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VALLEYS OF THE EASTERN MARGIN OF THE BOHEMIAN MASSIF: BRIEF OUTLINE OF THEIR ORIGIN, AGE AND NATURAL HAZARDS

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Abstract. Deep valleys of the eastern margin of the Bohemian Massif which open into the Carpathian foredeep represent its characteristic feature. Based on the occurrence of Miocene sediments they are attributed pre-Miocene age and erosional origin. New knowledge obtained from geomorphological, geophysical and sedimentological research indicates that tectonic movements brought about by the collision of the North European platform and the Carpathian–Pannonian blocks at the turn of the time between Carpathian and Badenian in Upper Miocene play an important role in the formation of valleys. The tectonic predisposition of valleys causes susceptibility to the formation of some natural hazards, above all of mass movements, piping, and flash floods.

Key Words: Bohemian Massif, forebulge, normal faults, gravitational spreading, slope failures, deep–seated creep, gravity mass flows, piping, flash floods.

1. Introduction

On the basis of new, detailed investigations opinions about the origin and the age of valleys of the eastern margin of the Bohemian Massif are now being reassessed. The belief that these valleys arose as early as in the pre-Miocene period through the process of erosional cutting of rivers deep into their bedrock is based on the sole fact that they contain Miocene sediments here and there, most frequently of the Lower Badenian age. The hypothesis was satisfying in its simplicity; it was built using the geosynclinal model of the evolution of Paratethys, a part of which was also the eastern border of the Bohemian Massif. New discoveries made about the decisive role of the collision and the subsequent subduction of the Bohemian Massif at the eastern border of the North European Platform, with Carpathian and Pannonian blocks at the period of Styrian movements between Carpathian and Badenian, have brought complications into the solution of the problem of the tectonic and geodynamic evolution of both the Carpathian foredeep and of both its outer and inner borders. Detailed geomorphological research contributes new and revealing knowledge to the study of this complex development which was in progress on the outer slopes of the foredeep.

2. NEW DISCOVERIES ABOUT THE EVOLUTION OF THE EASTERN MARGIN OF THE BOHEMIAN MASSIF

Quite in line with the model of flexural extension of the upper continental crust in the collisional foredeep [Bradley and Kidd 1991], as the principal feature of neotectonics on the eastern margin of the Bohemian Massif after its collision with the Carpathian–Pannonian blocks, is the tectonic uplift and the formation of the so called forebulge presenting purely specific morphological features [Hrádek 1995a,b]. Despite the fact that the plate–tectonic model of Bradley and Kidd was established for collisions of the continent – arc type we are now beginning to perceive its additional applicability to the collision of continent–continent type, at least as much as the border of the bending platform is concerned. Zolotarev (1987) calls the platform part that has been influenced by a near orogene a "periorogenic zone".

The eastern margins of the Bohemian Massif are either of fault type, with fault scarps, or tectonically inclined, forming, thus, a part of a flexural bend [Roth 1980; Hrádek 1987]. By their fault scarps the borders fall down into two grabens, called the Moravian Gate and that of Vyškov, which arose on the rim of the Bohemian Massif as a consequence of its flexural bending and which constitutes, at the same time, the rudimentary Lower Badenian foredeep in Krystek's (1983) sense of the term. The inclined margins dip into the broader sections of the foredeep. Quite a different setting was formed at that location where the massif border is intersected by important tectonic lines and where a topography of parallel basins and ranges [Hrádek 1991; Ivan 1992] has formed (e.g. in the Brno Basin, at the head of the submarine canyon of the Nesvačilka Graben filled in Paleogene), or in those places in which grabens on triple junctions, as part of the so called turtle carapace structure of blocks [Hrádek 1983], simultaneously with the foredeep arose along old Variscan faults in the course of upwarping (an example of this can be seen in Rakovec valley).

The forebulge consists of a number of partials domes, half–domes or tilted half–horst, separated transversally by depressions or by valleys; the origin of which is subject of the present paper. The eastern slopes of the forebulge which form the outer slope of the foredeep display a step–like character due to several half–grabens they contain [Hrádek and Ivan 1974; Hrádek 1983; Hrádek 1987; Hrádek 1992] (Fig. 1).

At the period of the forebulge's origin, the old submeridional graben structure (NNE–SSW) of the Boskovická brázda Furrow along with its projections to the north were rejuvenated and renewed in the new shape of a graben or half–graben which separated the elevation of that forebulge from the morphological border of the Bohemian Massif. The elevation morphostructure is more or less striking, narrowing or widening in places, which is in a way analogous to the Slavkov Ridge on the inner side of the Lower Badenian

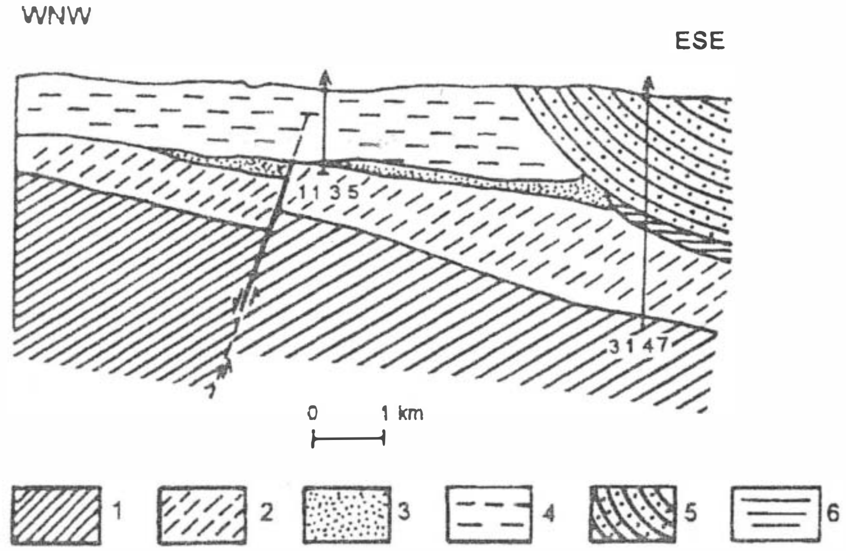

FIG. 1. System of tilted blocks with half-grabens on the southeastern slopes of the Bohemian Massif lying in the basement of the foredeep at the contact of the flysch thrust belt of the Western Carpathians (according to Adámek, 1985). 1. Crystalline rocks of the Bohemian Massif. 2. Jurassic limestones and marls. 3. Eggenburgian sediments (Miocene). 4. Sediments of the Carpathian (Miocene). 5. Front of the flysch thrust of the Western Carpathians. 6. Sediments of Upper Cretaceous.

through this morphostructure and opening into the Carpathian Foredeep is linked with forebulge's development as well. Most valleys, or at least part of them, display the characteristics of complicated tectonic valleys or ramp valleys. Their origin and their structure have been influenced by the development of the adjacent part of the foredeep, by the structure of the forebulge, and by the degree to which the preceding tectonic disturbance of rocks occurred in the older tectonic stages of its geological evolution. Each valley[1] bears features of a purely specific development in which a significant role has been played by normal faulting making it unwise, at the same time, to completely exclude the role of erosional evolution. For example, the development of the Jihlava valley.

3. DEVELOPMENT THE JIHLAVA VALLEY

In the section between the Boskovická brázda Furrow and the Carpathian foredeep the river overcomes the southern part of the ridge-shaped igneous Brno Massif. The ridge with features of half-dome up to inclined half-horst, which makes part of the forebulge consist of a system of step-like blocks, normal antithetically faulted

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[1] We deal with valley sections of the rivers Dyje, Jevišovka, Jihlava, Bobrava, Svratka, Svitava, Rakovec, Romže, Třebůvka, Moravská Sázava and Odra, and possibly others before they leave the Bohemian Massif.

and inclined to the southeast. Individual blocks are separated by several half-grabens (Fig. 2). A striking aspect is featured by the Silůvky half-graben crossing southwards the Jihlava valley in the Bránická kotlina Basin.

A geomorfological analysis of the valley zone of the Jihlava, of up to 6 km in width, shows delimited hanging higher-placed subparallel grabens with tectonically subsided sediments of the Older Miocene which separate step-like arranged and inclined towards the valley axis blocks. There is an expressed frontal, lateral and distal fault limitation to the blocks. Some parts of them have obviously also been subjected to surface flexural bending directed towards the valley. The faults in the saddles and at the feet of the grabens can both be identified morphologically. The tectonic limitation of blocks established by means of a geomorphological analysis has also been confirmed geophysically [Hrádek 1995a,b]. The faults separating the higher blocks from the lower ones in grabens have been traced by radar sounding and shown to be either narrow or wide failure zones of up to 30 m in width. In the grabens two or more parallel downhill-dipping zones of disturbance running along the footlines of the slopes delimitating the graben have been discovered. One clean-cut disturbance zone situated at the foot of a steeper scarp is typical for half-grabens. Another, similar situation is found in the striking fault saddles of the slopes – those areas are cut by wide disturbance zones (Fig. 3).

The main valley is also unevenly filled with both tectonically subsided Miocene sediments preserved from the older (Eggenburgian–Ottnangian) sedimentation phases, as well as with sediments deposited in the newly originated grabens of the Lower Badenian age. Upper Miocene sediments fill the bottom of the valley beneath the flood plain, mainly in its eastern part. Lower Miocene deposits are preserved even on slopes. In the middle part of the valley the river passes through a higher-situated threshold which juts out from the graben bottom; this passage was achieved by means of a cut in an incised meander. The Pleistocene river terraces evolution was dependent on the pace of removal of Miocene deposits from the valley. The above mentioned basin, Bránická kotlina, was formed at the crossing point of crossing of the tectonic valley graben and the Silůvky half-graben.

The tectonic development of the valley in the period of the transition between the Carpathian and the Lower Badenian phases of the Miocene can also be proven sedimentologically. Deposits from the Older Miocene, resting above the eastern part of the valley, are tectonically disturbed by reverse, dip slip faults. The tectonic uplift with local extension in the Lower Badenian was accompanied by both gravitational disturbances at the borders of blocks and by susceptibility to rockfalls and debris avalanches, rotational rockslides along their planar failures submarine flows of slumps and debris that were remoulded into clay and subsequently liquefied during their movement.

Deposits, having witnessed diastrophic events, are proof of their sliding-down into the depression newly formed by normal faults. They have been identified in exposures and excavations [Hrádek 1987; 1992]. One exposure has also revealed tectonic contacts of debris avalanche deposits of Lower Badenian rocks of Brno Massif along the renewed planar surface of fissures (slickensides ?) begun in the preceding stages of its tectonic development. Matrix of sedimentary

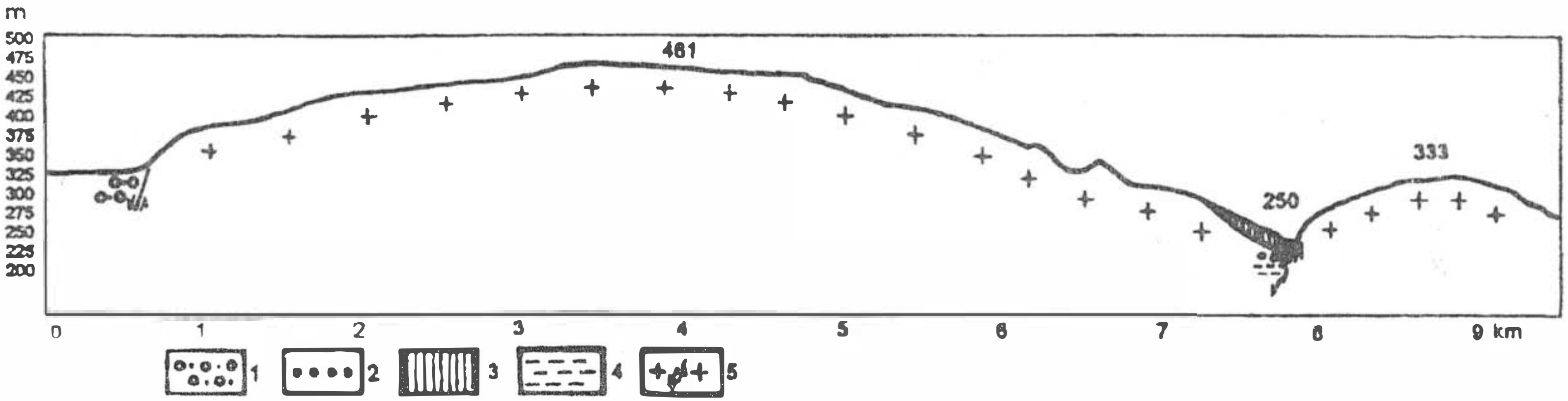

FIG. 2. Cross section of the forebulge in the southern part of the Brno Massif across the so called Hlína halfdome. 1. Permian conglomerates. 2. Pleistocene fluvial gravels. 3. Pleistocene loess sheet. 4. Miocene sediments, 5. Granodiorites and metabasites of the Brno igneous massif, disturbed by normal faults.

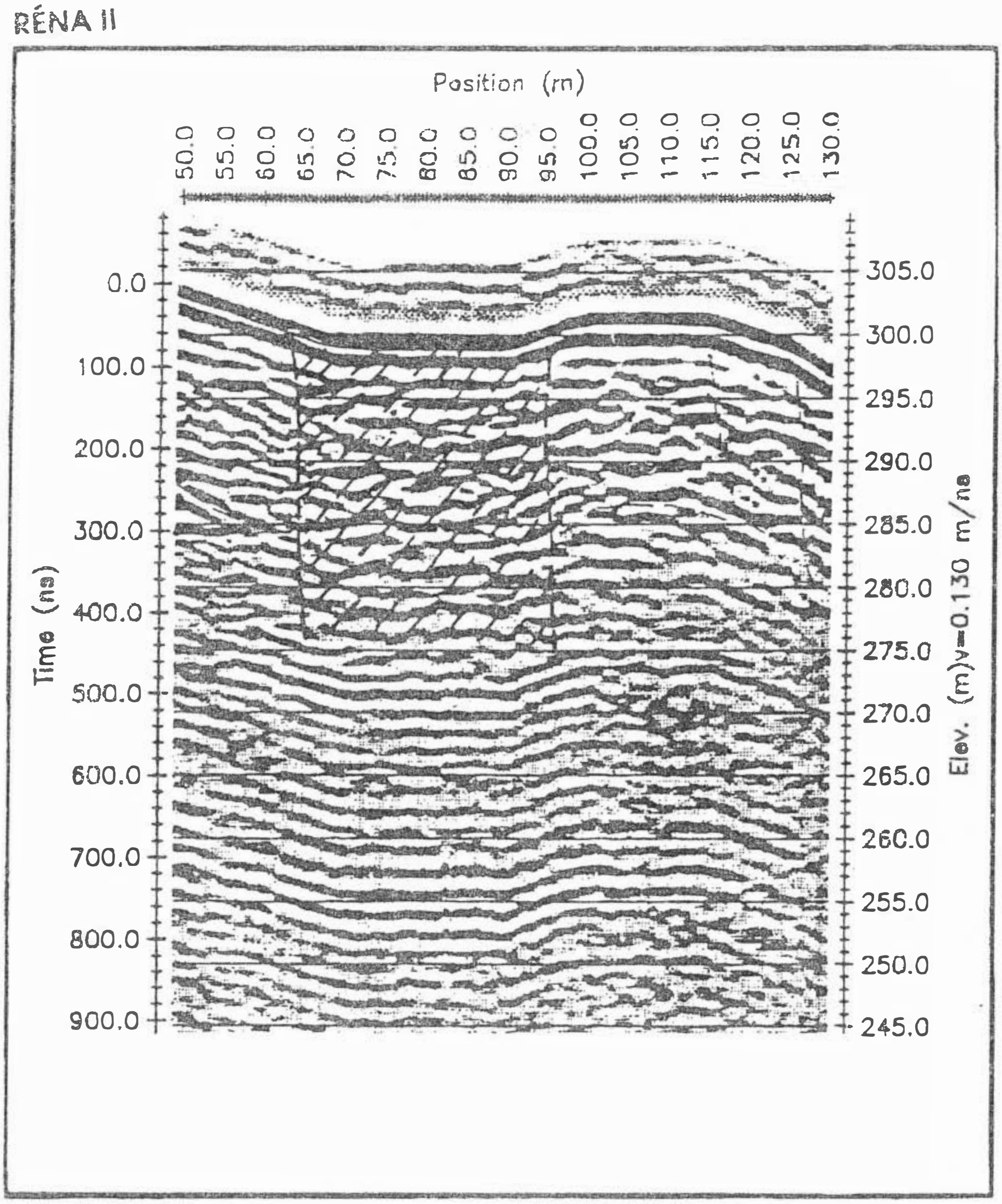

FIG. 3. Radar record of a steeply dipping fault in the fault saddle on the southern slope of Réna Hill. The graphic record shows a clear fissuring of the massif down to the depth of 15–20 m in the tectonic zone of 30 m of width at the foot of the higher slope. The fissuring manifests itself in numerous irregular reflections.

breccia consisted originally of calcareous mud. The origin of gravity mass flow deposits is connected with erosion effects exerted upon the bedrock [Hrádek 1987]. The deposits, the origin of which resulted from gravitational disturbances, are quite absent in the Older Miocene strata in the section west of Ivančice, where e.g., Eggenburgian–aged bentonites are featured by their extraordinarily clean sorted clays, quite in contrast to their present position in a deep valley.

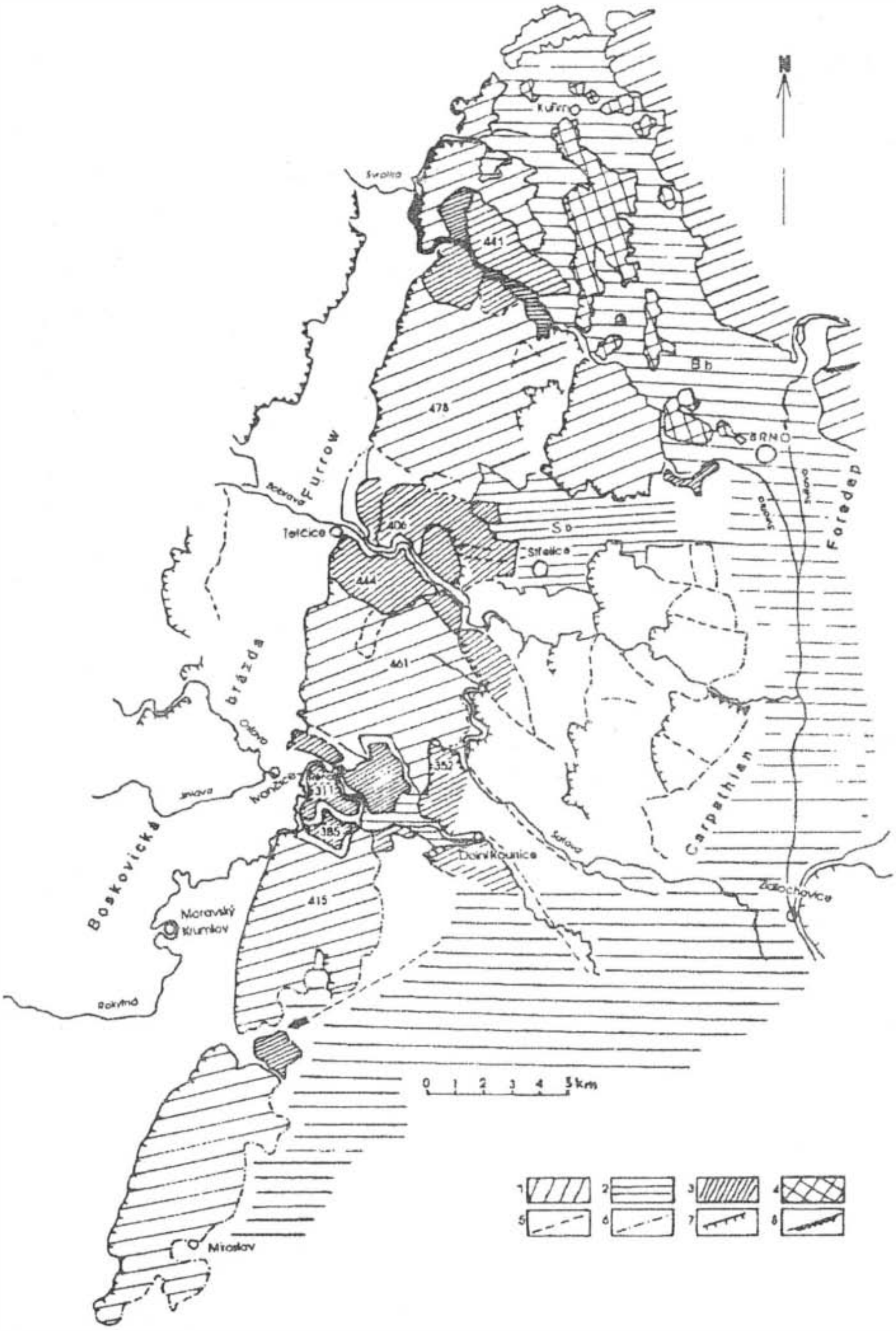

FIG. 4. A structural geomorphic map of the southern part of the forebulge on the eastern outer slopes of the Bohemian Massif. Zones with systems of relatively subsided smaller blocks were used by rivers and reworked them into the form of present valleys. The arrow-marked graben with Miocene sediments to the south of Moravský Krumlov was not used as a river valley. 1. The top part of the forebulge on the southeastern margin of the Bohemian Massif formed by a system of antithetic tilted blocks that are separated by half-grabens. 2. Basins formed in the course of normal antithetic faulting of the outer slopes of the forebulge. 3. Smaller normal faulted blocks in the most disturbed zones of the forebulge. 4. Blocks rising from basins showing basin and range topography. 5. A likely course of some faults. 6. Contact of tilted blocks with the Miocene filling of the foredeep and the basins of outer slopes of the forebulge. 7. The fault-limited half-grabens. 8. Fault scarps. Bb: Brno basin. Sb: Střelice basin. Areas without hachures along the Carpathian Foredeep means outer slopes of Bohemian Massif.

Beginning with the actual state of research it can be supposed that valley development is closely connected with the margin uplift of the Bohemian Massif, with the origin of the forebulge and partial normal faulting in those places which have experienced tectonic disturbance. The formation of the valley was clearly conditioned by the already existing strong tectonic disturbance of granodiorites and metabasites of the Brno Massif within the zone of the Ivančice–Trboušany Fault, featuring disturbances of NW–SE, NNW–SSE, W–E and NNE–SSW directions (Fig. 4). During the course of the uplift this markedly disturbed and, consequently, incoherent zone suffered relatively normal faulting along with the formation of a cover of Older Miocene sediments which had originally been deposited on the flat margin of the platform (Fig. 5).

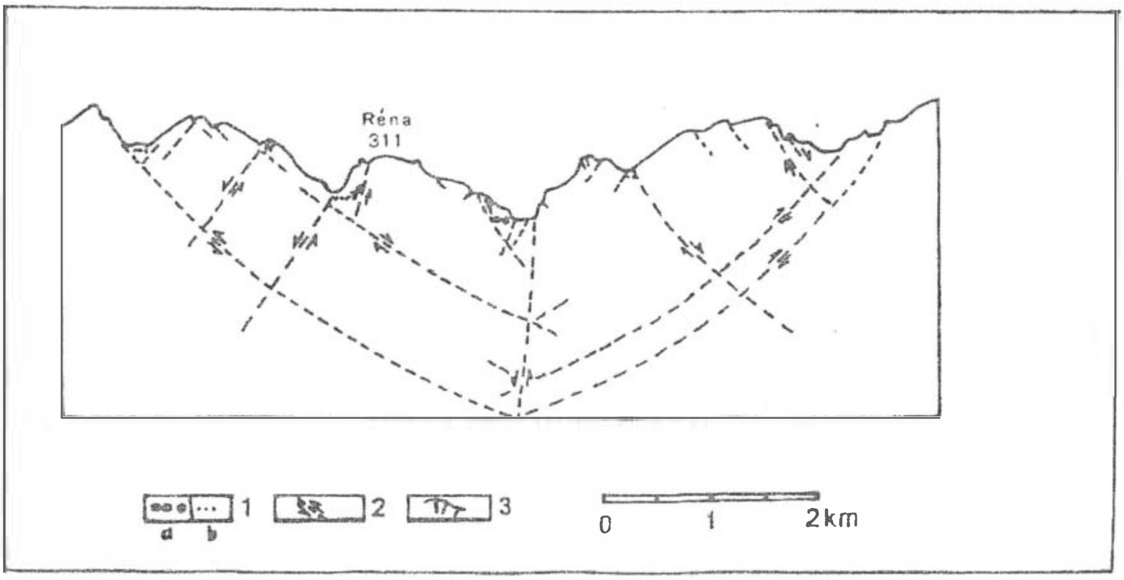

FIG. 5. A cross profile of the Jihlava valley with a hypothetical representation of its tectonic structure. 1 A. Sediments of the Lower Miocene. 1 B. Sediments of the Upper Miocene. 2. Supposed faults and their motion trends. 3. Gravitational dilatant cracks.

The manner and the style of this normal faulting are still the subject of investigations.

4. NATURAL HAZARDS

The tectonic valleys and the slopes of the forebulge are liable to some types of natural hazards. They constitute the kind of environment that is characterised by strong tectonic disturbance, local extension and origin of gravitational failures, particularities in the position of the Miocene and the Pleistocene sediments featuring various lithological properties (above all differences between permeable loesses and impermeable Miocene clays at their underlying bed with influences on the action of permeating water), and, finally, by the shape of small catchments at the closure of the half–grabens. Such an environment creates preconditions for the origin of deep seated creep, of piping, and of flash floods.

The process of gravitational spreading in the Jihlava valley is most intensive, and is quite similar in this point as much as gravitational failures are concerned, to processes that are present on originally glaciated mountain ridges. The strong tectonic disturbance can be clearly seen in the cuts of communications lines, where there are frequent rock falls, the loosening of blocks and the accumulation of debris.

In the inclined surfaces of those blocks which form valley slopes and on their margins quite a number of gravitational failures in the form of downhill–facing scarps, various types of tensional gashes, double–, triple– and multiple–crested ridges and slope benches have also been found. The dependence of these morphologically perceptible features on rather deep failures has also been confirmed geophysically (Fig. 6). At the head of submarine Vranovice canyon which is tectonically overdisposed, the deep seated creep of slopes along these gravitational failures, especially on the margins of the blocks, can be viewed upon, as in the case in question, as the continuation of present tectonic movements and a "sinking" of blocks into the loosened deeper bedrock. The slope unloading is of course also caused by fluvial erosion which clears away Miocene sediments that continue to fill valley bottoms.

A substantial feature of the gravitational disturbance of this type of downhill–facing scarps and of the double–crested or multiple–crested ridges are the appearances of tensional stresses, open tension fissures, and dilatant cracks, which open into positions close to the divide between the grabens or in the upper parts of slopes. They are seen in georadar records as double diffractions and oblique reflexes dipping downslope of the valley. The dilatant cracks on the divides in granitic rocks are featured by systems of gully–like gashes with pairs of mutually antagonistic dipping failures which limit wedge-like shaped blocks visible in georadar record and in outcrops as well; the above systems are ramified fanwise in the form of bows [Hrádek 1995a]. The multiple appearances of tensional stress brought about by the parallel failures of disturbed borders of the blocks above the grabens have also been found in slope benches. The surface of uphill facing benches beneath the top of the ridge indicates the origin of rotational shear planes linked to normal faults of small blocks [Hrádek 1995a].It can be stated that most of these failures are situated in gravitation spreading stress fields which are characterized by the properties of the above mentioned gravitation landforms, i.e. both extension or compression.

In those slopes with Miocene clays, covered by permeable Pleistocene loesses, gullies often arise the development of which, is decisively influenced by piping. The piping process speeds up during sheeted rains when surface above cavities collapses and gullies propagate both in the width and in their head parts. The appearance of the phenomenon consists in the fact that there is an over–supply of rain water infiltrating along vertical fissures into the loesses of as much as 4 m in depth. At their base, water reaches the impermeable bedrock of Miocene clays and hollows out underground tunnels leading towards the bottom of gullies. After the cavities have collapsed the process affects another zone of loess that had yet to be disturbed. This is the way in which gullies actively prolong themselves and become broader both laterally and

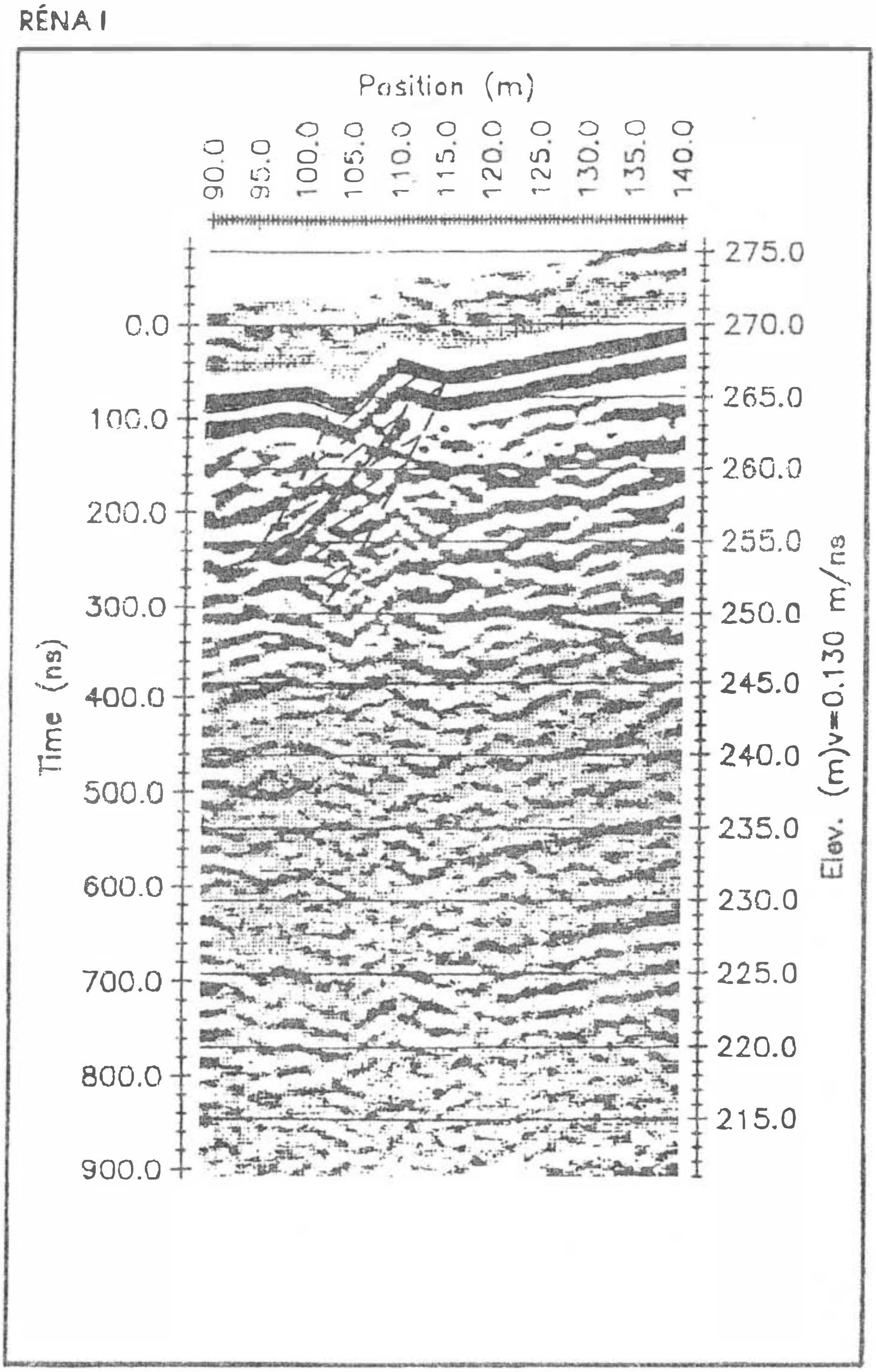

FIG. 6. Radar record of a slope failure forming a simple downhill–facing scarp. In underlying rock the massif disturbance formed an 11 m wide zone showing clear appearances of tension stress. The failured zone that manifests itself by irregular reflections dips towards the north–east.

Both gravitational failures and piping put the stability of communications, transport structures and houses at risk and turn the forebulge–affected territory into a hazard area. More attention must be paid to geological surveys before commencing with the building of transport facilities. In cases such as these the use of both geomorphological and geophysical investigations is necessary.

At the opening of the small catchment of Mlýnský potok Brook, a 5 km^2 area into Jihlava in the Bránická kotlina Basin there is the village of Nové Bránice. Besides piping, this catchment is susceptible also to the formation of flash floods. The main presupposition for their formation is constituted by the asymmetry of the catchment, one side of which, namely the western one, consists of long slopes following exactly the lines of the surface of blocks inclined towards the east with a dense network of dells; the opposite side, on the contrary, is formed by short steep slopes on block fronts with remnants of Lower Miocene sediments. A capture shape, which has developed irregularly in thus way, makes it possible for a large amount of water, in the course of storm runoff, to pour down, especially from long the western slopes, into the brook channel; the latter, however, cannot take it in, the consequence being a quick bank overflow and the menace to the village of a flash flood.

On May 26, 1994, there was a cloudburst in the capture of the Mlýnský potok Brook. In the course of the three–hour rain, from 8 to 11 P.M., the precipitation record showed 108 mm (out of which cca 90 mm fell in the first hour). During the first hour there was a flash flood which inundated many houses. The channel discharge at the peak of the flood was calculated as 30 m^3.s^{-1}. Adding to the flood's origin were imperfections in the organization of rain water outflow from the catchment, i.e. the liquidation of protective dams upstream from the village and large areas covered by those plant species dangerous in terms of erosion hazards (vineyards, maize) which had an accelerating effect on the water's outflow [Hrádek and Ondráček 1995].

5. CONCLUSION

The tectonic origin of valley sections at the eastern margin of the Bohemian Massif was crucially affected by the formation of the forebulge and the strong tectonic disturbance of the rocks in those zones running along the main faults. The neotectonic elevation, called forth by an uplift which was itself a part of a flexural bending, occurred after a continent – continent type of collision between the North European Platform and the system of Carpathian–Pannonian blocks on the Carpathian–Badenian period divide. This alpine morphostructure can be delimited using geomorphological methods. The tectonic valleys either open themselves into graben–like sections of the Lower Badenian foredeep, into its salients, or link up to the grabens of the submarine canyons of Nesvačilka and Vranovice in the basement of the foredeep. The main proof of the tectonic origin of valleys, demonstrated using the example of the Jihlava, are: the block morphostructure and the geophysically proven existence of faults at the contact line of higher– and lower–placed blocks in the grabens; reverse,dip slip deformation of the Lower Miocene sediments above the valley; and the identification of sediments of submarine gravitation flows and debris avalanches directed towards the newly formed valleys called forth by tectonic movements in the Upper Miocene. The tectonic development of the valley continues at present very slow by the processes of gravitational spreading and deep seated creep with manifold morphological appearances of failures and stress fields, e.g. crack and fissure opening by dilatation and step–like normal faulting of blocks which follow the planar or rotational shear planes. The valley's developmental peculiarities have formed the necessary conditions for the existence of natural hazards. In addition to gravitational spreading induced processes it is furthermore piping and flash floods, that require increased attention. Areas affected by slope unloading, spreading and deep seated creep display disturbed stability conditions.

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ÚDOLÍ VÝCHODNÍHO OKRAJE ČESKÉHO MASIVU: STRUČNÝ NÁSTIN JEJICH PŮVODU, STÁŘÍ A PŘÍRODNÍCH RIZIK

Mojmír HRÁDEK

Hlubokým údolím východního okraje Českého masívu, ústících do karpatské předhlubně, je často přisuzováno předmiocénní stáří a erozní původ. Nové poznatky opírající se o geomorfologický, geofyzikální a sedimentologický výzkum ukazují, že na vzniku údolí se podílely tektonické pohyby vyvolané jako odezva kolize severoevropské platformy s karpato–panonskými bloky, na rozhraní karpatu a badenu v miocénu. Tektonická predispozice údolí vyvolává náchylnost ke vzniku některých přírodních rizik, zejména svahových pohybů, tunelové eroze a bleskových povodní.