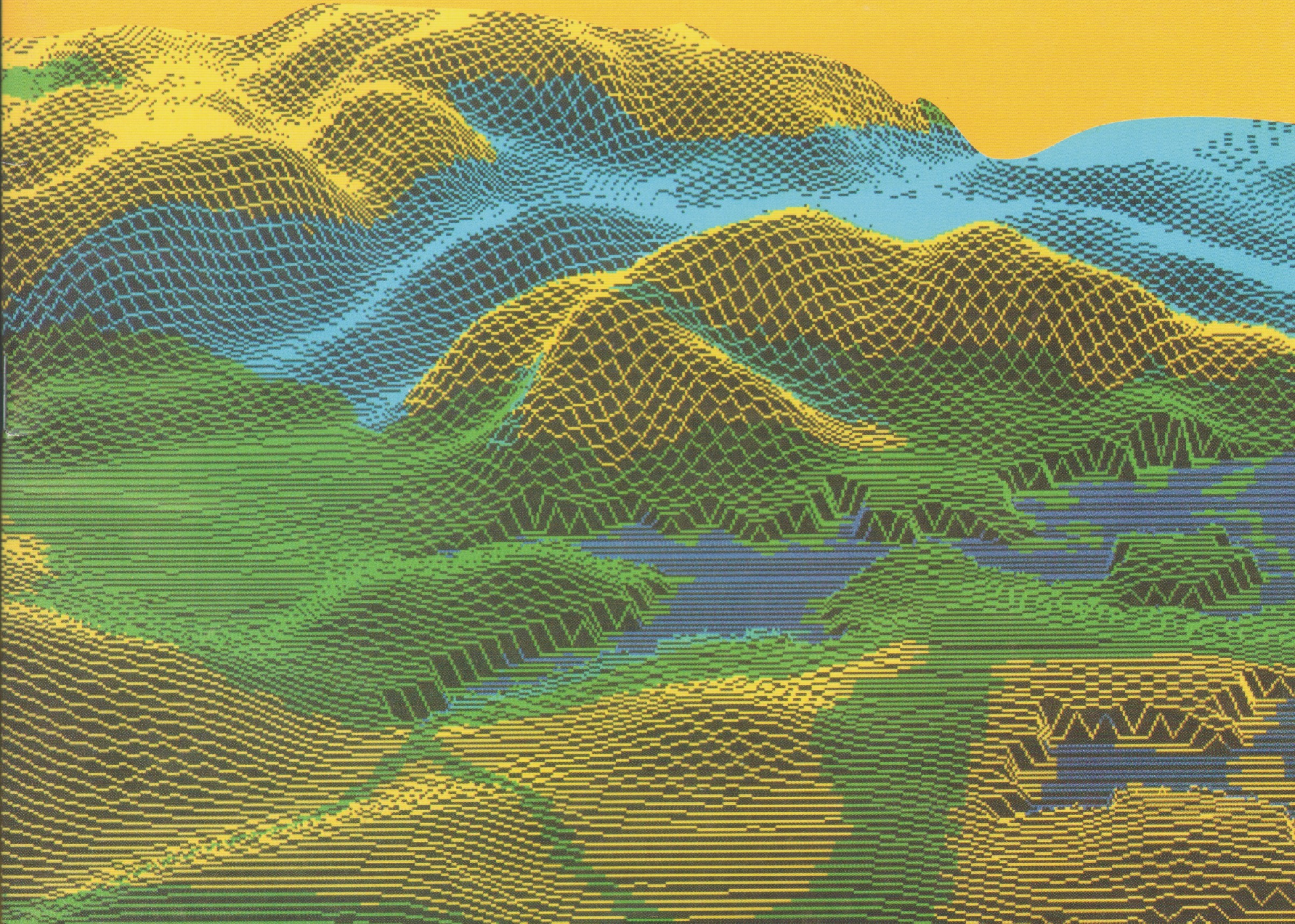
MORAVIAN GEOGRAPHICAL REPORTS

VOLUME 4 NUMBER 2 1996 ISSN 1210 - 8812



MORAVIAN GEOGRAPHICAL REPORTS

PRICE

75 CZK
mailing costs are invoiced separately
subscription (two numbers per year)
145 CZK
including mailing costs

MAILING ADDRESS

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PRINT

PC - DIR, Ltd., Brno, Technická 2

ISSN 1210-8812

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SLOPE FAILURES IN METAMORPHIC BASEMENT ROCKS OF THE DYJE RIVER VALLEY, PODYJÍ NATIONAL PARK, CZECH REPUBLIC

Jaromír DEMEK - Jiří KOPECKÝ Sn.

Abstract

The present paper deals with the results of geomorphological and speleological mapping of slope failures in the segment of deep meandering Dyje River valley downstream of the town of Vranov nad Dyjí. Detailed geomorphological mapping at a scale of 1:5 000 has enabled an interpretation of the mechanism involved in the development of slope instabilities.

Shrnutí

Poruchy svahů ve skalních horninách údolí řeky Dyje v Národním parku Podyjí, Česká republika.

Autoři se v článku zabývají výsledky geomorfologického a speleologického mapování poruch svahů v úseku hlubokého údolí řeky Dyje pod Vranovem nad Dyjí. Podrobné geomorfologické mapování v měřítku 1:5 000 umožnilo interpretaci mechanismů činných v poruchách svahů.

Key words: slope failure, rock slab buckling, toppling, rock fall, rock slide, pseudokarst cave, The Dyje River Valley, The Podyjí National Park.

1. Introduction

In 1995, the authors geomorphologically mapped the eastern half of the map sheet at a scale of 1:5 000 Vranov 2-4 and the western half of the sheet Vranov 3-4 for the Directorate of the Podyjí National Park. The National Park was established in 1991 and is located in the SE part of the Czech Republic on the border with Austria (in an area called the Bohemian-Moravian Highland). Its axis is formed by a deep valley of the Dyje River (known as the Thaya River in Austria) between the towns of Vranov nad Dyjí to the West and Znojmo to the East. A basic feature of the territory is a difference between the levelled surface of the Bohemian-Moravian Highland and the deep valley of the Dyje River. The river has eroded a deep incised meander valley in the resistant metamorphic rocks. Slope failures on the steep valley slopes were described by Roth (1863). The authors have conducted a detailed investigation into the slope failures in hard rocks on that section of the Dyje River valley to the SW of the town of Vranov nad Dyjí. Investigation difficulties were caused by densely forested steep slopes and a chaos of cliffs, tors, rock pillars and blocks.

2. Situation

The map shows a 6.65 km long section of the deep Dyje River valley beginning at Zadní Hamry (part of the town of Vranov nad Dyjí) and ending at the castellated rocks of the Schwalbenfelsen in Austria. Here the river flow elevation is approx. 300 to 290 m. In the mapped area, the Dyje River forms three deep incised valley meanders-upper, middle and lower. The incised valley meanders exhibit a pronounced asymmetry in the cross profile with the undercut valley slopes on the outside of meander curves and the slip off meander spurs on the inside.

The plan view of the Valley meanders is rectangular rather than being regularly arcuate, phenomenon Ivan - Kirchner (1996) attribute to high resistance of the basement rock.

The spur of the upper valley meander is called the „Rock Labyrinth". The spur runs in the WE direction and

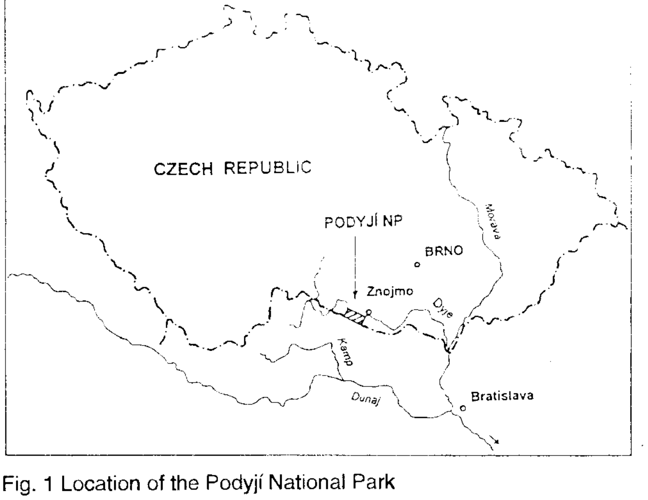

Fig. 1 Location of the Podyjí National Park

is about 250 m long. The spur elevation decreases from the levelled highland surface (the tract is called Braitava) towards the river. The „Rock Labyrinth" is composed of tors, rocky crests and blocks divided by dilatated fractures. On its sides, the spur is bordered by cliffs.

Špalek (1935a) described the meander core developed by the upper meander spur cutoff. The route around it (a meander scar) abandoned by the Dyje River has been recently filled with alluvial cones of the brook U zborceného mostku. On the undercut rocky left-side slope on the outside of the upper meander, cliffs developed of up to 30 m in height.

The spur of the middle valley meander was formed by the crest of Ledové sluje (Ice Caves). The spur has a ENE-WSW direction and is about 800 m long. The rocky section (crest) is about 550 m long. Its highest point occurs at about 130 m above the river bed. The undercut right-side valley slope on the outside of the middle meander exhibits an amphitheatric form. This steep slope is about 220 m high and in cross section is composed of two parts: upper and lower. The upper part (up to 130 m high) is formed by rows of cliffs, rock pillars, and short rocky crests divided by amphitheatric heads (niches) of dells and short slope valleys. The lower one, less inclined, is represented by talus slopes with angular blocks, block streams and block fields.

The spur of the lover valley meander is called Býčí hora (Bull Mount). The spur trend, from W to E, is about 750 m long. Its highest point is about 190 m above the river bed. The spur is basically rounded. On its surface the authors mapped cliffs, dilatated fractures and pseudokarst dolines. Opposite of the undercut on the leftside of the valley slope, below the Smuggler's Trail, it is steep and rocky. There are frequent cliffs exposing bedrock rocks and prominent castellated similarly rocks as in „U křemenné žíly" (At Quartz Vein Rock), „U jeskyně" (At Cave Rock) or „Zikova skála" (Zika Rock). This slope is 270 m high.

On the valley bottom, a narrow floodplain has developed in two levels.

The surroundings of the Dyje River deep valley have been levelled. To the West of the valley, in the forest tract of Braitava, there are parts of a planated surface of about 535 m in elevation („U letohrádku" - At A Country-Seat). The basement rocks are near the surface and form castellated rocks, tors and convex shaped monadnocks. The planated surface is undulated by dells and by right tributaries of the Dyje River on the upper reaches. Nearer the deep valley, the lower reaches of the right tributaries are more incised. Gullies have developed on some of the valley bottoms.

To the East of the Dyje River valley, the authors found the remnants of a planation surface in the tract called „U Vranovské brány" (At the Vranov Gate) at an elevation of 496 m and in the „Větrník" tract at an elevation of 510 m. At this place long dells and upper reaches of the left tributaries of the Dyje River were also found. In addition, these valleys are incised nearer the deep valley of the Dyje River.

3. Morphostructure

The mapped area is represented on a detailed geological map of the Podyjí National Park published in 1993 (Batík, 1993). As to it morphostructure the mapped area is situated in the southeastern part of the Bohemian Massif. The basement rock throughout the mapped Dyje River valley section is the Bíteš leucocratic orthogneiss of the Moravicum Unit (Batík, 1993). Two-mica gneiss, the predominant rock, has a well developed schistosity and typical augen structure. In the predominant rock abundant intercalations of biotitic amphibolite and intercalations of biotitic or two-mica paragneiss are formed. The basement rocks are folded, sheared and crushed to form defect zones of variable width. Dimensions of the folds range from a few cm up to 20-30 m.

Batík (1993) mapped a fault parallel to the axis of the middle valley meander spur at the Ice Caves. Interestingly, the schists become weaker and more ductile with the increasing mica content.

4. Morphochronology

Little data exist on the relief development of the Mesozoic Period. The Tertiary Period saw the culmina-

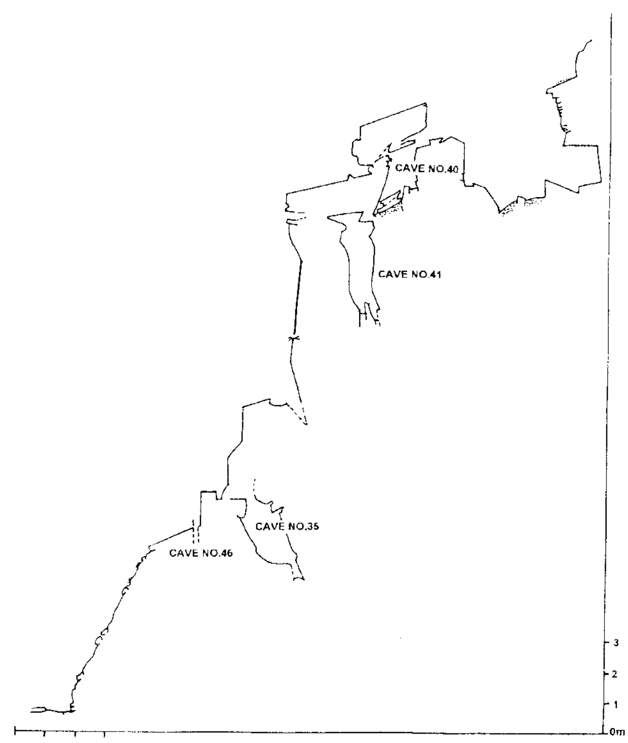

Fig. 2 Schematic cross section through the northern slope of the meander spur of the Ice Caves. Constructed by J. Kopecký Sn., 1996

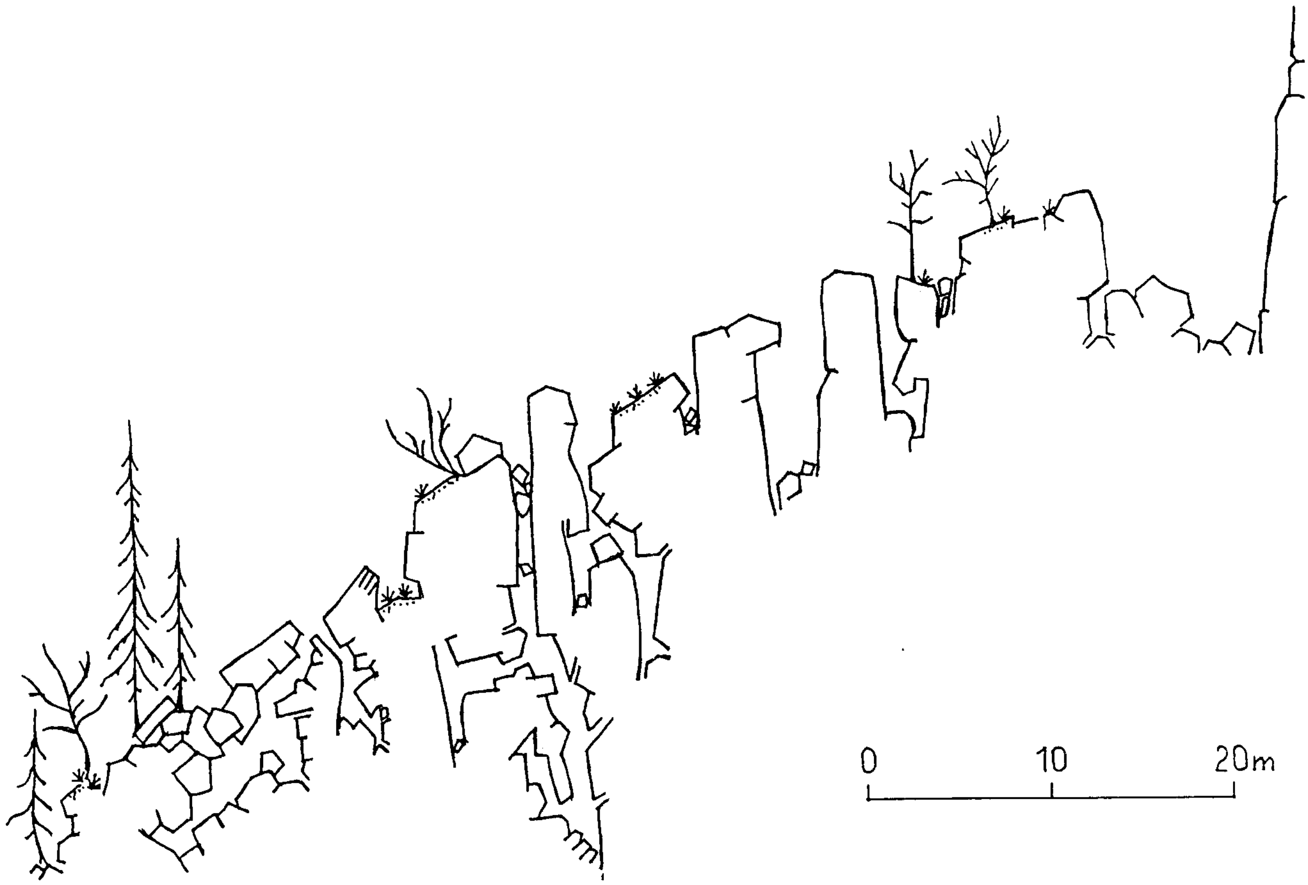

Fig. 3 Profile of the northern slope of the meander spur of the Ice Caves and pseudokarst caves in the „pillar No. 1 (northern)". Constructed by J. Wagner, 1994

tion of the development of a regional planation surface with thick kaolinitic weather mantle (a peneplain?). During the Lower Miocene, the studied territory was the part of a shallow sea. Predominantly clastic marine deposits sedimented onto the basement rocks. During the slow sea regression, the Dyje River valley formed the marine deposits in Miocene (Batík, 1993). Tectonic uplift at the southeastern part of the Bohemian Massif increased the gradient of the river and its power to erode. This process resulted in erosion of the deep meandering valley, in steepening of the valley slopes with subsequent stress relief, and slope instabilities. These instabilities range from rock slab buckling, toppling and minor rock falls up to large scale rock slides. During the cold phases of the Pleistocene, the area was in a periglacial zone with intensive cryogenic processes (Vítek, 1979), which supported slope instabilities caused both by unloading and spreading.

5. Slope failures

Slope instability developed on the northern slope of the middle meander spur. The spur is about 800 m long and runs in an ENE-WSW direction. Its elevation decreases from the highest point at the monument (430 m a. s. l., 130 m above the river) towards the WSW (down to 50 m above the river bed). The ENE section of the spur exhibits the form of a rounded ridge. From the monument to the WSW the spur forms a rock crest. The length of this section is about 550 m. The crest is limited by cliffs on both sides. The South-facing cliffs are more coherent and higher. The basement rocks are loosened along the fissures in the NW-SE, ENE-WSW and NEN-SWS directions. The dilatated fissures are partially filled with angular blocks, some of them forming wide gaps. On the spur, WSW of the monument, a rectangular net of dilatated fissures forms a stone pavement. The surface is divided into large blocks separated by wide gaps. Pseudokarst dolines developed at the beginning of the spur on fissure crossings. Several dolines are funnel shaped and round or oval in the plane view. The dolines range in size from a few meters up to 25 m in diameter.

The headwall of the rock slide is situated on the northern slope just below the monument (spot height 430 m). The terrain above the headwall is characterized by prominent weathered zones and gaps. The headwall has in the plan view an arcuate form and runs in the ENE-WSW direction. The wall is generally 25 m to 30 m high (Fig.2). Along the headwall, there are the subsided blocks of gneiss wich have, a valleyward moved at the same time. A major trough that originated through these movements is filled with angular blocks of large dimensions. In an ENE direction from the monument, the depression is less prominent, but can easily be followed in the field. The trough is obviously identical with a fault shown on the above mentioned geological map by Batík (1993).

The rockslide complex consists of a number of secondary troughs of slide debris (Fig.2 and Fig. 3) separated by blocks of relatively intact bedrocks (locally called „pillars"). The surface of the rock block subsided along the headwall corresponds to the elevation of 410 m, that is about 20 m lower than the surface of the spur (spot height 430 m a. s. l.). The secondary troughs and dilatated fissures parallel to the headwall are separating other blocks on the northern slope. The blocks are steplike, arranged on the northern slope, some of them forming the antiscarps. The troughs separating the surface of the block are filled with angular rock fragments. Below the blocks, there are entrances into the pseudokarst caves.

The caves concentrate into 2 huge blocks of relatively intact rocks („pillars"). However, loosening of the bedrock in these 2 „pillars" reaches very deep since the caves currently mapped are situated at the depths of as much as 40 m below the terrain surface (Kopecký, 1996) that is up to a niveau of 340 m a. s. l. The dilatated fissures which are not accessible by speleologists reach even deeper.

The largest caves exhibit a width of up to 6 m. Polishes (slickensides) were found in the caves near the headwall fault.

The fissure caves prevail. Only the uppermost parts of large caves and the small caves themselves are of block cave type. Prevailing are also pseudokarst caves with multiple niveaus. In the depth of slope, the caves in one trough communicate (are connected) with the caves in another parallel trough. The largest cave system has a polygon of more than 500 m. This is also an evidence of the extensive and deep loosening of the bedrock.

The caves are famous for their content of underground ice. It is a unique phenomenon in the warm climate of South Moravia. The cave microclimate was investigated in the 19th century (Roth, 1863). In the spring of 1996, after several years with a small content of cave ice, thick ice filling in caves and in blockfields was observed.

In the lower third part of the northern slope, there are creeping or dormant blockfields (Fig. 4) composed of the thick landslide debris. In the creeping sections of the blockfields, blocks are moving. In the spring of 1996 a trail running through the blockfields was buried by the blocks.

Geomorphological mapping to define the rockslide limits and to locate surface evidence of failure planes formed the er investigation work on the slide. Mapping scale 1:5 000 depended on the topographic base and the amount of detail available. The caves were investigated and mapped at a scale of 1:5 000 (Kopecký, 1996). The rockslide had been targeted for monitoring since 1990 (Zvelebil et al., 1996).

Rock slide is a result of gravitational movements and spreading of the steep-sided valley slopes. Depths of a major trough are indicative of a deep-seated deformation. The initial development of slope instability would have been caused by the following predominant modes:

i) effects of slope deformations resulting from the linear erosion of a deep valley of the Dyje River and related stress relief in the bedrock,
ii) weak zones in the gneiss massif (e.g. the above mentioned fault of the Ice Caves Meander Spur), and
iii) lateral erosion of the Dyje River at the foot of the northern slope connected with a cutoff (Špalek, 1935a, 1935b).

6. Spreading of ridges and crests

The authors studied spreading of ridges and crests in the area of the „Rock Labyrinth" and the Bull Mt. A ground reconnaissance of densely forested ridges indicates that their top has undergone significant deformations. The ridges are broken up by troughs and partially-infilled with rock debris. There are fissures, up to several meters wide, running parallel to the axes of ridges and crests. Other dilatated transversal fissures run across the ridge. Troughs have sharp edges and appear to be relatively fresh. The fresh appearance of the majority of troughs is indicative of ongoing gravitational deformation.

Also, pseudokarst caves were found in these ridges. Both the Mahr Fissure Cave (14 m deep, 2.3 m width, 3.5 m high) and the European Elder Cave (5 m deep, 4 m high, 1.5 m width) are to be found in the southern cliff of the Bull Mount. Troughs were also found on flat surfaces.

7. Spreading on the right valley slope

On the right valley slope, downstream of Benátky (part of the town of Vranov nad Dyjí), there are frequent cliffs exposing the bedrock. The steplike arranged cliffs are separated by slope dells with amphitheatric head parts. Near the upper bridge, in the lower part of the right side valley slope, there are, several block streams formed by huge angular blocks. The huge blocks of gneiss reach the dimensions of 11x6x5 m. Heads of block streams are situated at the foot of high cliffs. They are an evidence of the repeated rock falls. Fresh blocks in the Dyje river bed are an evidence of the Holocene rock falls.

The authors investigated the retreat of valley slope sections by gravitational processes on the undercut rocky right-side slope on the outside of the middle meander. The amphitheatric slope is 220 m high.

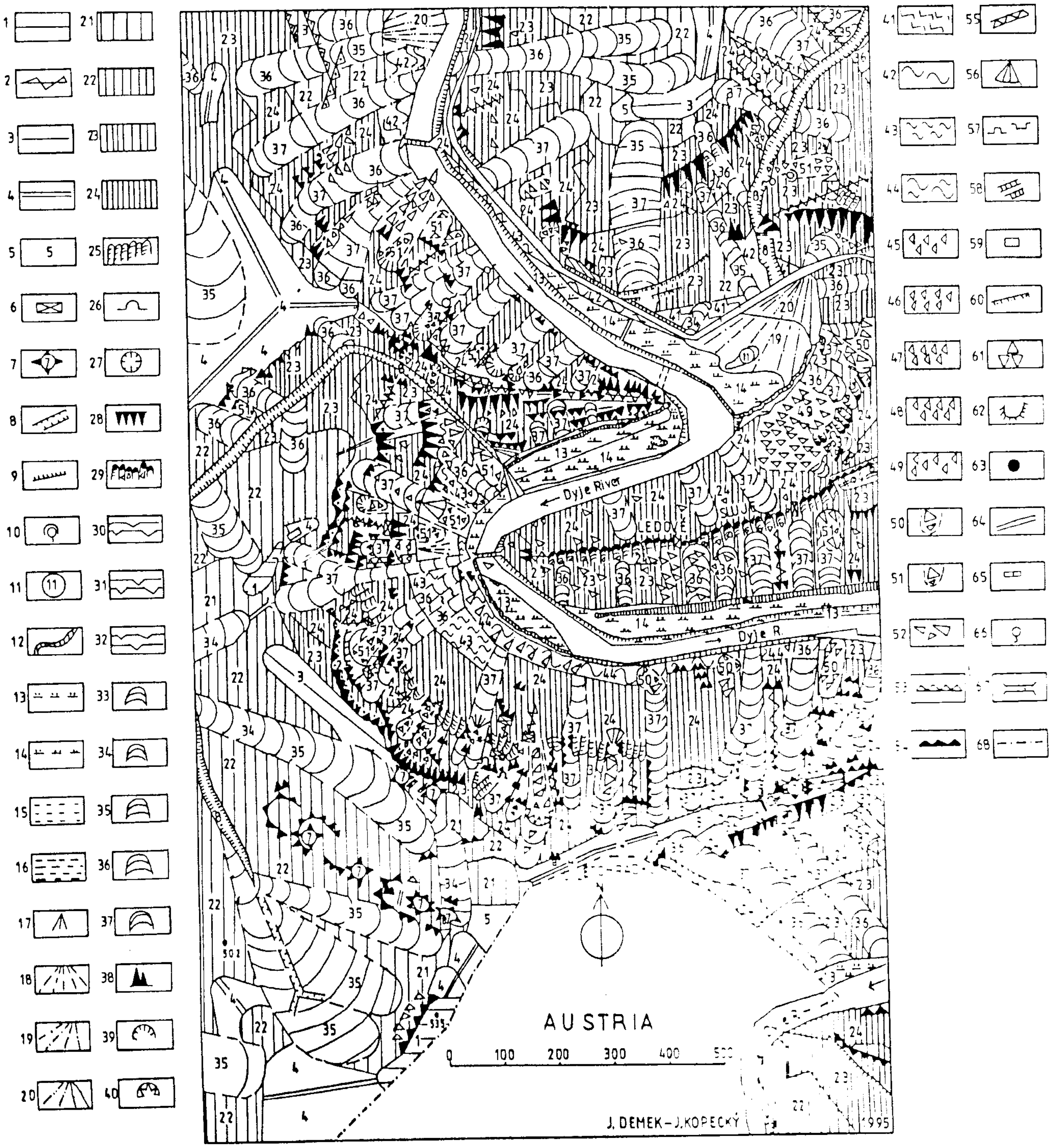

Fig.4 Detailed geomorphological map of the Dyje River Valley in the surroundings of Ice Caves

Legend to the detailed geomorphological map. Explanations:

1. Remnants of the polygenetic planation surface (etchplain), 2. narrow and rocky ridge, 3. narrow and rounded ridge developed by intersection of valley slopes, 4. broad and rounded ridge developed by the intersection of slopes, 5. spur, 6. rock pillar, 7. monadnock, 8. gully, 9. scarp developed due to lateral river erosion, 10. spring niche, 11. cutoff, 12. abandoned river bed, 13. low floodplain, 14. high floodplain, 15. accumulation bottom inclined to the axis of valley with inclination 0-2, 16. accumulation bottom inclined to the axis of valley with inclination 2-5, 17. accumulation bottom inclined to the axis of valley with inclination 5-15, 18. surface of alluvial cone with inclination 0-2, 19. surface of alluvial cone with inclination 2-5, 20. surface of alluvial cone with inclination 5-15, 21. valley slope inclined 2-5, 22. valley slope inclined 5-15, 23. valley slope inclined 15-25, 24. valley slope inclined 25-35, 25. valley slope inclined 35 and more, 26. pseudokarst cave, 27. pseudokarst doline, 28. frost-riven cliff, 29. rock wall modelled by cryogenic processes, 30. cryoplanation terrace inclined 0-2, 31. cryoplanation terrace inclined 2-5, 32. cryoplanation terrace inclined 5-15, 33. dell inclined 0-2, 34. dell inclined 2-5, 35. dell inclined 5-15, 36. dell inclined 15-25, 37. dell inclined 25-350, 38. tor, castle-koppie, 39. nivation hollow with smooth slopes covered by soil and scree, 40. nivation hollow with cliffs, 41. crest, 42. talus slope inclined 5-150, 43. talus slope inclined 15-25, 44. talus slope inclined 25-35°, 45. block field inclined 0-2°, 46. block field inclined 2-5°, 47. block field inclined 5-15°, 48. block field inclined 15 -25°, 49. block field inclined 25-35°, 50. block stream composed of angular block inclined 5-15°, 51. block field composed of angular blocks inclined 15-25°, 52. angular block, 53. root area of rock slide, 54. headwall of rockslide, 55. trough, dilatated fissure, 56. dejection cone, 57. quarry, active, abandoned, 58. sunken road, 59. pit, 60. agricultural balk, 61. agricultural damp, 62. mine dump, 63. bunker, 64. road, 65. country seat, 66. spring, 67. bridge, 68. state boundary.

Legenda k podrobné geomorfologické mapě. Vysvětlivky:

1. Zbytek (plošina) polygenetického vrcholového zarovnaného povrchu, 2. úzký a skalnatý hřbet, 3. úzký a zaoblený hřbet vzniklý protnutím svahů, 4. široký a zaoblený hřbet vzniklý protnutím svahů, 5. spočinek na svahu, 6. skalní věž, skalní pilíř, 7. suk, 8. strž, 9. stupeň vzniklý boční erozí vodního toku, 10. pramenný výklenek, 11. okrouhlík, 12. opuštěné koryto vodního toku, 13. nízká niva, 14. vysoká niva, 15. akumulační dno ukloněné ke středu údolí (údolnici) se sklonem 0-2°, 16. akumulační dno ukloněné ke středu údolí (údolnici) se sklonem 2-5°, 17. akumulační dno ukloněné ke středu údolí (údolnici) se sklonem 5-15°, 18. povrch náplavového kužele o sklonu 0-2°, 19. povrch náplavového kužele o sklonu 2-5°, 20. povrch náplavového kužele o sklonu 5-15°, 21. údolní svah o sklonu 2-5°, 22. údolní svah o sklonu 5-15°, 23. údolní svah o sklonu 15-25°, 24. údolní svah o sklonu 25-35°, 25. údolní svah o sklonu 35° a více, 26. pseudokrasové jeskyně, 27. pseudokrasový závrt, 28. mrazový srub, 29. skalní stěna modelovaná kryogenními geomorfologickými pochody, 30. kryoplanační terasa se sklonem 0-2, 31. kryoplanační terasa se sklonem 2-5°, 32. kryoplanační terasa se sklonem 5-15°, 33. úpad o sklonu 0-2°, 34. úpad o sklonu 2-5°, 35. úpad o sklonu 5-15°, 36. úpad o sklonu 15-25°, 37. úpad o sklonu 25-35°, 38. izolovaná skála, skalní hradba, 39. nivační sníženina s hladkými svahy pokrytými hlínou a balvany, 40. nivační sníženina se stupňovitými skalními svahy, 41. hřeben, 42. úpatní halda o sklonu 5-15°, 43. úpatní halda o sklonu 15-25°, 44. úpatní halda o sklonu 25-35°, 45. balvanové moře o sklonu 0-2°, 46. balvanové moře o sklonu 2-5°, 47. balvanové moře o sklonu 5-15°, 48. balvanové moře o sklonu 15-25°, 49. balvanové moře o sklonu 25-35°, 50. balvanový proud složený z hranáčů o sklonu 5-15°, 51. balvanový proud složený z hranáčů o sklonu 15-25°, 52. hranáč, 53. odlučná oblast skalního sesuvu, 54. skalní stěna odlučné oblasti skalního sesuvu, 55. hranáčová závrtová strouha, 56. dejekční kužel, 57. lom, opuštěný, činný, 58. úvoz, 59. jáma, 60. agrární mez, 61. agrární halda, 62. těžební halda, 63. řopík, 64. silnice, 65. letohrádek, 66. pramen, 67. můstek, 68. státní hranice.

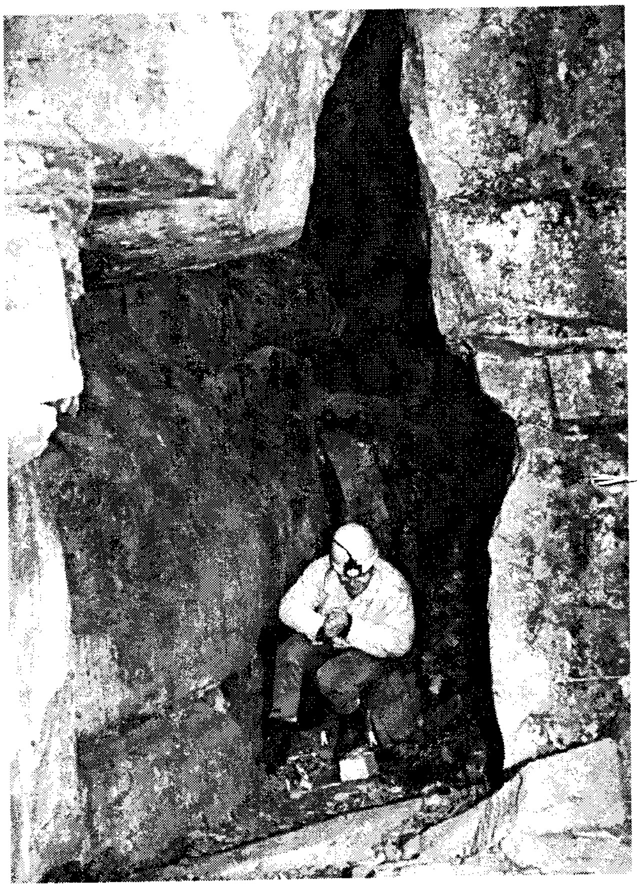

Fig. 5 Fissure cave BR1 in the central part of the „southern pillar" on the northen slope of the middle meander spur. The broda and deep trough has a prolongation as a cave system.

Gneïss on the slope exhibits both the sheet jointing in some parts and the strong folding in others (e.g. near the Country-Seat in the Braitava forest tract).

The valley slope is composed of an upper and a lower part. The upper steep part is about 130 m high. The general slope inclination is over 35. It is well known that high stress (rock pressure) will occur in valley s[illegible]es if the overall inclination of valley slopes exceeds 25 (Beetham et al.,1991). There are frequent cliffs exc[illegible]ing the bedrock rocks (mostly gneiss) and the prominent rock pillars like the Eagle Nest Rock, the Upper View Rock (464 m a. s. l.), etc. A lower, less inclined part of the slope represents the talus slope with angular blocks, block streams and block fields.

Slope instabilities on this slope range from rock slab buckling on cliffs, toppling and rock falls to large failures.

The first type is the rock slab buckling on cliffs, induced by very severe horizontal stress. Near to the surface, the high horizontal stress exceeds the vertical stress by order(s) of magnitude. Rock slabs slides accumulate at the foot of the cliffs.

The second type of instability is the toppling of rock pillars. The toppling dilatates the fissures and causes the development of pseudokarst fissure caves.

The third type is the rock fall from the cliffs. This process was most active during the transition phases between the cold and warm periods of the Pleistocene. However, the fresh blocks in the river bed are an evidence of the Holocene rock falls. The blocks fallen from the cliffs form the block streams, block fields and scree slopes at their feet .The largest block stream at a cliff foot is about 100 m long and 60 m wide. The block stream consists of angular blocks with dimensions of about 4x2x1.5 m in size.

The fourth type consists of large failures. The upper edge of the slope is rimmed by rows of headwalls. The headwalls are arcuated in the plan view. Dilatated fissures can be followed backwards from the headwalls into the flat terrain behind the cliffs. Individual headwalls are divided by nivation niches at the heads of the slope dells. Some of the niches exhibit smooth sides covered by soil. Other take the form of small cirques with cliffs. Rock sliding was caused by undercutting the slope by the nivation processes combined with stress release. There are blocks and block streams at the bottom of the dells (Fig. 4). Blocks which have slid along the sl[illegible] surfaces marked by headwall forms antiscarps in some places.

The slope dells are divided by narrow rocky crests with rock pillars. Dilatated transversal fissures divide the

Fig. 6 Fissure cave BR4 in the „Southern pillar" of the northern slope of the middle meander spur. The cave is covered with Carge slat-like bloks of gneiss.

crests into relatively intact blocks and rock pillars. Toppling of pillars is the reason for a common presence of the fissure caves. Most of the crests end at up to 40 m high cliffs which are situated approx. 90 m above the Dyje river bed (Fig. 4). Dells crossing this level of the end cliffs are narrowed, sometimes exhibiting a form of gorges. Features of unloading were observed on the cliffs. Unloading slabs divided from the cliffs have slid to their feet.

The talus slope at the foot of the slope is a complex structure consisting of the slope deposits of various kinds. Most prevalent are colluvial deposits composed of loam with angular blocks. At some places (Fig. 4), block streams and block fields consisting of scree have developed. There are also deposits of both alluvial and debris cones.

8. Spreading of the left valley slope around the Smuggler's trail

The undercut left-side valley slope around the Smuggler's Trail is steep and rocky. There are frequent cliffs exposing the bedrock rocks and prominent castellated rocks as in „U křemenné žíly" (the Quartz Vein Rock), „U jeskyně" (the Cave Rock) or „Zikova skála" (the Zika Rock). The described slope is 270 m high.

The prominent rock group called Cave Rock is mostly situated above the Smuggler's Trail. It is a rocky ridge running along the slope in the E-W direction. On the southern side, there is a rock group bordered limited by cliffs. There are also transversal dilatated fissures forming troughs which are partly filled with angular rock fragments.

The Smuggler's Trail crosses this rock group below high cliffs which are 83 m long and 30 m high. The cliffs are parallel to the Dyje river bed. The bedrock (gneiss) is shattered. The fissures are dilatated. Near the Trail, a combined pseudokarst cave developed. The cave is 6 m deep, 1.5 m wide and 3.5 m high. Below the trail, there are short rock crests ending in cliffs (about 13 m high). At the foot of cliffs rock streams reaching up to the Dyje river bed have developed.

The prominent rock group Zika Rock is situated below the Smuggler's Trail. The rock group consists of 4 parallel ridges separated by gorges. The ridges are bordered by high cliffs. The cliffs parallel to the Dyje River bed are about 22 m high. At the foot of the cliffs, block streams consisting of huge blocks (up to 4 m in diameter) developed. The block streams reach the Dyje river bed.

9. Conclusions

Results of the geomorphological mapping facilitate interpretation of the mechanism involved in the development of slope failures in the deep meandering valley of the Dyje River. Detailed investigations in the Dyje River valley have revealed that the development of slope failures is controlled by rock mass properties and by steep valley topography.

Acknowledgments

The mapping was financially supported by the Directorate of the Podyjí National Park. The authors express their gratitude to Sandra Sweeney, The Palacký University of Olomouc for editing the manuscript and for valuable comments.

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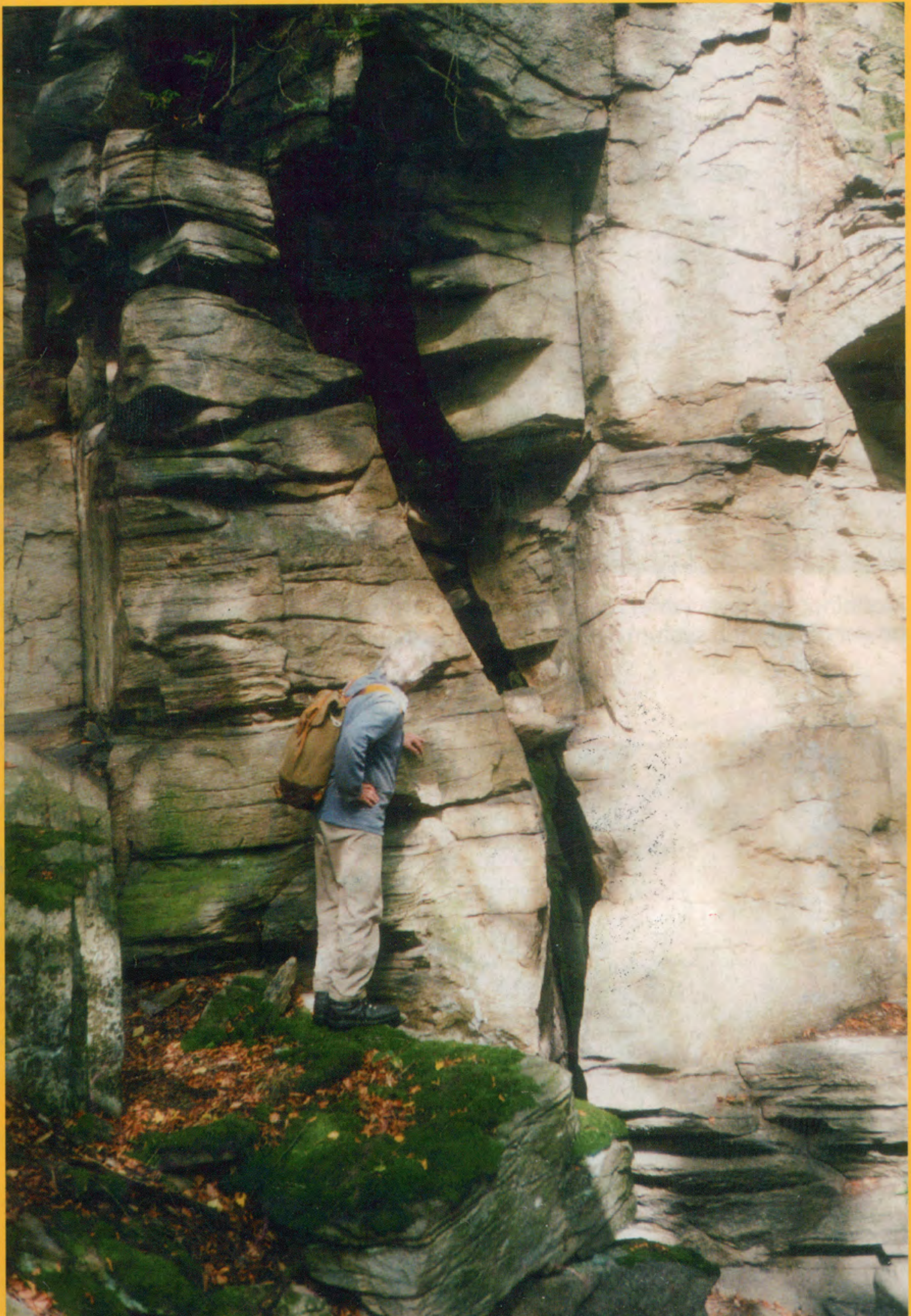

Opening of rock fissures due to deep-seated creep of gneiss of Bíteš on the left valley side of the River Dyje

Photo: Jaromír DEMEK