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DISCORDANCES OF THE TOP SURFACE OF CARBONIFEROUS DEPOSITS OF THE UPPER SILESIAN COAL BASIN

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Abstract: Geological boundaries of the structural stages between Late Variscan Moravian–Silesian–Cracow orogene and Saalian Sławków Graben taphrogene, Early and Late Kimmerian epeirogene, Middle Alpine Silesian–Cracow Monocline, and Late Alpine Carpathian Foredeep are defined as discordances. These structural surfaces of different age, present in the top surface of Carboniferous deposits of the Upper Silesian Coal Basin, were investigated in morphotectonic research. Discordances in the morphotectonical record separate older faulted and folded Carboniferous deposits from younger, nearly subhorizontal rocks of epi-Variscan cover. This polychronic and polygenetic geological heterochronous boundary of the top surface of Carboniferous deposit consists of the following coeval discordances: sub-Permian, sub-Triassic, sub-Jurassic, sub-Cretaceous, sub-Miocene and sub-Quaternary. Those buried erosional surfaces with ancient landforms were some formed by terrestrial, others by marine planation. The repeated erosion of Carboniferous deposits and sedimentation of covers as well as fault, monocline and fold-flexure deformations are reflected in differentiated configuration of discordances in the height range from about 400 m a.s.l. to 6000 m b.s.l.

Key words: morphotectonic of discordances, Carboniferous to Quaternary events.

INTRODUCTION

The Upper Silesian Coal Basin (USCB) structural investigations from hundreds outcrops in underground mines, 30,000 boreholes, and numerous seismic profiles gave detailed data for the construction of the subsurface map of the Carboniferous deposits top surface. This map is one of the primary tools used to morphotectonic studies of discordant boundaries between geological units such as structural stages. The term "morphotectonic", from a geological viewpoint, refers to morphostructures of the discordance and to processes that are associated with the erosional evolution of landform, and the deformation, such as faulting and tilting, folding and thrusting, subsidence and uplift. Another, geomorphological view of structural surfaces, angular unconformities, palaeosurfaces, bottom and top erosional boundaries between geological units is defined as the study of landform developed on the basement of active structures produced by tectonic processes, and reworked or destroyed landform during transgression and initial sedimentary burial (Widdowson, 1997). On the other hand, tectonic of discordance is concerned with the deformation during subsidence and orogenese or epeirogenese.

Morphology and tectonic studies of heterochronous discordance in the top surface of Carboniferous deposits are important for recognition of the extent of coal seam outcrops at monochronous palaeosurface of erosion at the bottom of sedimentary covers of different age. The Permian to Pleistocene strata of the USCB are represented by terrestrial and marine variety facies, which reflects the evolution of the erosional and depositional system of discordances. The top surface of Carboniferous deposits have been morfostructure with denivelation up to 1500 m, and composed of tectonic structures with amplitude up to 2000 m (Fig. 1). The USCB contains the main Late Variscan discordance: the sub-Permian surface, and post-Variscan: the sub-Triassic surface. During the Mesozoic time, at the margin of Mid-Polish and Tethys basins, two disconformities evaluated: the sub-Jurassic and sub-Cretaceous. The sub-Miocene surface of Carboniferous deposits represents boundary between the Mid-European Platform and the Carpathian Foredeep, and the Carpathian orogene. The youngest discordance of Carboniferous deposits developed as the effect of the glaciations during the Pleistocene

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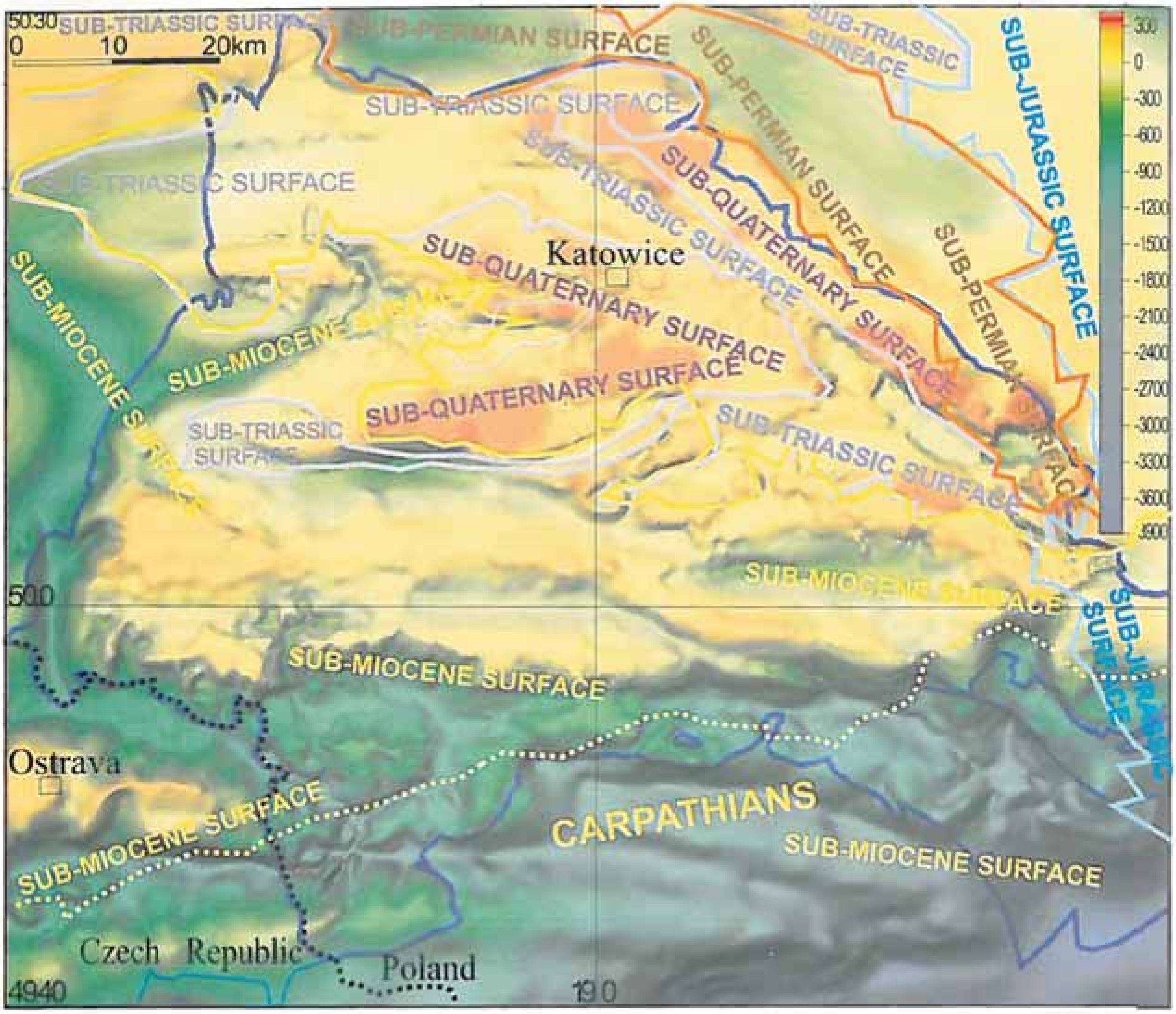

Fig. 1. Shaded relief map on the top surface of Carboniferous in the USCB and distribution of following discordances: under — the Rotliegend molasse, the Triassic and Jurassic covers, and the Miocene of the Carpathian Foredeepand Quaternary sediments. Map is computerized by Z. Małolepszy and simplified

time. These six discordances, representing principal events and corresponding morphotectonical cycles, are recognised throughout the Upper Silesian region and can be applied to regional correlation of the Variscan orogene, epi-Variscan Middle European Platform and the Carpathian foreland (Jura, 2000, 2001).

TOP SURFACE OF CARBONIFEROUS DEPOSITS — LATE VARISCAN DISCORDANCE

Upper Carboniferous coal-bearing deposits and underlying Dinantian and Culm sediments are covered in a mosaic pattern by Rotliegend rocks of the Sławków Graben, Triassic, Jurassic and Cretaceous sediments of the Silesian–Cracow Monocline, and Miocene molasse of the Carpathian Foredeep. Quaternary deposits fill the Late Pliocene river valleys and basins. The southern part of the USCB is plunged, due to the overthrust of the Carpathian nappes, in the internal foredeep, under Beskid Mountains at the depth of about 5–6 km (Figs. 1 and 2).

The lithological structure of the Carboniferous top surface of the USCB is built of Culm silicoclastic sediments, Dinantian carbonate rocks and Silesian coal-bearing deposits. Petrographic, lithologic and sedimentologic features of these strata and series as well as their thickness are much differentiated (Kotas, 1995). The Carboniferous rocks show different resistance to weathering and erosion. The coal-bearing thick-bedded siltstone and sandstone series are important structural elements of discordance configuration and also, at present of the Silesian Upland landscape (Jura, 1988, 1992, 1995). Much of the geomorphic diversity of angular unconformities is due to structural control of folded and faulted sedimentary rocks but extensive tilted and folded strata provide more complex structural controls of erosion.

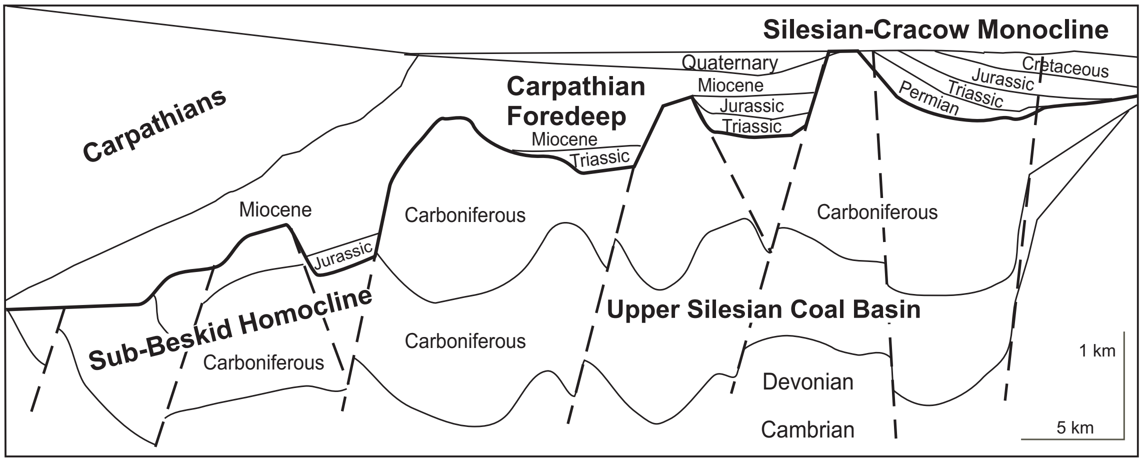

Fig. 2. Generalized stratigraphical profile of bounding heterochronous discordance of the top surface of the Carboniferous deposits, represented by: sub-Permian (10 Ma — erosional hiatus and 5 Ma — non-depositional hiatus), sub-Triassic (15 Ma — erosional hiatus and 5 Ma — non-depositional hiatus), sub-Jurassic (25 Ma — erosional hiatus and 40 Ma — non-depositional hiatus), sub-Cretaceous (45 Ma — erosional hiatus and 15 Ma — non-depositional hiatus), sub-Miocene (45 Ma hiatus and 5 Ma — non-depositional hiatus) and sub-Quaternary (5 Ma hiatus and 2 Ma — non-depositional hiatus) surfaces

The tectonic structure of the USCB includes the orogenic stage of the Upper Silesian Depression, taphrogenic stage of Permian Sławków Graben, cover stage of Middle Polish epeirogen, and molasse-overthrusting stage of the Carpathians. The Mesozoic cover of the epi-Variscan Platform and Miocene molasse of the Carpathian Foredeep are separated from each other by discordance surfaces and divided into structural stages and substages. The structure of the Upper Silesian basin consists of the edges of fold-intrusive zones of the Moravosilesian and Cracow stages, and Upper Silesian Massif in the south (Jura, 2001). Towards the centre they change into broad synclines (troughs) and anticlines (saddles), and domes (Kotas, 1985; Jura, Trzepierczyński, 1997). In the inversion tectonics of the USCB, the older structures of a bow-like almost W–E course are represented by medium folds and lateral flexures in the northern zone, and main anticline and brachysyncline, and secondary southern folds. Longitudinal folds with the E vergence turn towards the SW in the western part of the USCB and towards the SE in the eastern part (Geological Atlas, 1994). The younger folds occur in the imposed transversal position and their course is close to N–E in the lateral western and eastern parts of the Upper Silesian Depression. The folds are accompanied by longitudinal and transverse faults. The youngest set of faults of the NNW–SSE course and partially also southern step faults are located along the Permian Sławków Graben.

At the top surface of Carboniferous deposits of the USCB, the zone of mottled weathering occurs (Dopita, *et al*., 1997). Changes of colour (from grey to mottled) reach 15 m or even 100 m in the alteration zones of oxidation and combustion of coal beds. The buried rocks of mottled weathering are deeply eroded by terrestrial, other marine planation, and locally preserved by saprolite and regolith, and by hard duricrust of palaeosols, protecting the underlying altered Carboniferous deposits from erosion. Palaeoweathered mantle represents correlation horizon of coeval discordances, and they give many genetic premises to interpret morphology of discordances and classification of form (Liszkowski, 1996). Deep profiles of great weathering were formed during Stefanian, Permian and Early Triassic. The Late Triassic, Liassic and Early Cretaceous were periods of stripping of the saprolite and regolith products. In the Paleogene, landscape-etching processes was developed (Fig. 3).

SUB-PERMIAN DISCORDANCE

The sub-Permian surface occurs in the northern and eastern parts of the USCB (Fig. 1), in the floor of Rotliegend volcano-clastic rocks of Sławków Graben. In the Asturian and Uralian phases, the morphostructure of discordances started from folding and uplift of Upper Silesia mountain ranges, including the Moravosilesian belt from the west, and Cracow fold-intrusive belt from the northeast. Their denivelations reached 2000–3000 m. According to the structure of Carboniferous sediments, in the Upper Silesian Depression developed the high-relief desert of the tectonically active inner-mountain basin, i.e. taphrogenic Sławków Graben. In the conditions of warm and dry climate, weathered mantles with carbonate (calcrete) and ferruginous (ferricrete) duricrusts developed (Fig. 3). They were underlined by weathering zone of a thickness up to 30 m and locally up to 100 m.

A consequent system of deep synclinal V-shaped valleys cut across tectonic junctions and anticlinal ridges in places of poor resistance. At the foot of Dębnik–Siewierz ridge or Cracow fold-intrusion range, pre-eruptive carbonate gravel series on piedmont cone with rock falls and olistholits of Myślachowice Conglomerate Formation developed (Jura, Trzepierczyński, 1997). Its thickness was about 200 m. In Rotliegend,

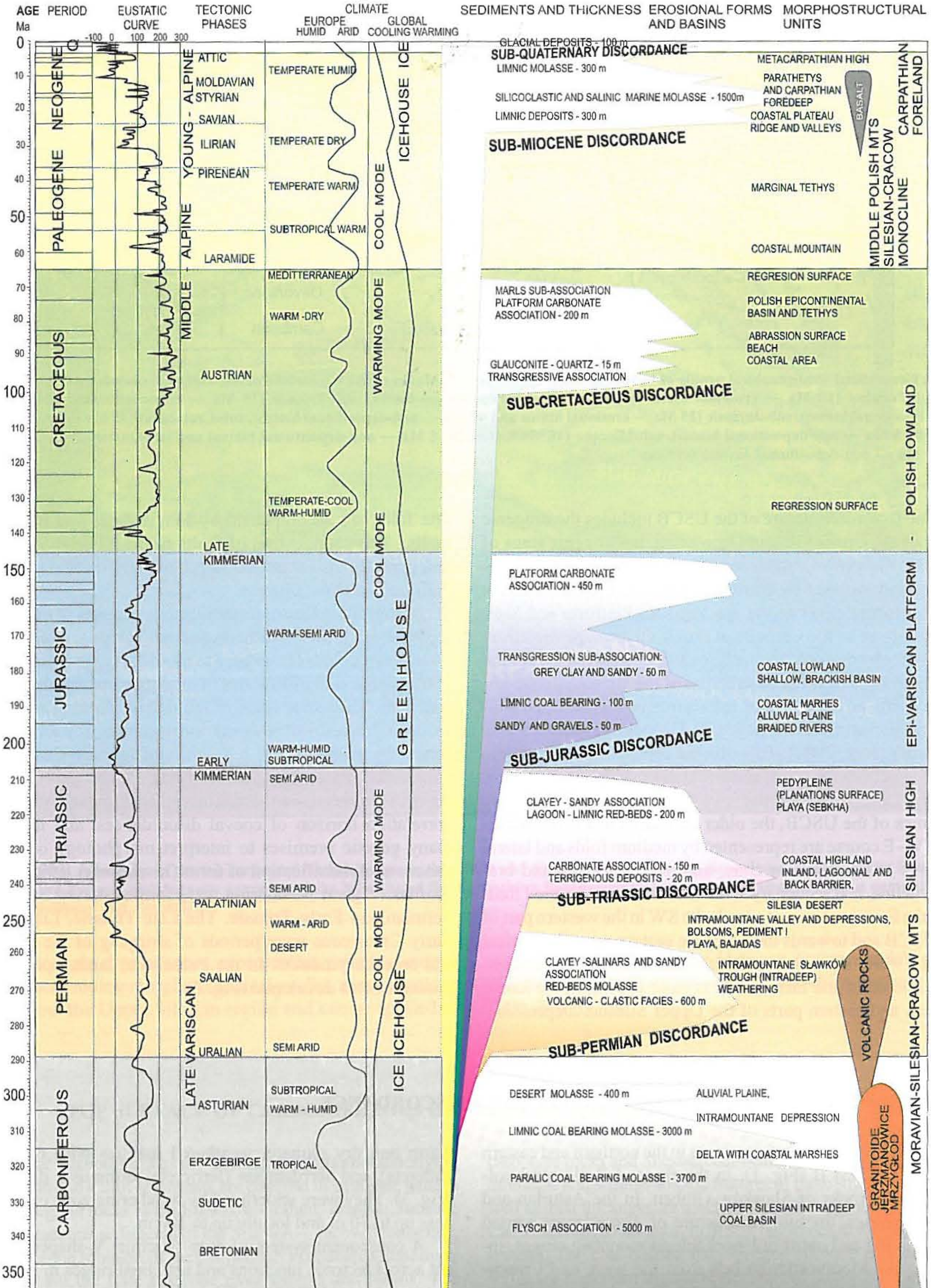

Fig. 3. Discordances evolution of the top surface of Carboniferous of the USCB (sea level according to Haq *et al.*, 1987, and Golonka *et al.*, 1997; climate according to Bless, Fernandez-Narvaiza, 1995; Golonka *et al.*, 1998; Price, 1999; compiled)

the postorogenic volcanism of Saalian phase activated and a graben of *pull-apart* type developed at the foot of melaphyritic rift volcanoes and porphyritic cone volcanoes. The Permian grabens were filled with eruptive series of porphyritic-carbonate conglomerates with volcanites of the thickness up to 150 m and tuffs of the thickness up to several tens of meters (Jura, 1997). The denivelations of the Upper Silesia mountain between the anticlinal ridges with volcanoes and footwall of Dębnik–Siewierz fault scarp gradually decreased but molasses material got finer. Uppermost of Rotligend sedimentation was fine-grained, indicating a slowing in the rate of erosion and the development of closed interior basins, or endoreic bolsons, in arid conditions. In local basins of playa type, sandy-clay and silt material up to 600 m thick, with gypsum of over-eruptive series of Sławków Formation, was deposited (Marek *et al*., 1997).

The sub-Permian discordance changed its tectonic structure several times, especially in the Saalian phase and during the inversion of the graben in Zechstein, probably with an inversion of fault throws slips of Sławków Graben. The sub-Permian surface contains multiple deformations originated during the Middle Alpine and Late Alpine phases (Figs. 2 and 3; Jura, 2001). The morphotectonic of the sub-Permian surface indicates that the synorogenic mountain relief formed concordantly with folded structure that reaches 500–1000 m. This discordance at the bottom surface of the Myślachowice conglomerate features forms elongated valleys and depressions with overdeepenings and horsebacks. Relief shows a scissors-like Rotliegend displacement, and reflects the folded-flexural structures of the basement.

The sub-Permian discordance developed in a dynamic way and it has a character of a diastrophic surface formed in late-Variscan, taphrogenic (postorogenic), morphotectonic cycle (Fig. 3). It separates the folding stage of the Variscan orogen from the Zechstein taphrogenic molasse, and from foreland basin sub stage in the north of Upper Silesian Depression.

SUB-TRIASSIC DISCORDANCE

The sub-Triassic surface is very common in the USCB (Fig. 1). The beginning of its development is shown by Late Variscan dictyogenic movements of the orogen with a surface morphotectonically discordant to low mountains (Moravian–Silesian and Siewierz–Dębnik ranges) and Sławków basins. In the Lower Triassic, dry and hot climate prevailed and sea level was uplifted by 100 m (Fig. 3). Valley network was associated with Carboniferous rocks of different resistance in synclines and subsidence depressions (Jura, 1988, 1997). Anticlinal and half-horst humps and ridges were covered with a thick weathered mantle of reddish rubble-clay material and clayey corestone of ferricrete duricrusts. The bleached zone of mottled weathered rocks underlay the mantel with kaolinized and hematized horizons from sub-Triassic surface of a thickness of about 15–30 m.

As the coast of Mid-Polish Sea moved towards the south, littoral deposits developed from the washing of weathered mantles and alluvia redeposition (Mader, 1992). Świerklaniec Beds of Early Triassic age filled valleys and basins (up to the height of 20–25 m) in the Upper Silesian coast, which showed diversified shoreline of Dalmatian type. The sub-Triassic surface is covered by Rhaetian and Muschelkalk marine carbonate sediments of the thickness up to 150 m (Fig. 3). In the southern part of the USCB, the coast of Sudetic–Silesian land (eastern part of the Vindelitian High) occurred. Since the erosion surface had been covered in Rotliegend, the subsidence and uplifting began, reflected in re-burying and transformation of the landscape (Jura, 2001).

The surface of the sub-Triassic discordance represents a post-orogenic and post-taphrogenic surface and also a sub-cover surface of the epi-Variscan Middle European Platform. This surface developed in the post-Variscan morphotectonic cycle (Fig. 3) and represents a final form of a peneplanation of the fold-intrusive orogen, which shows Variscan consolidation and termination of the isostatic movements.

SUB-JURASSIC DISCORDANCE

The sub-Jurassic surface occurs in the northern and eastern margins of the USCB and represents a Mesozoic intra-cover surface of Middle European Platform (Fig. 1). During the Early Kimmerian epeirogenesis, a slow emergence and regression caused erosion of Keuper clays and of more resistant Triassic carbonate rocks and Carboniferous coal-bearing series. Warm and semi-dry climate (Fig. 3) influenced development of the relief reversed to the basement structures — concave-bottomed valleys. Fine material was washed out but weathered mantles and breccias with calcretes, locally silcretes and dolomitic duricrust developed. They contained carbonate conglomerates and lithic sandstones.

In Liassic, pre-transgressive denudation, sedimentation and redeposition occurred in the floodplain and river-mouths, where material of quartzite gravels of Połomnia Beds was accumulated (Feldman-Olszewska, 1997). In the depressions at the riverbanks, mangroves and peat bogs developed with sedimentation of coal-bearing and dark clays association (Marek *et al*., 1997). In Dogger, the transgression impulses progressively involved the coastal plain and caused diachronous burying of sub-Jurassic surface with marine deposits of sands and gravels, Callovian sandy marls and limestones (Fig. 3). The transgressive sediments up to 10 m thick caused significant smoothness of landform in the southeast part of the USCB.

In the Malm, loamy mounds developed and sedimentation of rock limestones occurred along the "Cracovian Jura". In the areas of the Upper Silesian Coal Basin, a submerged abrasion plain probably developed (Jura, 2001).

The sub-Dogger surface in the USCB was subjected to weak deformations during the subsidence (as compared to Middle Polish Basin) and to strong deformations in its southern part on the developing labile Tethys shelf (Late Kimmerian phase). Main discordance deformations are younger. The sub-Jurassic surface shows features of the coastal lowland and island. The preserved thickness of the Jurassic cover, attaining 150–200 m, may indicate the changes of the landscape.

SUB-CRETACEOUS DISCORDANCE

Although the sub-Cretaceous surface occurs beyond the erosional limits of the USCB, the Cretaceous sediments used to cover a large part of the Carboniferous outcrops (Fig. 1). On the regression surface in Volg and on the terraces, the Carboniferous strata of pre-Jurassic surface with structural benches were uncovered. In subtropical, dry climate of lower Cretaceous, lateritic weathering and denudation intensified (Fig. 3). Relative lowering of Upper Silesian terrace caused deposition of Albian pre-transgressive sands and development of abrasion forms during the transgressions in Cenomanian, Turonian and Senonian (Marek *et al*., 1997). A wide abrasive platform on the regression surface of Malm limestones and Early Cretaceous pediplane of the USCB was formed. The transgressive sediments in Cracow area and Opole Basin reached the thickness of about 100 m. This shows the relative height of the Upper Silesian terrace in Cretaceous and relative height of the abrasion coast on the sub-Cretaceous surface.

The sub-Cretaceous discordance was subjected to broad bending during a subsidence in Miechów, Opole and Southern Moravia Basins (Jura, 2001). Its amplitude reached several hundred metres. Main folding and faulting in the Middle Alpine phases produced the Silesian–Cracow Monocline and the morphostructure of the Tethys coastal mountains.

The surface of sub-Cretaceous discordance represents intra-cover panacordation, which exceeds the limit of Kimmeridgian sediments. It developed in Late Kimmerian epeirogenic and talassogenic morphotectonic cycle. The sub-Cretaceous surface separates cover horizon, built of Triassic and Jurassic sediments, from the subhorizon built of Late Cretaceous sediments (Fig. 3). The development and covering of the sub-Cretaceous surface resulted in total peneplanation of the Upper Silesian island caused by the planation and burying of sediments in the adjacent depressions with zones of subsidence in Miechów, Opole and Southern Moravia Basins.

SUB-MIOCENE DISCORDANCE

The sub-Miocene surface between Carpathians and their foreland is a boundary of a complex morphostructure and genesis (Fig. 1). Together with the uplifting of fold-epeirogenetic mountains of a morphotectonic concordation, the area of the USCB was placed at a high coast of Tethys. In the Paleogene, conditions favourable to the inversion of fold structures and formation of structural escarpments and tropical basins occurred. The Tethys coast was significantly dismembered by system of flat-bottomed valleys. Erosion smoothed intervalley forms (Jura, 1992). In the mountain summits, the coal outcrops burnt down and regolitic covers with deep kaolinitic weathering profiles developed. In Early Miocene, relative lowering (folding of external Carpathians in Savian phase) and decrease of erosional force occurred, associated with ingressions of Para-Tethys Sea in deep valleys, which were transformed into submarine canyons (Fig. 1). In the highland of ria coast, fine alluvial and lacustrine sediments of Kłodnica Formation were deposited in closed valleys or playas.

The transgression in the Eggenburgian initiated filling of submarine canyons by lower Carpathian molasse, represented by the following formations: conglomerate of Sucha, sandstone of Stryszawa and mudstone of Zebrzydowice, of the summarized thickness up to 1000 m. The overthrust of the Carpathian front in the Styrian phase and widening of transgression in Moravian into the bending foredeep, renewed burying of Carboniferous relief by middle marine molasse of the Dębowiec conglomerate, Skawina mudstone and siltstone, and evaporate deposits of Wieliczka Formations (Fig. 3; Oszczypko, 1998). Their thickness reached 1300 m. After the third ingression in the upper Badenian, the Carpathian Foredeep in the Upper Silesia was filled with upper molasse of the siltstone Gliwice Formation (up to 400 m thick). During the transgression, the mountain relief was slightly modified and only structural benches developed on the inherited crest flatnesses and plateaux (Jura, 1997). In the Attic phase, after the subsequent overthrust of the Carpathian front, the sea basin declined and the foredeep was filled with terrestrial molasse of the Sarmatian Kędzierzyn Formation (up to 200 m thick). Then, after the Volovian phase, it was filled with molasse of Sośnicowice Formation (up to 100 m thick).

The sub-Miocene formation was deformed many times, mainly by step faults in the Savian, Styrian and Moldavian phases, and by the tilt or flexure (bending) of the internal part of the Carpathian Foredeep into the sub-Beskid Homocline and into Metacarpathian High in the foreland. The amplitude of bending towards the south reached 5000 m and probably 10,000 m at the distance of 50 km (Fig. 1).

The sub-Miocene surface originated in the Late Alpine morphotectonic cycle. The folded epi-Variscan epeirogen of Middle European Platform was a base of the discordance. Molasses of the Carpathian Foredeep covers the sub-Miocene surface of mountain relief.

SUB-QUATERNARY DISCORDANCE

The sub-Quaternary surface is formed by patchy glacigenic sediments, which cover the Carboniferous, Permian, Mesozoic and Neogenic strata in valleys and hills. In the late Pliocene, in moderate climate with dry periods, washing and weak erosion predominated. Locally, fluvial accumulation of the material from Sudetic and Carpathian Mountains occurred (Gozdnica Series and Sośnicowice Gravels). In eo-Pleistocene, the lowering of erosion base by 150 m (Fig. 3) accelerated the stripping of resistant rocks from the cover of Neogene sediments together with plateaux and hills of the sub-Miocene surface. In the meso-Pleistocene, the studied area was covered by the ice sheet,which renewed erosion in the exposed valleys with periodical accumulation of fluvial erosion. The covering of the erosional surface was initiated by the sediments of Southern Polish glaciation that were then partially eroded before the Odranian glaciation (Lewandowski, 1995). The sediments of the Odranian glaciation are widely spread together with a postglacial relief with sandurs, kames and moraine hills. In the neo-Pleistocene, periglacial erosion was rather limited and also accumulation of the Vistula River was not significant.

The sub-Quaternary surface was subjected to strong glacioisostatic movements with a clear uplift after the Odranian deglaciation. Its amplitude reached 50 m. The glacigenic flexure overlapped geodynamic deformations of the Carpathian Foredeep and Metacarpathian High. These deformations represented derivatives of isostatic compensation of stresses between the Carpathians pushed towards the east and northeast, and grabens pulled back to its foreland (Jura, 1995).

The sub-Quaternary discordance originated in the top surface of the Carboniferous sediments of the USCB in the sculpturing glacigenic cycle as a discontinous uncovered from the Miocene sediments and a concordance that developed on their basement. It is a partially formed discordance that still develops with significant anthropogenic transformations, especially caused by mining.

CONCLUSIONS

Morphotectonics of the discordances of different age present in the top surface of Carboniferous–Permian, –Triassic, –Jurassic, –Cretaceous, –Miocene, –Quaternary boundaries of the Upper Silesian Coal Basin is connected with landscape evolution, burial by sediments, glacial deposits or by lavas. The erosional and depositional events of discordances have been modified by tectonics, especially basin subsidence, uplift, and epeirogenic structures. These discordances developed during six major morphotectonic cycles (Fig. 3).

1. The sub-Permian surface indicates the synorogenic mountain relief concordant with folded structure that reaches 500–1000 m. Anticlinal ridges and synclinal depressions dominated the landscape. This morfostructures became a typical pull-apart intramountains basin, connected with the volcanic intrusions during the Saalian phase.

2. The sub-Triassic surface has got typical coastal highland relief. Freshwater sediments of Buntsandstein age and marine deposits of Muschelkalk age, up to 200 m of thickness, cover the post-Variscan pedyplain.

3. The sub-Jurassic surface developed in Late Kimmerian epeirogenic morphotectonic cycle. The sub-Jurassic intra-cover panacordation of the epi-Variscan Middle European Platform is a final form of the peneplanation of the coastal plain in the talassocratic conditions.

4. The sub-Cretaceous surface has an abrasion character. The thickness of the Upper Cretaceous sediments in the Nida and Opole Trough is above 800 m, and shows the amplitude of the Middle Alpine subsidence and epeirogenic movements of the Upper Silesia area.

5. The sub-Miocene surface represented the mountains relief covered by the Miocene molasse deposits. The Late Alpine morphostructures refer to the bending of the sub-Beskid Homocline and Metacarpathian swell up to 10 km.

6. The sub-Quaternary surface has got highland relief with changes in level up to 100–150 m. Quaternary fluvioglacial deposits infilled the river valleys.

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