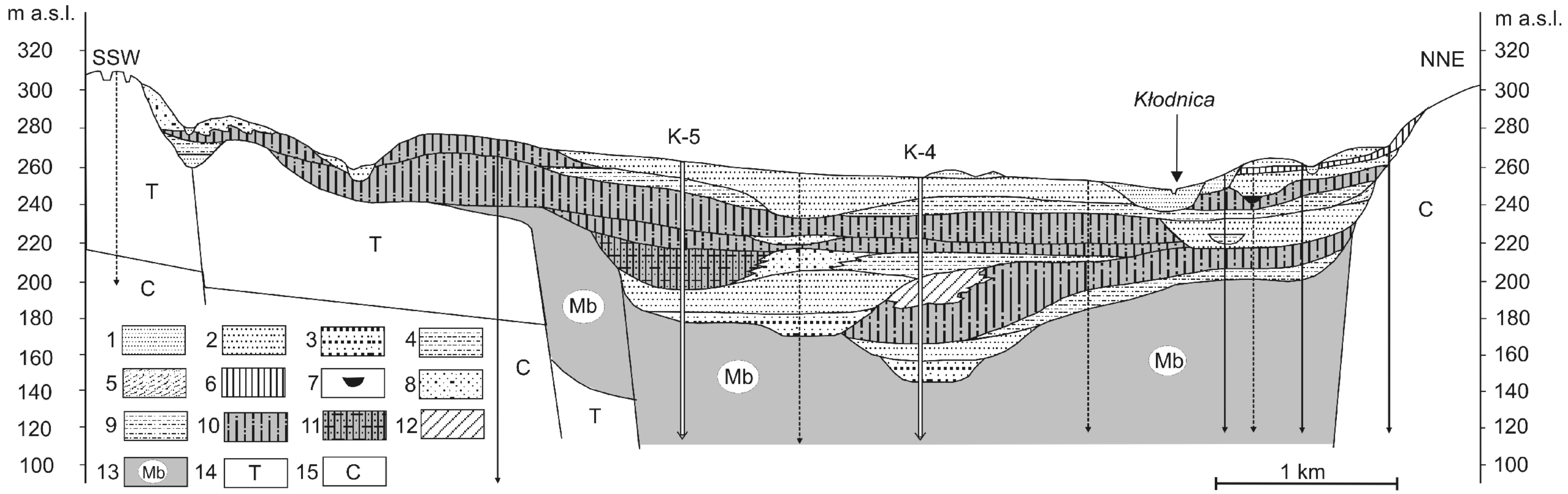

Fig. 4. Geological cross-section trough the Kłodnica Graben Quaternary infill. *1* – aeolian sands, *2* – alluvial sands, *3* – alluvial sands and gravels, *4* – alluvial sands with silt intercalations, *5* – silty, loess-like till, *6* – loess, *7* – peat, *8* – glaciofluvial sands and gravels, *9* – glaciolacustrine silts and clays, *10* – silty tills, *11* – clayey tills, *12* – glacial xenoliths of Miocene deposits *13* – Miocene (Badenian) siltstones and claystones, *14* – Triassic rocks, *15* – Carboniferous rocks.

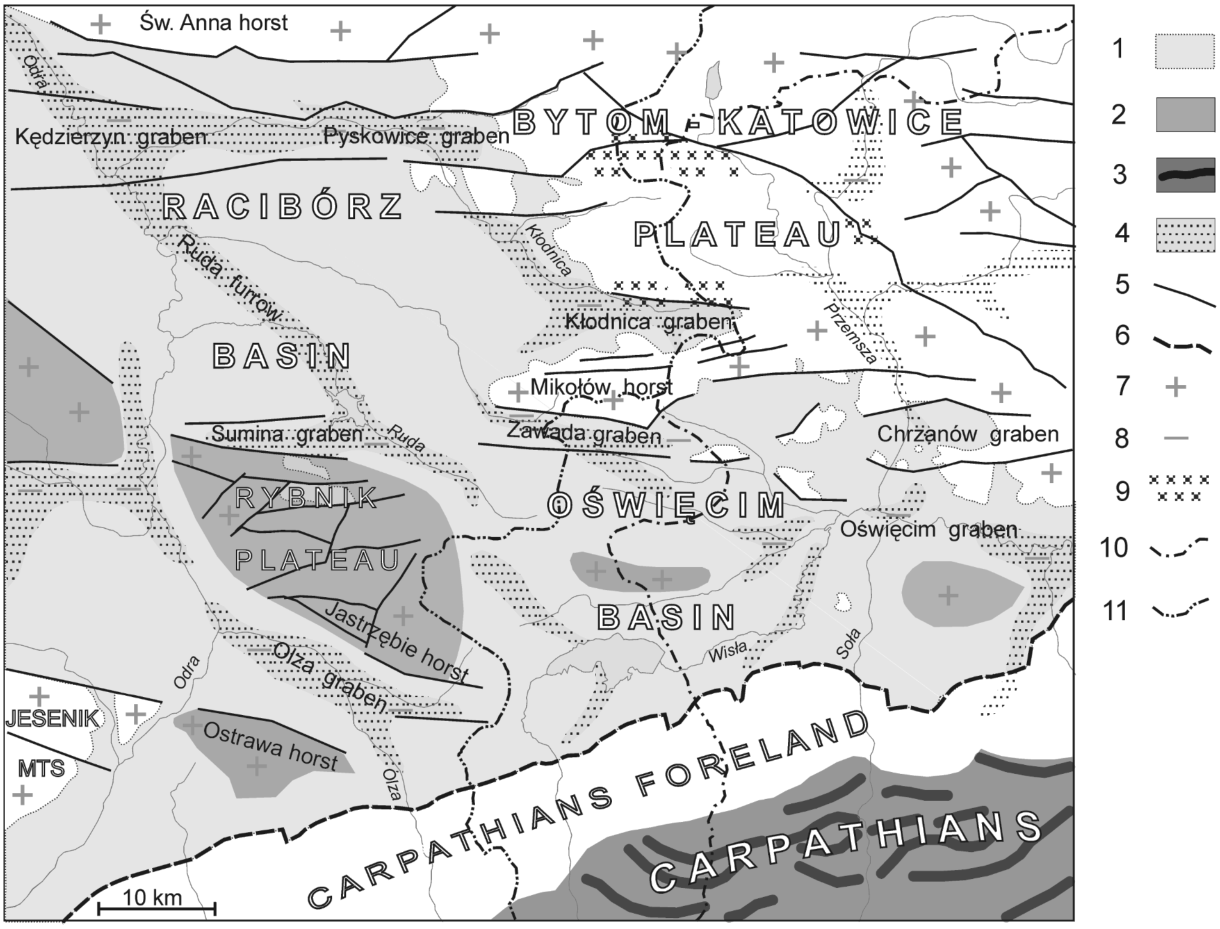

Fig. 5. Neotectonic sketch of the southern part of the Upper Silesia region and surroundings: *1* – Miocene marine strata of the Carpathian Foredeep, *2* – neotectonically uplifted main ridges of the Carpathian Foredeep, *3* – Carpathians and their principal ridges, *4* – Pleistocene cover thicker than 60–120 m, *5* – the main Neogene faults rejuvenated in Pleistocene, *6* – Carpathian frontal thrust, *7* – neotectonically uplifted areas, *8* – neotectonically lowered areas, *9* – areas with seismic activity, *10* – fossil Odra/Vistula watershed of Middle Pleistocene age, *11* – present-day Odra/Vistula watershed.

grabens. The Quaternary cover upon these horsts is completely reduced. Their morphogenesis of these structures is usually linked with development of the Carpathian Foredeep or with geomorphic evolution of the Tethys coastal block-mountains during the Laramide polyphase, modified by young-Alpine orogenic phases (Jura 2001). Nevertheless the present-day erosional topography is characterised by evident tectonic scarps. These faults were presumably rejuvenated by glacioisostatic movements during the Quaternary (Liszkowski 1982, 1993), as suggested by reduced thickness of glacial sediments upon horsts (Fig 2; Lewandowski 1995, 2003). The amplitude of Pliocene–Quaternary uplift in the Upper Silesia region is estimated at 30–40 m, thus the total maximum difference between the positive and negative movements must have attained 100–120 m.

The results of neotectonic uplift are especially well expressed in the Cracow-Wieluń Upland, which is located to the east of the Upper Silesia region, in its closest neighbourhood. These are indicated by the Neogene and Pleistocene karst-derived deposits as well as caves noted at different geomorphic levels (Gradziński 1962, Madeyska 1977, Głazek, Szynkiewicz 1978, Lewandowski, Ciesielczuk 1996). This conclusion is supported by contemporaneous and fossil topography of Late Jurassic limestones (Tomalkiewicz 1975, Szubert 1993, 1998, Nowak 1993). The late Pleistocene rejuvenation of Krzeszowice Graben scarps was favoured by the fact that relatively young (Vistulian) slope covers are present there, whereas deposits of older glaciations are lacking (Pawelec 2005). The Cracow-Wieluń Upland underwent step-like uplift during the Neogene and Quaternary, the scale of uplift increasing in southwards, and reaching a maximum value at least 150 m in vicinity of Cracow (cf. Zuchiewicz, 2000).

YOUNG ALPINE TECTONIC PHASES

It is well known that grabens and horsts were formed along a second-order crustal fault during the post-Variscan tectonic phases. Unlike Variscan structures, the young Alpine faults are oriented W–E (Bukowy 1974, Kotas 1985, Jura 1995). Most opinions assume that thrust tectonics of the Silesian-Cracow region was connected with pre-Badenian movements. The younger Alpine phases were most probably of secondary character and marginal influence on the origin of tectonic structures (Dżułyński 1953, Bogacz 1967, Radwański 1968, Bukowy 1974). Such features like: erosional character of the sub-Miocene surface and lack of faults in Miocene strata (Jura 1992, 2001) are especially suggestive for such an interpretation. Aleksandrowicz (1964) expressed a different opinion, maintaining that tectonic movements took place simultaneously with the Miocene deposition. This interpretation is proved by preservation of deposits of the same age at different levels, and by the presence of Badenian fault breccias. The Late Miocene – Sarmatian age of block tectonics in the "Cracow Bolt" was suggested by Gradziński (1962) and Rutkowski (1986, 1989). Poly-cyclic development of morphotectonic structures of sub-Miocene surface in the Upper Silesian Coal Basin was suggested by Jura (2001). In his opinion the Tethys coastal block-mountains, 500–1000 m high, were formed close to the ocean shore during block-like movements of the Laramide polyphase. These were subsequently modified during several tectonic stages, and followed by molasse sedimentation in the Middle Miocene. In the final stage ("Styrian" and "Moldavian" phases), a system of step faults was formed on the sub-Miocene surface (Jura 2001).

A much younger age of the development of the sub-Miocene surface was inferred by Lewandowski (1993, 1996). An analysis of the structural pattern of the Carpathian Foredeep (Ney *et al.* 1974, Połtowicz 1993) and Meta-Carpathian Swell suggests that differences in levels of Late Paleogene peneplane, from several hundred metres to at least 1000 m, is definitely of tectonic origin (Lewandowski 1993). The main phase of block tectonics on the foreland of folding Carpathians resulted in subsidence of the Carpathian Foredeep and coeval compensational uplift of distal Meta-Carpathian Swell (Oszczypko, Tomaś 1985, Bajgier 1998). These movements took place during the Styrian, Moldavian and Attican "phases" of Middle and Late Miocene age. Secondary movements of much smaller scale had amplitude up to a few tens of meters, and took place in Pliocene (the "Rhone", and "Vallachian" phases). This statement is supported by the results of neotectonic studies in the Western Carpathians (Zuchiewicz, 1998), Sudetes and the Sudetic Foreland (Oberc, Dyjor 1968; Badura, Przybylski 1995a, 1995b, 2000).

PRESENT-DAY TECTONIC MOVEMENTS

Extensive research has recently been carried out into mining-controlled seismic phenomena, *i.e.* "induced seismicity" (Czarniecka 1988, Idziak *et al.* 1999, Teper 1998, Teper *et al.* 1992). According to Jureczek and Kotas (1985) the Upper Silesian Coal Basin (USCB) embraces five seismic sub-regions: the Bytom Syncline, Main Anticline, the Kazimierz Syncline, central part of the Main Syncline, and the surrounding of Rybnik. In the Teper's (1998) opinion the present-day seismicity can be governed by tectonic stress in the zones of large active dislocations (Kłodnica Fault). Teper claims (1998) that the source of this stress is derived either from the Carpathian orogen pressure or active fractures in Carboniferous bedrock. One of such fractures is traced along the 50°N latitude (Kutina 1974). Rejuvenation of faults is usually connected with mining-derived strain of rock mass. Epicentres of seismic shocks are dispersed irregularly over the Upper Silesian Coal Basin (Fig. 5); therefore some Upper Silesian regions are geodynamically unstable. This conclusion results from structural and fractal analyses of fault network pointing to the presence of seismogenic structures in northern part of the Upper Silesian Coal Basin (Teper 1998). These are two thrusts located between the Bytom and Central blocks, *i.e.* the Kłodnica Fault and the axial zone of the Bytom Syncline.

Apart from vertical movements some horizontal neotectonic movements are also presumed in the USCB. The N–S compression and NE–SW simple shear causing sinistral rotation in the present-day stress-field (Jura 1995, 2001) are interpreted from the results of morphometric analysis of the sub-Quaternary surface of the Carpathian Foredeep, together with its relationship to young Alpine tectonic structures. The source of this phenomenon originates from eastward shift of the Western Carpathians in relation to the Carpathian Foredeep. This movement is indicated by the presence of asymmetric depression of the pull-apart type. Jura (1995, 2001) claims that 50 m of subsidence is a result of compensation of isostatic displacements in the contact zone between the Carpathians and marginal grabens.

Subsidence is ubiquitous in the Upper Silesian region, where extensive coal mining started about two centuries ago. The largest subsidence troughs, 20–30 m deep, are noted in surrounding of Bytom, Knurów and Rybnik. The scale of these movements is estimated by precise levelling (Kowalczyk 1969), and SAR interferometer (Perski 1999, 2000). Mining-derived subsidence, together with other anthropogenic land changes, is a good measure of present-day vertical movements of the Upper Silesian Coal Basin compared to the other areas of Poland (Wyrzykowski 1985, 1990).

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