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LANDFORM EVOLUTION IN MOUNTAIN AREAS

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GEOMORPHOLOGY OF THE DIENDORF FAULT AREA ON THE SE MARGIN OF THE BOHEMIAN MASSIF IN SW MORAVIA AND NE AUSTRIA

Abstract. The contribution describes general neotectonic development, main present-day landforms and key stages of Cenozoic geomorphological evolution of the Diendorf Fault Area situated in the contact region between the SE margin of the Bohemian Massif and the Alpine-Carpathian Foredeep. The position of the area within the Moravo-Silesian Zone, a Palaeozoic tectonic lineament orientated NNE–SSW, is highlighted. The partial reactivation of old fault zones during Alpine movements in the Eastern Alps and Western Carpathians, together with several Miocene marine transgressions created in the marginal part of the Bohemian Massif a specific landscape, which is characterised by intensively fragmented crystalline topography with many exhumed landforms. Schematic chronology of landscape evolution in the area is proposed, based on integrated evaluation of geological, geomorphological and geophysical data. Major phase of tectonic segmentation is dated to the Oligocene–early Neogene period, while the actual altitudinal contrast between the higher elevated crystalline terrain of the Massif in the NW and the lower sedimentary relief of the Foredeep in the SE is likely of the Late Miocene–Quaternary age. Within the relatively uplifted block, the latter stage of differential movements induced large-scale denudation of the Miocene sedimentary cover and considerable incision of main streams.

Key words: Bohemian Massif, Alpine-Carpathian Foredeep, Diendorf Fault, tectonics, geomorphology

INTRODUCTION AND STUDY AREA

The paper deals with gross geological and geomorphological features of the Diendorf Fault Area in south-western Moravia (Czech Republic) and northern Lower Austria. The described area of specific tectonic character is situated within the contact region between the SE margin of the Bohemian Massif and the Alpine-Carpathian Foredeep (Fig. 1). The contribution is focused on its most complex part including a tectonic belt of approximately 60 km length and 10 km width which extends NNE–SSW between the towns of Moravský Krumlov in Moravia and Maissau in Austria, in the text below being simply referred to as the "Zone".

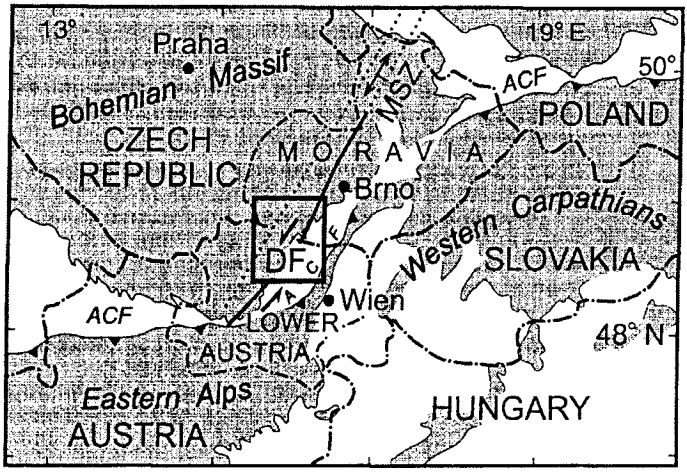

Fig. 1. Geotectonic position of the Diendorf Fault Area within Central Europe. MSZ — Moravo Silesian Zone, ACF — Alpine-Carpathian Foredeep, DF — Diendorf Fault

The paper intends 1) to indicate main geomorphological effects of the Alpine orogenic movements on the margin of the European Platform on the periphery of the Alpine-Carpathian tectonic junction, 2) to give general description of present-day landforms, 3) to demonstrate significant role of the old geological history in the development of actual topography in the surveyed part of the Bohemian Massif, and 4) to propose major neotectonic stages of regional landscape evolution for the study area. The brief information on the area was based on integrated evaluation of geological, geomorphological and geophysical data.

The general geology and topography of the region are shown on Fig. 2 and Fig. 3.

GEOLOGY AND TECTONIC EVOLUTION

The Bohemian Massif, a marginal component of the European Platform, is mostly composed of solid igneous and metamorphic rocks of Proterozoic–Palaeozoic age. Palaeozoic sedimentary complexes occur rarely in the described region. The adjacent Carpathian Foredeep is mainly filled with poorly consolidated marine and brackish clastics of Early–Middle Miocene age, deposited over the old basement during repeated transgressions throughout the Alpine orogeny (Brzobohatý and Cicha 1993; Chlupáč et al. 2002). The study area provides a complicated mosaic of exposures with both major types of rocks of very different strength, largely covered by Quaternary sediments.

The Diendorf Fault, the main regional fault element, constitutes a prominent linear component of the Moravo-Silesian Zone which is a Palaeozoic lineament crossing NNE–SSW the eastern part of the Bohemian Massif (Schermann 1966;

Jaroš and Mísař 1967; Zeman 1978). Different tectonic regimes alternated during formation of the actual architecture of the zone and, thereby, local rocks became much more fractured as compared to the neighbouring regions. A strong Variscan activity is testified to by approximately 1000-m-thick Permo-Carboniferous strata in tectonic graben-like structures like the Boskovice Furrow in Moravia (Malý 1993) or the Heiligenstein near Zöbing in Austria (Vasicek and

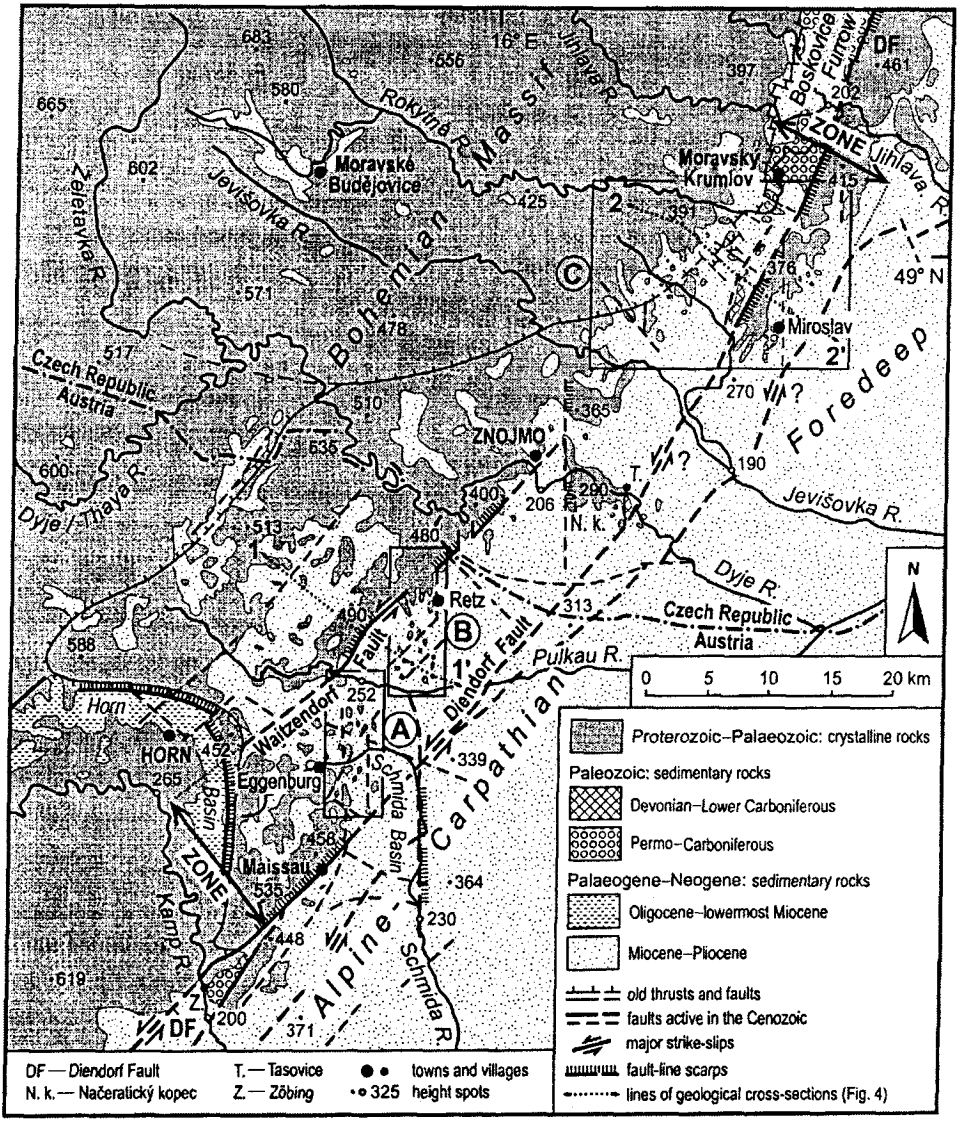

Fig. 2. General geology of the study area without Quaternary formations. The contact area between the Bohemian Massif and Carpathian Foredeep is formed by a tectonic zone developed between the Waitzendorf and Diendorf Faults. A, B, C — sections illustrated in detail on Fig. 5

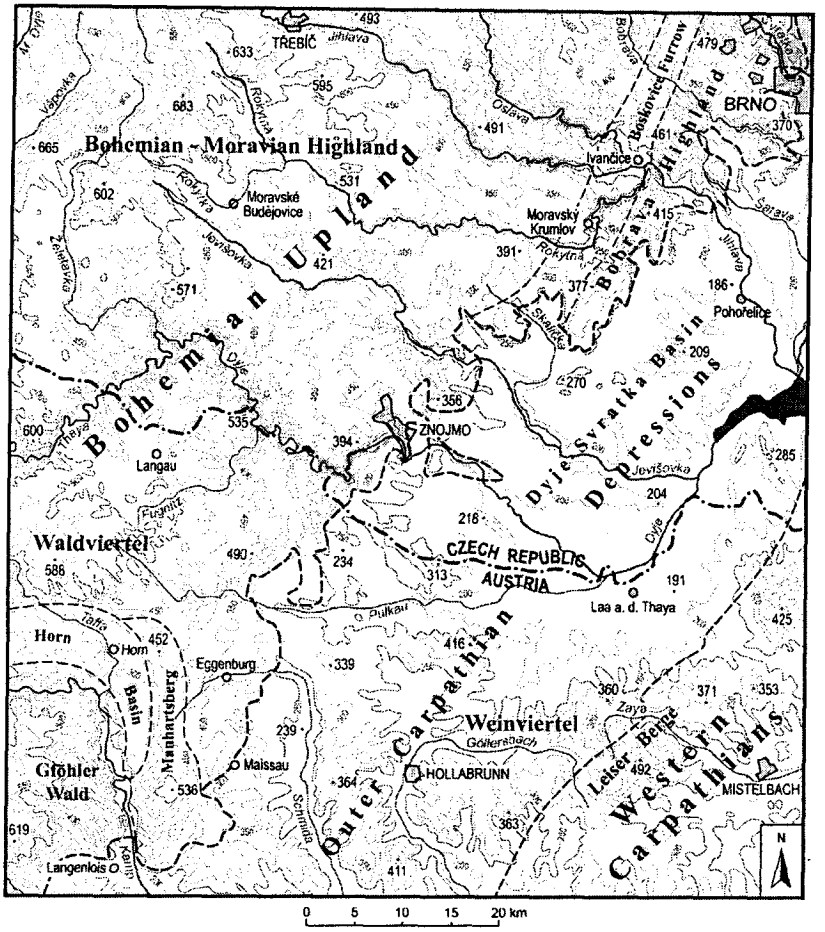

Fig. 3. Topography of surveyed segment of the SE Bohemian Massif and adjacent part of the Carpathian Foredeep, showing the main landscape units. Contour interval 50 m. Note the flat surface of the Dyje–Svratka Basin, the steep scarps SW of Znojmo and near Maissau, and the incised valleys of major streams on the margin of the Bohemian Upland

Steininger 1999). The latest movements in the Tertiary and Quaternary played a fundamental role in the evolution of present-day morphology of the SE Bohemian Massif. The old tectonic predisposition of the Moravo-Silesian Zone was the important factor. Uneven shifting of the Eastern Alps and Western Carpathians induced in front of the Alpine belt in S Moravia and N Austria a regional marginal downwarp of the Bohemian Massif, accompanied by an intensive tectonic segmentation under prevailing extensional regime (e.g., Decker 1996; Decker and Peresson 1996). Dominant movements along NE–SW and N–S-trending normal faults were there associated with supplementary, minor sinistral strike-slip motions and created a complex transtensile pattern, called the Diendorf Fault System (Roetzel 1996; Roetzel et al. 2002).

The area of the studied tectonic "Zone" is bounded by two major subparallel reactivated faults trending NE–SW, the Waitzendorf Fault in the NW and the Diendorf Fault in the SE. Between them many subsidiary parallel and oblique, N–S-orientated dislocations were detected. In the north, the "Zone" is connected with the Permo-Carboniferous structure of the Boskovice Furrow, which has been in the Cenozoic tectonically and structurally renewed and presently it acts as a distinct elongated morphological depression.

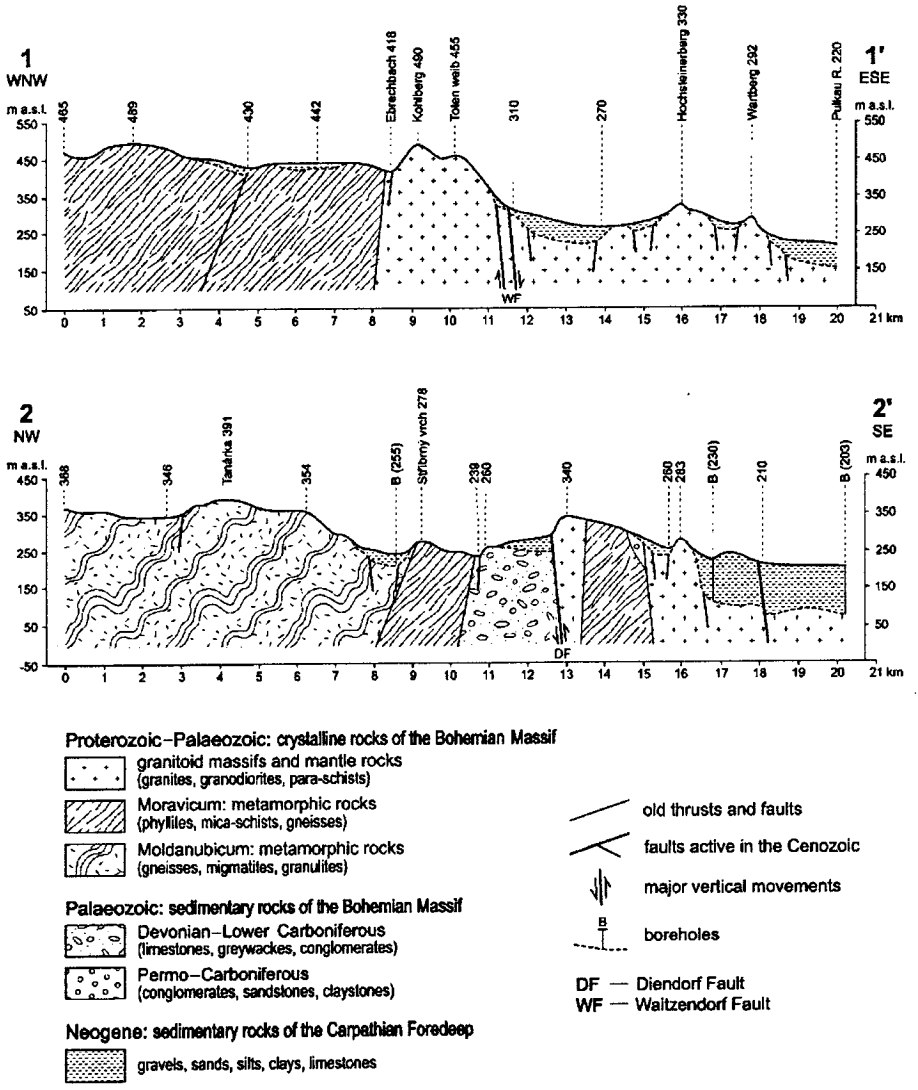

Fig. 4. Schematic geological cross-sections through the fragmented SE marginal slope of the Bohemian Massif. 1 — granitic area in NE Austria, 2 — area of diversified lithology in SW Moravia. Vertical exaggeration: 10x. For location see Fig. 2

GEOMORPHOLOGY

The study area includes a marginal slope of the Bohemian Massif bounded by the Diendorf and Waitzendorf Faults. It forms a complex transitional area separating two regions of relatively poorly differentiated topography — an upland of the Bohemian Massif with typical altitudes of 350–600 m a.s.l., and a hilly relief developed in the Carpathian Foredeep situated mostly at 200–350 m a.s.l. The altitudinal differences thus attain 150–250 m (Fig. 4), being a little higher in Austria. The marginal slope consists of several long fault-line scarps, a few larger tectonic blocks, a number of elongated asymmetric bedrock ridges and numerous low inselberg-like horsts (Photos 1, 2). Relief energy values of the small hills usually do not exceed 50 m. The rocky outliers are surrounded by flat topography on the Miocene deposits accumulated in many small and larger grabens. Well-bore data documented the presence of several tens of metres thick sedimentary sequences, in extensive basins up to 200 m. The lithology of inselberg-like elevations is differentiated, however, granitic rocks markedly prevail. Moreover, granitic exposures are usually crowned by frequent rock forms and loose boulders, showing sometimes core-stone weathering.

Photo 1. View of the 200 m high fault-line scarp along the Waitzendorf Fault on the margin of the Bohemian Massif north of Retz, NE Austria, separating a higher surface on the crystalline rocks (in the left) and a lower sedimentary relief of the Carpathian Foredeep (in the right). The elongated crystalline ridge with summit elevations in the centre of the photo constitutes a transitional element between both different landscapes

Photo 2. Inselberg-like elevation Stoitzenberg southwest of Rőschitz, NE Austria. The low granitic protrusion is elongated in N–S direction. The flat area in the foreground is built up of Miocene and Quaternary sediments deposited in a small basin

The most typical feature of the "Zone" is an evident NE–SW and N–S alignment of many crystalline and sedimentary landforms. The elongation of morphological elements highly corresponds with present fault lineaments, in the Austria forming even a specific divergent duplex system (Fig. 5). The geophysical and borehole prospecting confirmed the existence of similar orientation of bedrock forms — ridges and depressions — also in those parts of the "Zone" which are hidden under Miocene cover. Geomagnetic and geoelectric methods were mostly used (e.g., Hron 1980; Supper et al. 1999; Decker 2000). Hence, the small elevations and basins are regarded as transtensile elements created during extensional Alpine movements (Roetzel 1996).

EVIDENCE FOR EXHUMATION HISTORY OF MARGINAL PART OF THE BOHEMIAN MASSIF

Many crystalline surfaces on the SE margin of the Bohemian Massif are landforms repeatedly buried and exhumed from beneath Miocene sediments, as it is indicated by lot of geological and geomorphological evidence (e.g., Schaffer 1913; Dlabač 1976; Čtyroký 1991; Roetzel et al. 1999). Some of them are outlined in this part.

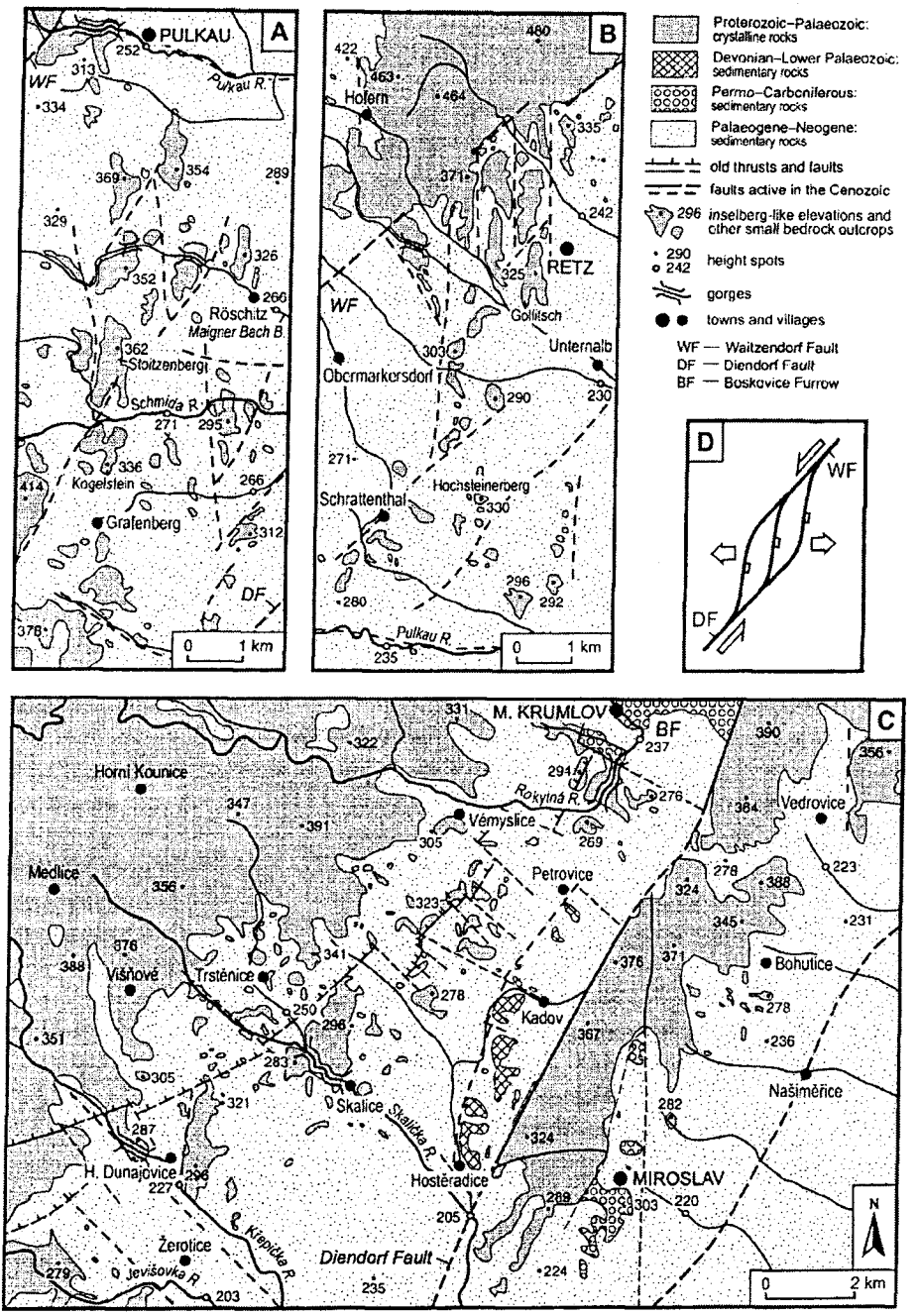

Fig. 5. Major areas with densely tectonically fragmented topography in NE Austria (A, B) and SW Moravia (C). The crystalline elevations are surrounded by a number of graben-like depressions filled with Miocene clastic sediments. For location see Fig. 2. Sketch D illustrates a simplified divergent duplex model of the landscape evolution, inferred for the NE–SW to N–S orientated topography developed between the Waitzendorf and Diendorf Faults in Austria (e.g., Decker 2000)

Many isolated marine, brackish, in marginal areas also fluvial and lacustrine denudational sedimentary remnants of the Carpathian Foredeep, deposited during several Early to Middle Miocene transgression periods, are presently preserved on the higher surface of the Bohemian Massif NW of the tectonic scarp along the Waitzendorf Fault (Fig. 2), witnessing a several-time inundation of that region. Stratigraphically analogous types of near shore facies of two older Miocene stages (Eggenburgian, Ottnangian) are situated in different altitudes both NW and SE of this fault line. The maximal difference in elevation between these areas attains nearly 200 m. Along the tectonic scarp of the Diendorf Fault near Maissau, a similar uneven distribution of the Early Miocene deposits exists, showing again a larger post-sedimentary denudation in the NW.

Similar evidence documenting exhumation history of the region is provided by a frequent occurrence of small depressions (pockets) filled with Miocene clastics situated even in the summit parts of many bedrock outliers in the foreland of the higher part of the Bohemian Massif (Photo 3).

Around the present-day inselberg-like hills, and partly also along tectonic scarps of the Waitzendorf and Diendorf Faults in Austria, a direct influence of pre-sedimentary bedrock configuration on the deposition during the first Miocene transgressions (Eggenburgian, Ottnangian) is evident. While the coarse blocks and beach gravels of abrasion origin, derived from coastal area, rim the slopes

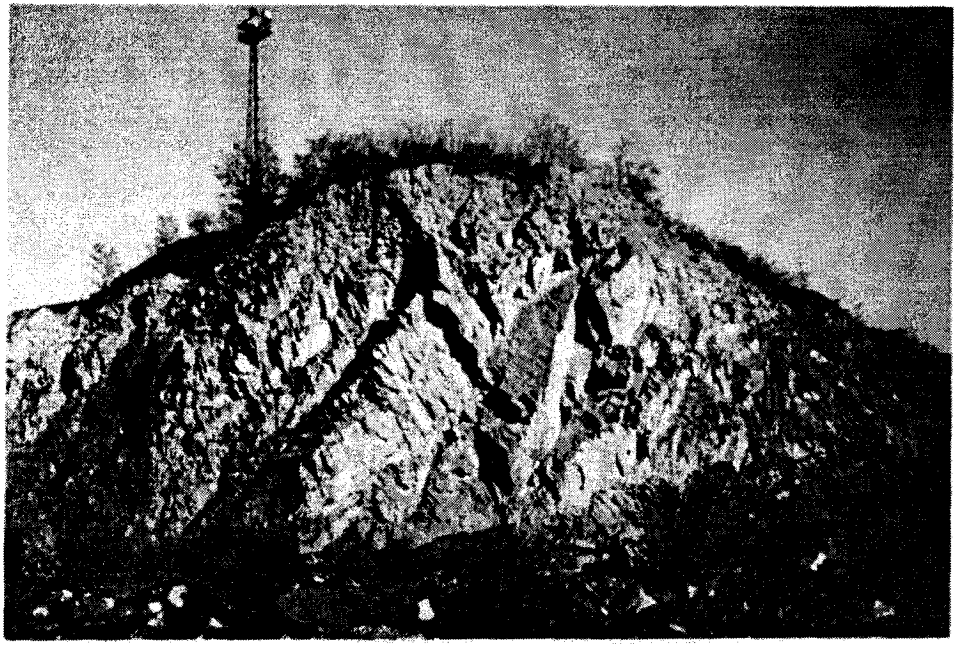

Photo 3. Depressions in strongly fissured Lower Devonian acroses filled with Miocene clastics. Tasovice quarry, SW Moravia. The outcrop is situated in the top part of the elevation of Načeraticky kopec constituting larger isolated basement block within the Carpathian Foredeep

and bases of rocky elevations, towards the adjacent depressions they are gradually replaced by sands, silts and clays. Similar relations to the local morphology as the grain-size distributions are in the same locations pointed out by the distribution of marine fossils in the Early Miocene deposits (Roetzel et al. 1999). These characteristic sedimentary conditions document that the main phase of horst-and-graben formation within the "Zone" can be dated already to the pre-Eggenburgian period.

In contrast, the sedimentary products of two last transgressions in the late Early Miocene (Karpatian) and early Middle Miocene (Badenian) in the Carpathian Foredeep, present in the vicinity of tectonic scarps along the Waitzendorf and Diendorf Faults, show a deposition in a deeper environment as they do not have a typical near-shore character (Roetzel et al. 1999). NW of the Waitzendorf Fault, deposits of these regional cycles hardly occur, what points out the strong post-sedimentary uplift of that area.

Geomorphological evidence of previous burial and exhumation of many bedrock outliers and ridges in front of the higher block of the Bohemian Massif is provided by short reaches of streams breaking in straight lines through these small crystalline elevations. In the adjacent lower flat sedimentary areas shallow valleys mostly evolved. The narrow gorges in bedrock exposures seem to be of epigenetic origin since the surrounding low-lying parts of the crystalline basement were not used for valley formation.

The described geological and geomorphological configuration of the region, together with mentioned interrelationships between old bedrock topography and young sedimentary cover documenting exhumation, enable one to propose a schematic evolution model of the study area.

CHRONOLOGY OF LANDSCAPE EVOLUTION

The major stages of regional landscape evolution, including two key phases of tectonic reactivation of the old fault lines, can be briefly summarised as follows.

1. Oligocene (?)–early Neogene. The first intensive, renewed movements between the Waitzendorf and Diendorf Faults occurred. In the "Zone", the initial forms of steep scarps along both the faults originated and the former compact surface of the Bohemian Massif was fragmented into a complex pattern of horsts and grabens. Normal faulting and sinistral strike-slip movements were the main relief-forming processes. However, present-day distinct topographical difference between the region in the NW and the region in the SE was not created yet.

The assumed beginning of major tectonic segmentation within the "Zone" (Oligocene) was inferred from the time of onset of continental collision between prominent southern spur of the solid Bohemian Massif and the overthrusting Alpine thust-fold belt. This N-directed compression was accommodated by a NE-di-

rected lateral extrusion of upper crustal blocks towards the Carpathian area (e.g., Decker 1996). The end of main tectonic fragmentation (early Neogene) was connected with the cease of thrusting in NE Austria and SW Moravia (cf. Decker 1996; Roetzel et al. 2002) and it was also supported by a substantial reduction in frequency of syn-sedimentary dislocations from the Eggenburgian to Ottnangian layers of the Carpathian Foredeep, found in several surface outcrops (e.g., Limberg quarry at the Diendorf Fault NE of Maissau; Decker 1999).

2. Early–Middle Miocene. The area was subjected to repeated significant subsidence and uplift associated with the last regional thrusting in the adjacent Alpine-Carpathian region. Several transgressions over rugged relief took place, and a complicated coast with numerous islands, peninsulas and embayments was formed during first phases of inundation. The structured bedrock topography induced a large diversification of sedimentary environments at the local scale. The strong abrasion acted on the seaward slopes of basement elevations. The whole region was completely buried by sediments of the Carpathian Foredeep at the end of the period. The final marine regression is dated to ca 15 Ma (Roetzel et al. 1999).

3. Late Miocene–Quaternary. A significant regional tectonic inversion has been the most important process. An intensive uplift of the present-day part of the Bohemian Massif in the NW against much less elevated actual Carpathian Foredeep in the SE has occurred. In this way, the second phase of tectonic reactivation in the "Zone" took place. However, the character of movements changed and the uplifting has been accommodated mainly by the activity of major fault zones within larger blocks of the Earth crust. Steep 100–200 m high tectonic scarps along the Waitzendorf and Diendorf Faults have attained during these vertical movements their present-day relative elevation and distinctiveness. Throughout the Quaternary, strike-slip activity of both main dislocations became slightly renewed again (Decker 2000; Roetzel et al. 2002), but the differential uplift of the Bohemian Massif has continued, as evidenced by the geomorphology of Pleistocene river terraces within the Dyje–Svratka Basin (Musil 1993).

The Late Miocene–Quaternary tectonic inversion has brought far-reaching landscape consequences, including a substantial diversification in the rate of denudation of Miocene marine sedimentary cover in the region and formation of a new river network draining the entire region towards the SE, mostly due to epigenesis (cf. Hrádek 1997). Three different types of landscape in the area have been developed.

1. In the Bohemian Massif, most of unconsolidated deposits have been removed. Crystalline surfaces of low relief energy prevail there nowadays. The major rivers formed narrow gorges with numerous incised meanders cut 100–200 m down the levelled solid rocks (Fig. 3, Photo 4).
2. In the Carpathian Foredeep, the denudation was less intensive and a flat relief on the sedimentary fill have mostly evolved. The streams created shallow valleys with occasional free meanders.

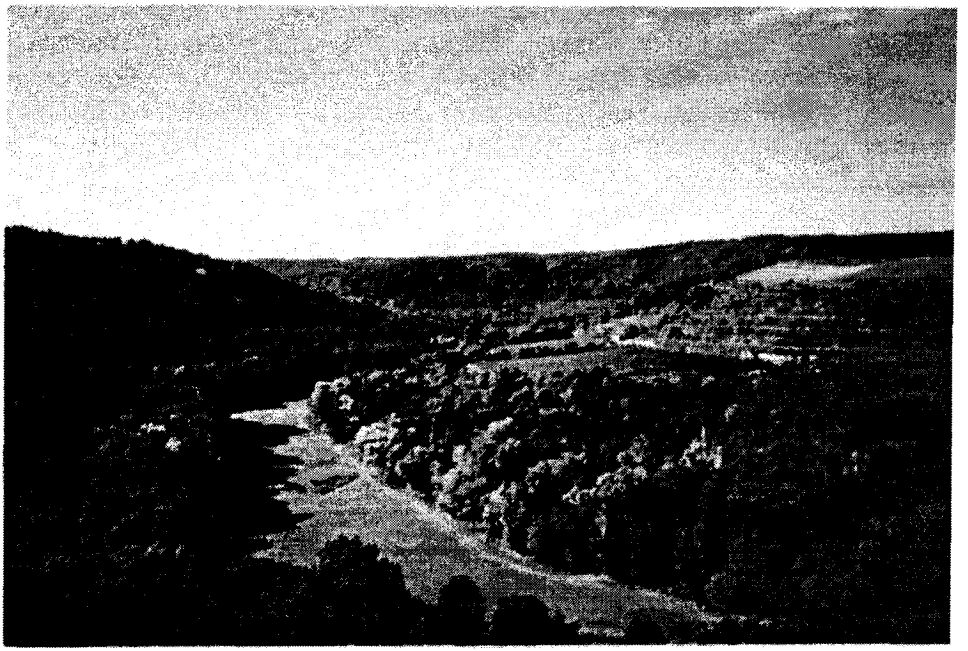

Photo 4. Canyon-like valley of the Dyje (Thaya) River cut down the levelled crystalline surface of the uplifted SE margin of the Bohemian Massif. Podyjí–Thayatal National Park, Czech–Austrian border zone

3. Within the tectonic "Zone", a partially exhumed landscape of contrasting topography with inselberg-like basement hills and intervening lower flat areas has originated. River reaches cutting through bedrock elevations alternate there with shallow sections running across sedimentary basins.

Any datable young post-transgression sedimentary covers which could directly document the exact age and detailed character of the mentioned landscape processes are rather scarce in the region. However, the available stratigraphic data provided especially by the Upper Miocene deposits of the palaeo-Danube River in the Bohemian Massif and Carpathian Foredeep (Roetzel et al. 1999) and by the relicts of clastic sediments of Late Miocene–Pliocene age preserved on the higher surface of the Bohemian Massif, dated on the basis of included rare Middle Badenian tectites — moldavites (Trnka and Houzar 1991; Hrádek 1997), enable tentatively to specify the ages of major periods of river incision and denudation of marine and brackish sediments.

The topographic position of most of the young deposits with moldavites is incompatible with the present-day fluvial system of the region. Thus, these sediments are supposed to have been accumulated during older phases of subaerial landscape drainage. This fact indicates the Pliocene–Lower Quaternary origin of actual deep valleys in the higher terrain of the Bohemian Massif. However, the main period of denudation of transgression sediments seems to be dated to a former stage, most probably to the Late Miocene–Pliocene. It is partly also proved by

the Pleistocene loess covers accumulated on the eastern (lee) sides of the inselberg-like bedrock hills, ridges, and tectonic scarps along the Waitzendorf and Diendorf Faults within the "Zone", showing that these basement forms were largely exhumed already prior to the Quaternary.

CONCLUSION

The transform area of the Diendorf Fault System represents one of transitional regions within the contact zone between the European Platform and the Alpine-Carpathian orogen where differential Cenozoic movements between the blocks of the Eastern Alps and Western Carpathians have been tectonically accommodated. The unique geotectonic position of the fault system in the marginal area of the Bohemian Massif and Alpine-Carpathian Foredeep has controlled the formation of actual specific geomorphological features, including distinct fault-line scarps and densely fragmented horst-and-graben topography, partially covered by Cenozoic sediments. The present-day situation of the region on the NW periphery of the Alpine-Carpathian junction was significantly predisposed by the reactivation of the Moravo-Silesian Zone, an important Palaeozoic tectonic lineament crossing the eastern part of the Bohemian Massif, where repeated strong movements, mostly during Variscan orogenesis, took place. The frequent inversions of tectonic regime within the Diendorf Fault Area continued even during the Tertiary and Quaternary, as documented by the occurrence of many geological fault structures and by landforms repeatedly subjected to burial and exhumation in the course of several marine transgressions and regressions. Consequently, many remarkable relations between the old and new structural elements are there preserved. The existing complex configuration of the study landscape enables one to infer the major regional evolutionary stages and, hereafter, the next research could bring even a key for the determination of more detailed denudational chronology in the surrounding areas.

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STRESZCZENIE

P. Roštínský

GEOMORFOLOGIA STREFY USKOKOWEJ DIENDORF NA SE OBRZEŻENIU MASYWU CZESKIEGO W SW MORAWACH I NE AUSTRII

Praca przedstawia rozwój neotektoniczny, współczesne formy rzeźby oraz zasadnicze stadia rozwojowe rzeźby strefy uskokowej Diendorf. Jest to obszar położony na kontakcie SE obrzeża Masywu Czeskiego i alpejsko-karpackiego rowu przedgórskiego. Omówiono pozycję tego systemu w obrębie tzw. strefy morawsko-śląskiej i lineamentu tektonicznego o kierunku NNE–SSW. Częściowe uaktywnienie starych linii tektonicznych podczas zróżnicowanych ruchów alpejskich we Wschodnich Alpach i Karpatach Zachodnich oraz kilka mioceńskich transgresji morskich, doprowadziły do uformowania specyficznej rzeźby charakteryzującej się urozmaiconą topografią obszaru granitowego oraz wieloma zespołami form ekshumowanych. Większość tych elementów rozwijała się w strefie krawędziowej, zajmującej pas o długości 60 km i szerokości 10 km pomiędzy miastami Moravsky Krumlov (Morawy) i Maissau (w Austrii). Występuje tam rzeźba krawędziowa uwarunkowana uskokami, wydłużone grzbiety i liczne wzgórza o charakterze inselbergów, otoczone małymi kotlinkami wypełnionymi osadami. Dominuje orientacja form NE–SW oraz częściowo N–S.

Wyróżniono dwa główne stadia ruchów tektonicznych. W oligocenie i najmłodszym neogenie miała miejsce główna faza fragmentacji podłoża. Podczas dolnego i środkowego miocenu miała miejsce transgresja morska na nie wyrównaną rzeźbę (depozycja osadów klastycznych). Druga faza zróżnicowanej aktywności tektonicznej jest wiązana z okresem późny miocen–czwartorzęd. Głównym procesem było intensywne podnoszenie współcześnie odsłoniętej części Masywu Czeskiego w stosunku do słabiej podnoszonego zapadliska alpejsko-karpackiego. Wysokości względne przekraczają 200 m. W większości podniesionych bloków zostały usunięte osady mioceńskie, a większe cieki formowały wąskie doliny z wieloma meandrami, wciętymi poniżej podłoża skalnego 100–200 m. W kotlinach na przedpolu zachowały się osady maskujące wcześniejszą rzeźbę.