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MOJMÍR HRÁDEK – ANTONÍN IVAN

STUDY OF THE BLOCK STRUCTURE AND NEOTECTONIC MOVEMENTS IN THE ČESKÁ VYSOČINA (BOHEMIAN HIGHLANDS) BY METHODS OF MORPHOSTRUCTURAL ANALYSIS

1. Introduction

The study of block tectonics represents a very progressive direction of research, both in geology and geomorphology. This is shown e. g. by the recognition of the importance of deep faults in earth's crust structure in world- wide scale (I. I. Chebanenko 1963), by formulating the conception of the block structure for old massifs (e. g. Variscan mountain ranges in Central Europe, J. Zeman 1970) and by investigations of the young and recent tectonic movements. The possibilities of application of geomorphological methods in research of the block tectonics are known but are used only rarely (E. S. Hills 1963). This is true even for the region of the Česká vysočina (Bohemian Highlands). Experience has shown that the best method for the recognition of the block structure and of the faults by geomorphological methods is the morphostructural analysis. Its basis is the interpretation of topographical maps and detailed field mapping. An important point of issue can be the results of geological investigations, mainly data on tectonics. There are many relief features on the basis of which the existence of faults and disturbance belts can be supposed. They manifest themselves most often in the arrangement of the valley pattern, in the direction and form of slopes, and in the distribution of young deposits. After the comparison of the results of field investigations carried out so far the construction of the map of block structure can be accomplished. The methods of the compilation af this map will be affected — mainly in the case of large-scale maps — by local geological and geomorphological conditions. A very good aid in the construction of maps of block structure are the topographical profiles.

2. The block structure of the Česká vysočina (Bohemian Highlands)

The territory of the Česká vysočina (Bohemian Highlands) belongs among regions where intensive tectonic movements often took place in the course of the geological development. The main periods of tectonic activity were the orogenetic Assynthian, Caledonian and Variscan movements. In the relatively recent geological past new movements usually designated as Saxonian tectogenesis took place on older or even newly formed faults. During its long development the Česká vysočina (Bohemian (Highlands) obtained features of a distinct compact unit in both geomorphological and structure-geological sense (the Bohemian Massif). According to classification of landforms suggested by I. P. Gerasimov (1946) the Česká vysočina (Highlands) can be considered a morphostructure. According to I. P. Gerasimov and J. A. Mescherikov (in

R. W. Fairbridge 1968) „Morphostructure consists of those forms of the earth's surface which are produced by the interaction between endogenetic and exogenetic forces, the endogenetic factor being predominant in the tectonic movements of the earth's crust. The morphostructure consits mainly of the major forms of earth's relief (mountain ranges, intermontane basins, plateaus, lowlands etc). However, morphostructures are also relatively smaller forms of relief, which are formed directly by tectonic movements, such as anticlines, basins, domes, arches, faults and other topographic elements." According to latest opinions the Česká vysočina (Bohemian Highlands) are divided by a system of deep faults of very old origin in a system of large blocks (J. Zeman 1970). These blocks (Fig. 1) are subdivided by faults of lesser significance (often even of younger origin) in partial blocks of smaller dimensions. The intensity of the block faulting is usually greatest in zones along deep faults. Perpendiculary to these faults the intensity quickly decreased. In greater distances from the deep faults are regions with extensive remnants of surfaces of planation which are tectonically almost not-disturbed.

The geological maps of some sedimentary regions of the Česká vysočina (Bohemian Highlands) (e. g. of the basins at the foot the Krušné hory, Ore Mts.) and of the basins in South Bohemia) show a very dense network of faults. In the adjacent crystalline regions the number of known or hypothetical faults is much smaller. These crystalline regions are built of much older and more rigid rocks and were also subject to a longer and more complicated development. The features of block structure are even in these crystalline regions often very evident.

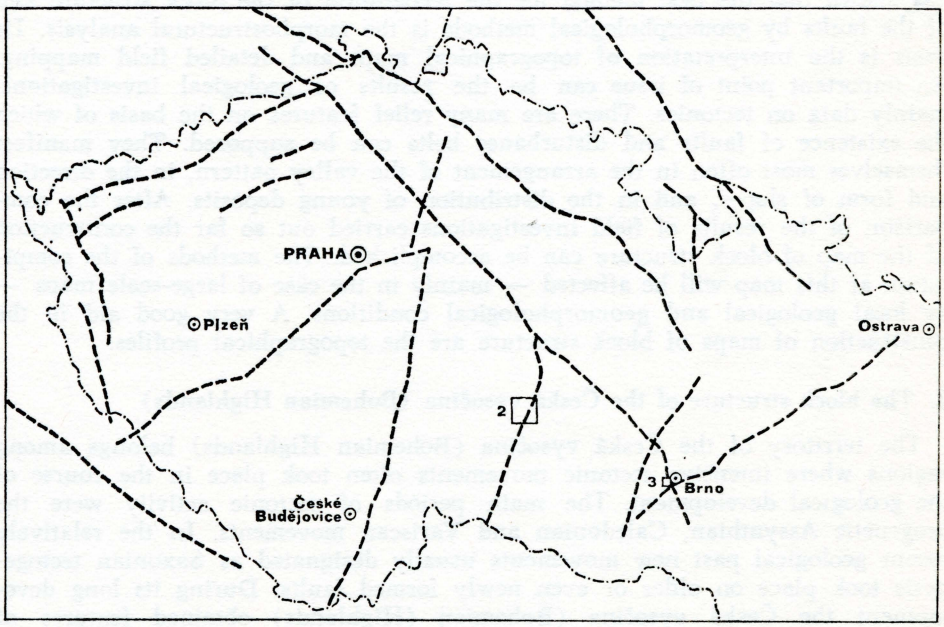

Fig. 1. Map of the main faults and fracture zones forming the block structure of the Česká vysočina (Bohemian Highlands)
(compiled on the basis of different sources).

The authors of this article investigated minutely by means of the method of morphostructural analysis two parts of the Česká vysočina (Bohemian Highlands) adjacent to the zone of the deep fault. The territory north of the town of Jihlava is situated in the central part of the Českomoravská vrchovina (Highland). It belongs to the Jihlavsko-sázavská brázda (Furrow). This territory was investigated by M. Hrádek. The SE margin of the Česká vysočina (Bohemian Highlands) on the contact with the Dyjsko-svratecký úval (Graben) in the environs of Brno) was studied by A. Ivan. The results show that the present relief originated mainly due to vertical neotectonic movements, especially along the zones of deep faults. The faults form in the relief distinct systems as is shown e. g. by main relief forms and by drainage pattern. The investigations have confirmed the supposed intensive block faulting both in the central and in the marginal part of the Česká vysočina (Bohemian Highlands) and brought a number of methodical knowledge on the basis of which even other parts of the Česká vysočina (Bohemian Highlands) can be treated.

3. The block structure of the relief of the central part of the Českomoravská vrchovina (Highland) north of the town of Jihlava

On the territory north of the town of Jihlava geological and geomorphological mapping on the scale of 1:25 000 was carried out in the years 1964—1970. In the course of this mapping close cooperation between the mapping geologist and geomorphologist could be realized. This cooperation resulted in the construction of the map of block forms and in the understanding of the tectonic structure of the territory in question.

From the geological point of view the territory north of the town of Jihlava is situated between three intrusive bodies of Variscan age, i. e. the central granite pluton (Moldanubian), the syenite massifs of Jihlava and Třebíč — Velké Meziříčí. The territory is built of sillimanite-biotite gneiss and migmatites of varied series of Moldanubicum. Across these rocks runs an important tectonic line — the mylonite zone of Přibyslav (J. Koutek 1935). This is founded on a deep fault separating the Bohemian and Moravian branches of the Moldanubicum. J. Zeman (1970) named this fault the West-Moravian deep fault. The regional gravitation field of the Bohemian part of the Moldanubicum is disturbed negatively, in the Moravian branch positively (L. Mottlová 1970). The mylonite zone of Přibyslav is older than Variscan.

The mylonite zone of Přibyslav is mostly several hundred metres up to 2 km wide. But its width increases up to 8 km in the region between Jihlava and Polná. In this section the mylonitized territory is bordered by marginal faults. The mylonite zone of Přibyslav manifests itself morphologically as a belt of a lower hilly relief reaching altitudes a. s. l. from 490 to 560 m, which is surrounded by a higher highland relief (up to 660 m). In the belt of the lower relief relics of sandy-clayey and gravely-sandy deposits have been found. These sediments were determined on the basis of plant relics as being of Pliocene age. On the base of this sediments the layer of gravels is developed. The relief of the territory north of the town of Jihlava has features of a block structure which have not been stated on the geological map on scale of 1:200 000, sheet Jihlava.

The morphostructural analysis of the relief was based on the study of topographical maps, on the investigation of Pliocene deposits and on the results of detailed geomorphological and geological mapping. Attention was paid mainly: to the drainage pattern (in which the regular repetition of sections of a certain direction can be seen), to the run of the foot lines of fault scarps, to the arran-

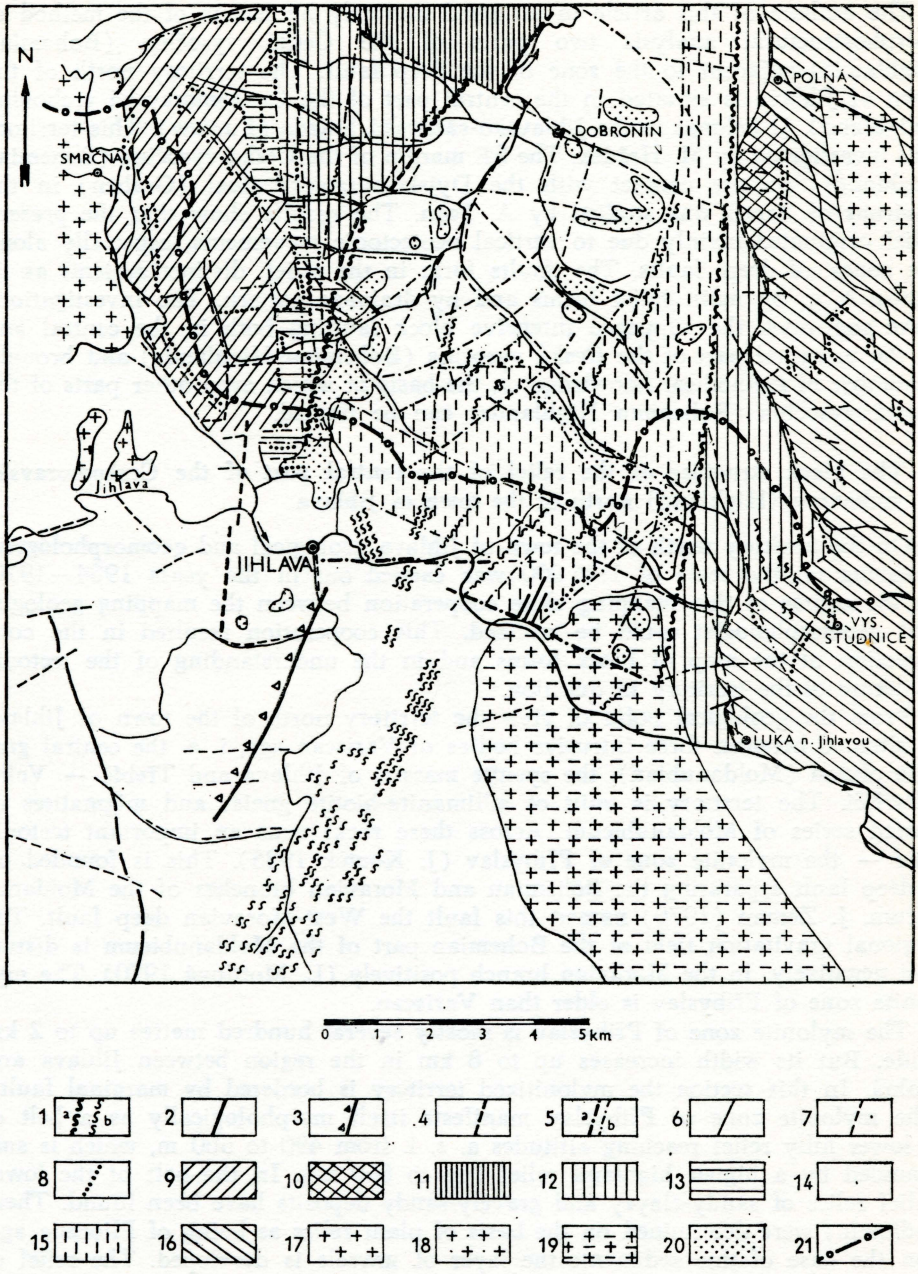

Fig. 2. Map of block forms in the surroundings of the town of Jihlava
1a Marginal faults of the mylonite zone of Přibyslav
1b Other mylonite zones
2 Geologically known main faults
3 Dislocation breccia
4 Geologically supposed main faults
5a Main faults supposed on the basis of morphostructural analysis

gement of cols, to the breaks of angle of inclination of slopes and of longitudinal profiles of streams, to the longitudinal profiles of ridges, to the distribution of Pliocene deposits, to the places where these deposits were deformed probably by tectonic movements, to the changes in thickness of deposits on short distances and to the altitudes above sea level of localities of Pliocene deposits.

On the basis of the morphostructural analysis the map of block forms was constructed. For this construction all faults were utilized which have been stated by means of geological or geophysical methods. In the map in the first place the two marginal faults of the mylonite zone of Přibyslav and number of other faults were designed. The marginal faults border the distribution of Pliocene deposits in W and E. From these main faults a number of mostly parallel faults of 2 nd order diverge fan-like, in W northwards and in E SE-wards. Faults of 2 nd order are connected with intrusions of granites and syenites of the Moldanubic pluton. Finally transverse faults of 3 rd order can be found here with NW — SE up to E — W directions and also diverging from the marginal faults of the mylonite zone of Přibyslav. Also the territory between the two marginal faults is segmented by a network of faults and mylonites. Fan-like divergent faults prevail, breaking and bending in their course from N — S to NE — SW direction. Even transverse faults of W — E direction are important.

On the basis of the morphostructural analysis and of the design of earlier geologically stated or supposed faults the following block forms could be distinguished in the territory investigated north of the town of Jihlava: (1) the system of horst ridges of the group of Vysoký kámen (660 m a. s. l.), (2) the belt of foot steps bordering the horst ridges in E and S, (3) moderately sloping blocks along the foot line of foot steps (foot blocks), (4) block forming bottom of the Jihlavsko-sázavská brázda (Furrow) — a intensively mylonitized territory of the Přibyslav zone which is step-like rising in the form of a transverse threshold (very flat ridge). East of the Jihlavsko-sázavská brázda is a relief, where traces of block structure are less distinct. This is due to the smaller resistance of sillimanite -biotite gneisses (a consequence of the migmatitization decreasing from W to E) and accordingly also due to increased denudation activity which partly destroyed the features of the block structure. Besides the above mentioned main blocks many other blocks can be distinguished which are not obvious in relief.

5b Other faults supposed on the basis of morphostrucural analysis
6 Less important geologically known faults
7 Less important geologically supposed faults
8 Foot lines of fault scarps
9 Territory strongly affected by neotectonic movements (system of horst ridges)
10 A distinct horst ridge
11—12 Foot blocks
13 Foot steps
14 Block of bottom of the Jihlavsko-sázavská brázda (Furrow)
15 Part of the bottom of the Jihlavsko-sázavská brázda (Furrow) (uplifted by neotectonic movements)
16 Territory with tectonic features partly destroyed by denudation
17 Central granite pluton
18 Syenite massif of Třebíč — Velké Meziříčí
19 Syenite massif of Jihlava
20 Pliocene sediments on the bottom of the Jihlavsko-sázavská brázda (Furrow)
21 Main European watershed (Elbe — Danube)

The following conclusion can be drawn on the basis of the morphostructural analysis of the relief of the central part of the Českomoravská vrchovina (Highland) north of the town of Jihlava: The Jihlavsko-sázavská brázda (Furrow) is a depression developed in Pliocene (as the paleontology and stratigraphy of sediments shows) by relative subsidence of the territory of the mylonite zone of Přibyslav under the uplift tendency of the Česká vysočina. As geomorphological investigation stated the graben is bordered on its sides by step-like fault scarps which probably developed in two stages of tectonic movements. The neotectonic movements also caused relative step-like uplift of the southern part of the Jihlavsko-sázavská brázda with amplitude of 70 m.

4. The block structure on the SE margin of the Česká vysočina (Bohemian Highlands)

The dependence of the relief forms on the block tectonics in the surroundings of Brno was proved most completely by J. Krejčí (1964). The intensive tectonic fracturing of the Brno massif is also well known. The tectonic relief is the result of young movements on a very dense network of faults. To this fact corresponds the complicated mosaic of fault blocks. According to our knowledge the blocks of the lowest order are bordered by faults only some tens or hundred metres long. The causes of intensive faulting and of origin of the specific tectonic relief in this territory have not yet been explained. Usually the connection with tectogenesis in the Alps and Carpathians was mentioned. In our opinion, there are several causes which can be summarized within the frame of a working hypothesis as follows:

1. Origin of the eruptive Brno massif (probably of Assynthian age) in the deep tectonic zone (L. Musilová 1969). The influence of this factor is demonstrated e. g. by the most intensive faulting in the narrow central basic belt of N—S direction (built of diabase and diorite). Here, according to L. Musilová greatest compression occured. Some aspect of these relations have been already recorded by K. Zapletal (1927).
2. Presence of several faults of great regional significance, e. g. the deep fault in the substratum of the depression Boskovická brázda (Furrow). Some authors consider this disturbance as a great left-lateral fault (J. Jaroš — Z. Mísař 1967). North of the town of Brno a deep fault runs on the line Tišnov—Kuřim. Other important faults bordering the Řečkovicko-kuřimský prolom (Graben) lie in the extenison of the Nesvačilka Graben which is a transverse structure in the pre-Tertiary substratum of the Carpathian foredeep. Again, the most intensive faulting was in the area of the intersecting of these faults (in the surroundings of the town of Kuřim).
3. Oscillatory tectonic movements of the SE margin of the Česká vysočina and their general uplift and doming in the neotectonic period (Neogene — Quaternary).
4. Effects of tectonic movements which took place in the adjacent part of the Carpathians can be considered as resonant-tectonic movements in J. Puscharovski's sense (1969).

The main features of the relief of the territory on the SW margin of the town of Brno were described by J. Krejčí (1964) and A. Ivan (1971). In this area four blocks of higher order can be distinguished. These are the horst of Kohoutovice (A in fig. 3), the horst of Červený kopec (B), the horst of Kraví hora (C) and the graben of the Pisárecká kotlina (Basin) (D). These four forms can be roughly defined already on the basis of the analysis of topographi-

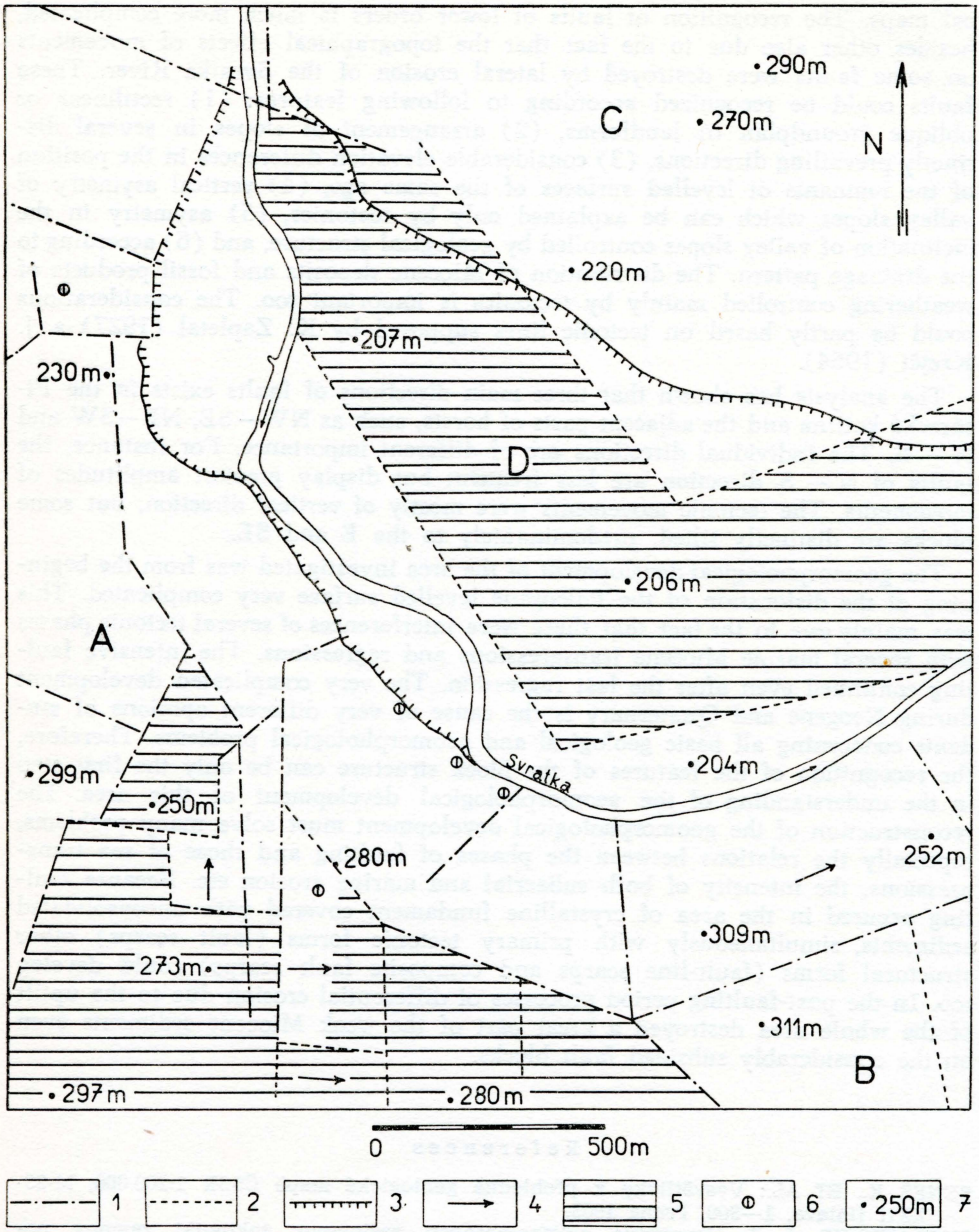

Fig. 3. Main features of the block structure of the Česká vysočina (Bohemian Highlands) in the SW part of Brno.

1 Topographically distinct, partly geologically proved faults (connected with composite fault scarps and fault — line scarps)
2 Topographically less distinct or undistinct faults (supposed on the basis of boreholes)
3 Margin of the bottom of the Pisárecká kotlina Basin
4 Direction of tilting of the fault blocks
5 Miocene sediments
6 Occurences of pre-Miocene deep tropical weathering products
7 Spot elevations of the ground surface
Capital letters — fault blocks of high order (see text).

cal maps. The recognition of faults of lower orders is much more complicated, besides other also due to the fact that the topographical effects of movements on some faults were destroyed by lateral erosion of the Svratka River. These faults could be recognized according to following features: (1) rectilinear or oblique groundplan of landforms, (2) arrangement of slopes in several distinctly prevailing directions, (3) considerable elevation differences in the position of the remnants of levelled surfaces of the same age, (4) vertical asymetry of valley slopes which can be explained only by tectonics, (5) asymetry in the inclination of valley slopes controlled by geological structure, and (6) according to the drainage pattern. The distribution of Miocene deposits and fossil products of weathering controlled mainly by tectonics is important too. The considerations could be partly based on tectonic lines supposed by K. Zapletal (1927) a J. Krejčí (1964).

The analysis has shown that three main directions of faults exists in the Pisárecká kotlina and the adjacent parts of horsts, such as NW—SE, NE—SW and N — S. The individual directions are of different importance. For instance, the faults of N — S direction are less frequent but display greatest amplitudes of movements. The tectonic movements were mostly of vertical direction, but some blocks are distinctly tilted, predominantely to the E and SE.

The geomorphological development of the area investigated was from the beginning of the dislocation of the Paleogene levelled surface very complicated. This was mainly due to the fact that there were interferences of several tectonic phases with several marine Miocene transgressions and regressions. The intensive faulting continued even after the last regression. The very complicated development during Neogene and Quaternary is the cause of very different opinions of students concerning all basic geological and geomorphological problems. Therefore, the recognition of the features of the block structure can be only the first step in the understanding of the geomorphological development of this area. The reconstruction of the geomorphological development must solve many problems, especially the relations between the phases of faulting and those of sea transgressions, the intensity of both subaerial and marine erosion etc. Because faulting occured in the area of crystalline fundament covered with unconsolidated sediments, simultaneously with primary tectonic forms (fault scarps) other structural forms (fault-line scarps and composite fault scarps) could develop too. In the post-faulting period processes of differential erosion due to the uplift of the whole area destroyed a great part of the weak Miocene sediments even on the considerably subsided fault blocks.

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VYUŽITÍ MORFOSTRUKTURNÍ ANALÝZY PŘI VÝZKUMU KERNÉ STAVBY A NEOTEKTONICKÝCH POHYBŮ V ČESKÉ VYSOČINĚ

Při výzkumu kerné stavby a neotektoniky je — zvláště v oblastech tvořených krystalickými horninami — vhodnou pracovní metodou morfostrukturní analýza. Tato metoda spojuje výsledky topografické, geomorfologické a geologické analýzy a pomocí nich dovoluje určit význam endogenních faktorů v utváření reliéfu. V silně tektonicky porušených územích, jakými jsou například pásma podél starých hlubinných zlomů, umožňuje morfostrukturní analýza podrobné řešení kerné stavby a stanovení druhu a velikosti pohybů. Jako příklady jsou analyzována území Jihlavsko-sázavské brázdy severně od města Jihlavy, ležící v mylonitizovaném pásmu přibyslavské zóny (M. Hrádek) a území na okraji České vysočiny v jz. části Brna, v jehož širším okolí se protíná několik starých, významných zlomů (A. Ivan).

Vysvětlivky k obrázkům:

1. Hlavní zlomy a poruchová pásma České vysočiny, z nichž je patrná její kerná stavba (sestaveno podle různých pramenů). (Měřítko 1:2 mil.).

2. Mapa kerných a strukturních tvarů v okolí města Jihlavy.
a — okrajové zlomy přibyslavské mylonitové zóny
1 —
b — ostatní mylonitová pásma
2 — hlavní zlomy geologicky dokázané
3 — tektonická brekcie
4 — hlavní zlomy geologicky předpokládané
a — hlavní zlomy předpokládané na základě provedené morfostrukturní analýzy
5 —
b — ostatní zlomy předpokládané na základě provedené morfostrukturní analýzy
6 — méně významné zlomy geologicky dokázané
7 — méně významné zlomy geologicky předpokládané
8 — linie úpatí zlomových svahů
9 — území silně ovlivněné neotektonickými pohyby — soustava hrásťových hřbetů
10 — výrazný hrásťový hřbet v s. části Brtnické vrchoviny
11—12 — úpatní kry
13 — úpatní stupně
14 — dno Jihlavsko-sázavské brázdy
15 — část dna Jihlavsko-sázavské brázdy vyzdvižená neotektonickými pohyby
16 — území s. části Brtnické vrchoviny s rysy tektonické stavby částečně setřenými denudací
17 — centrální (moldanubický) žulový pluton
18 — třebíčsko-meziříčský syenitový pluton
19 — jihlavský syenitový pluton
20 — pliocénní sedimenty na dně Jihlavsko-sázavské brázdy
21 — hlavní evropské rozvodí

3. Hlavní rysy kerné stavby České vysočiny v jihozápadní části Brna.

1 — topograficky výrazné, zčásti geologicky dokázané zlomy (u složených zlomových svahů a svahů na zlomové čáře)
2 — zlomy málo morfologicky výrazné nebo nevýrazné (předpokládané na základě vrtů)
3 — úpatí dna Pisárecké kotliny
4 — směr úklonu zlomových ker
5 — miocenní sedimenty
6 — výskyty předmiocenních hlubokých zvětralin tropického typu
7 — kóty povrchu terénu
Velká písmena — zlomové kry vyššího řádu (viz text).