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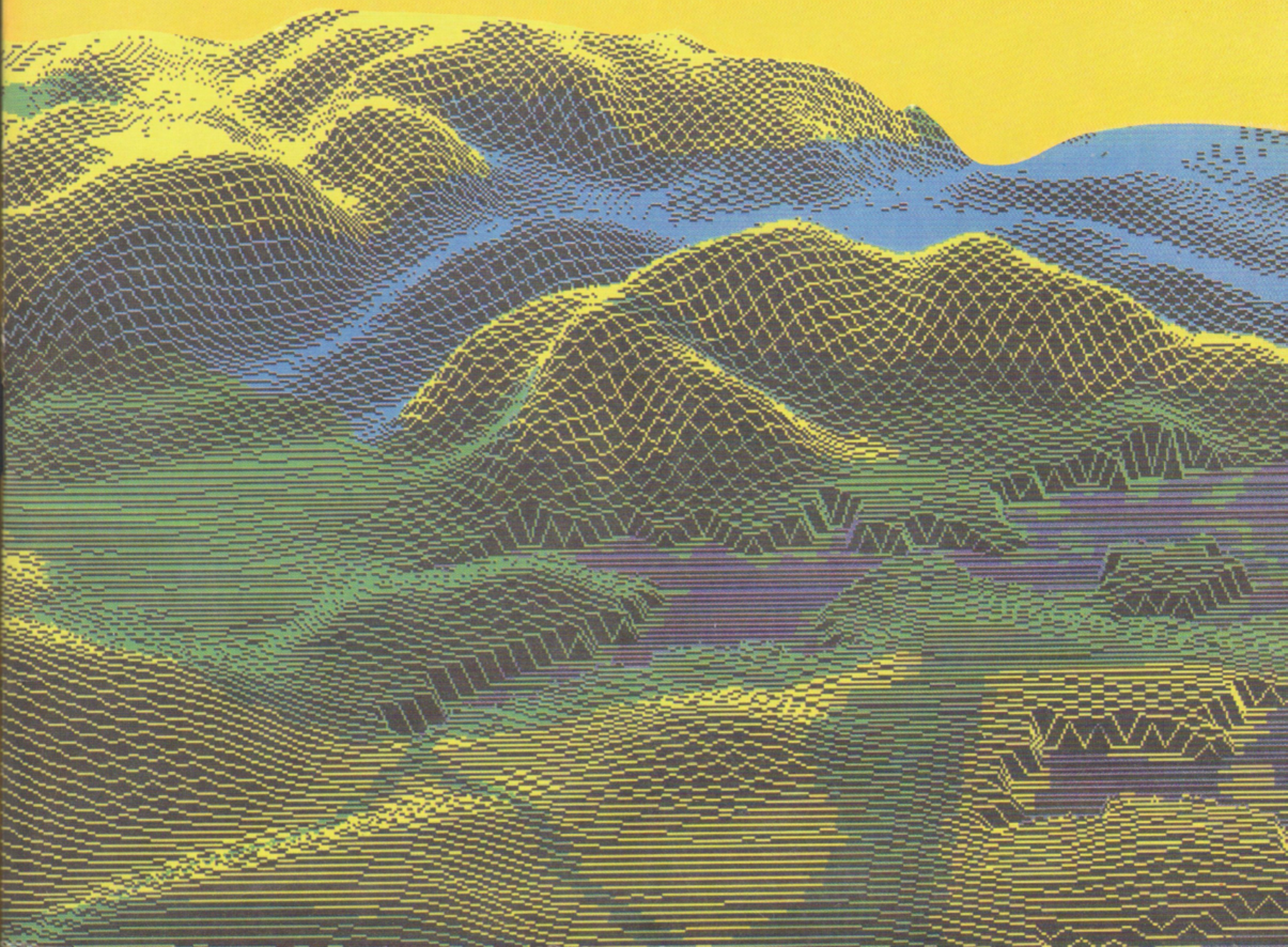

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Contents

GEOMORPHOLOGY OF THE PODYJÍ NATIONAL PARK IN THE SOUTHEASTERN PART OF THE BOHEMIAN MASSIF (South Moravia)

Antonín IVAN - Karel KIRCHNER

Abstract

The canyon of the Dyje river on the frontier between Moravia and Austria is a main landscape feature in the Podyjí National Park declared in 1991. The canyon is deep to 250 m and incised in various crystalline rocks, dissecting extensive planation surface with many rests of kaoline weathering crust. The canyon originated by surimposition from cover of Miocene sediments is also a unique landscape feature in the Bohemian Massif with many incised meanders, fissure ice caves, gravitational forms, block fields, tors, pseudolapiés and interesting anthropogenic forms.

Shrnutí

Kaňonovité údolí Dyje mezi Znojmem a Vranovem nad Dyjí na hranici s Rakouskem je základem Národního parku Podyjí vyhlášeného r. 1991. Kaňon v krystalických horninách je zahlouben pod regionální zarovnaný povrch se zbytky kaolinické zvětrávací kůry. V kaňonu až 250 m hlubokém jsou četné zakleslé meandry, ledové sluje, gravitační tvary, kamenná moře, tvary zvětrávání žuly a také neobvyklé tvary antropogenní.

Key words: Podyjí National Park, Geomorphology, South Moravia, Dyje canyon

1. Introduction

Political changes in Europe in the autumn 1989 have brought a possibility to investigate the formerly forbidden territories, in particular those adjacent to the "iron curtain". One of the most valuable territories includes part of the Dyje river valley situated on the Czech-Austrian border. The most exciting reach of the valley between the towns of Vranov nad Dyjí and Znojmo, in fact a canyon, has been declared the Podyjí National Park (NP) in 1991. Since 1978, however, it was a part of the Podyjí Protected Landscape Area even though in different acreage. In Austria, on the opposite side of the Dyje river the declaration of national park, the "Thayatal Nationalpark", is being prepared, too.

In addition to the romantic and rugged landscape, the Podyjí National Park surroundings is supplemented by attractive towns, viz Znojmo and Vranov nad Dyjí in Moravia and Hardegg in Austria, with interesting architectures and histories. On the other hand, with regard to intensive tourism and recreation in the area (particularly around the Vranov Dam, west of the Podyjí NP and upstream of the Dyje river), observation of protection rules in the park must be well secured.

Although, ironically, the area was forty years under barbed wire and many traces of former military activities there still exist , the environment is less damaged here than in the inner country. The last important and undesirable anthropogenic disturbance in the area of Podyjí NP was erection of the Znojmo Dam in 1966.

At the same time , it is not surprising, that both the landcape and the relief of the Podyjí NP are little understood and even the most remarkable feature, unique fissure ice caves near the town of Vranov nad Dyjí, which were discovered more than a hundred years ago, is studied in detail only now. In spite of a relatively early discovering of the fissure ice caves, main problem was believed to be presence of the perennial underground ice that was the matter of dispute only from the climatic and meteorological point of view (K. JARZ 1882). Later, some attention was devoted to relief forms in short papers of F. KOLÁČEK (1922) and V. ŠPALEK (1935a,b), too. Short descriptions can be found also in papers of J. SKUTIL (1950), J. VÍTEK (1979, 1982, 1992) and T. ANDREJKOVIČ (1993). Results of recent research have been published by J. ZVELEBIL - B. KOŠŤÁK - J. NOVOTNÝ - P. ZIKA (1993) and in report by V. CÍLEK (1993). In the wider areal context the papers of H.NOWAK (1969) and J. KARÁSEK (1985) are inspiring.

The authors have studied the Podyjí National Park relief by the method of detailed geomorphological mapping at the scale of 1 : 25 000. The relief is very dissected, not providing an easy survey and thus

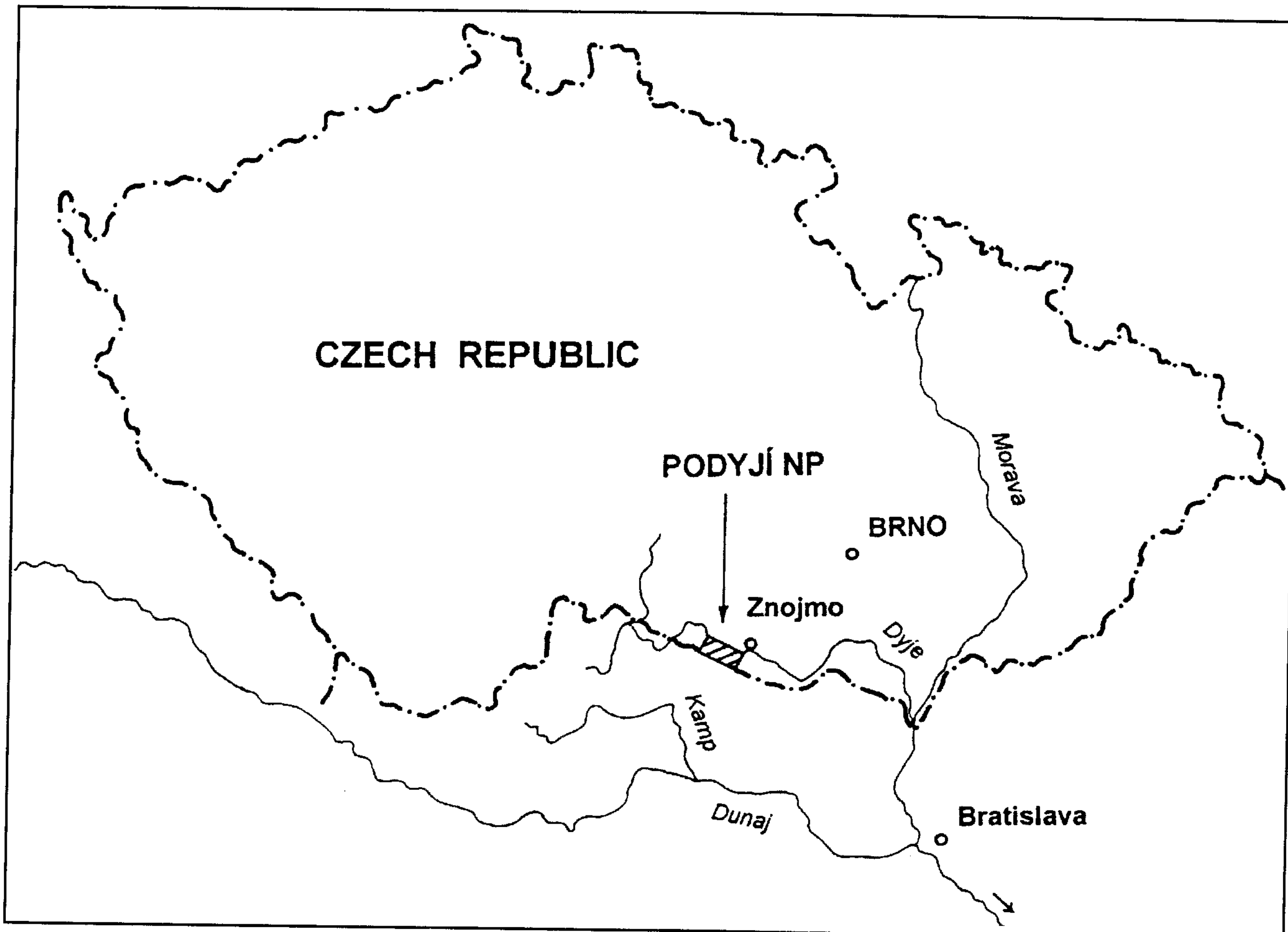


Fig. 1 Position of Podyjí National Park in south Moravia

time-consuming. On the other hand, numberless microforms, such as tors, low exfoliation domes, honeycombs, block fields, debris accumulations, cutoff meanders and interesting anthropogenic phenomena provide a good opportunity to resolve very complicated problems. We are pleased to express our thanks to people, who helped to make this research possible. We are indebted to Administration of the Podyjí NP in the town of Znojmo, particulary to its director ing. T.ROTRÖCKL, to the head of the branch of natural sciences, ing. ŠKORPÍK and to geologist, RNDr. T. ANDREJKOVIČ. The research was supported by internal grant of Czech Academy of Sciences No. 31 459 and grant of the Ministry of the Environment of the Czech Republic (No. 774/93). We also thank Doc. Dr. J KARÁSEK, Masaryk University Brno for constructive criticism of the manuscript.

2. Regional setting

With its area of about 63 km^2, the Podyjí NP is rather small, surrounded both in Moravia and Austria by relatively densely populated and high productive agricultural landscape. In this marginal area, the river of Dyje has been fixed as historical frontier between the two countries for almost a thousand years.

From the point of view of physical geography, geology and biogeography, the Podyjí NP is situated in the SE marginal part of the Bohemian Massif, close to the contact with the West Carpathians. This contiguity of two major landcape systems of Middle Europe is difficult to overestimate. At the same time, however, the Podyjí NP is not an obvious natural unit. Thus it is reasonable to study most of its problems in the larger area context.

From geomorphological point of view, the Podyjí NP is situated in the geomorphological subsystem of the Českomoravská vrchovina (Highland) in the unit, delineated as Jevišovická pahorkatina (Hilly land). The flat or rolling topography in altitude of 300-600 m, gradually rising westwards is a very characteristic feature of the area. On the other hand, this rather monotonous relief with some undinstinct hills contrasts strikingly with very deep valleys, too narrow for both settlements and roads.

In the Podyjí NP the only more important road that crosses the 40 km long reach of the Dyje canyon is between the small town of Hardegg in Austria and the village of Čížov in Moravia. Valley slopes of Dyje as well as those of low sections of its tributaries are continuously covered with deciduous and coniferous woods with distinct differences as related to aspect.

As to geomorphological units in the Podyjí NP neighbourhood and in drainage area of the Dyje river, in particular upstream, west of the Jevišovická pahorkatina (Hilly land), there is the Křižanovská vrchovina (Highland) in approximately the same altitude, with more dissected relief and small river in basins trending predominately to N or NE. The Javořická vrchovina (Highland), west of the Křižanovská vrchovina (Highland), is the highest unit of the Českomoravská vrchovina (Highland) and is dominated in its southern part by a rather monotonous, wooded topography of low rounded ridges and isolated hills underlain by granites. In crest parts, in the altitude of 600 - 700m (V.J. Novák 1935), the main European divide runs, coming from Austria and trending NNE. Here, the major rivers draining the southeastern part of the Bohemian Massif originate.

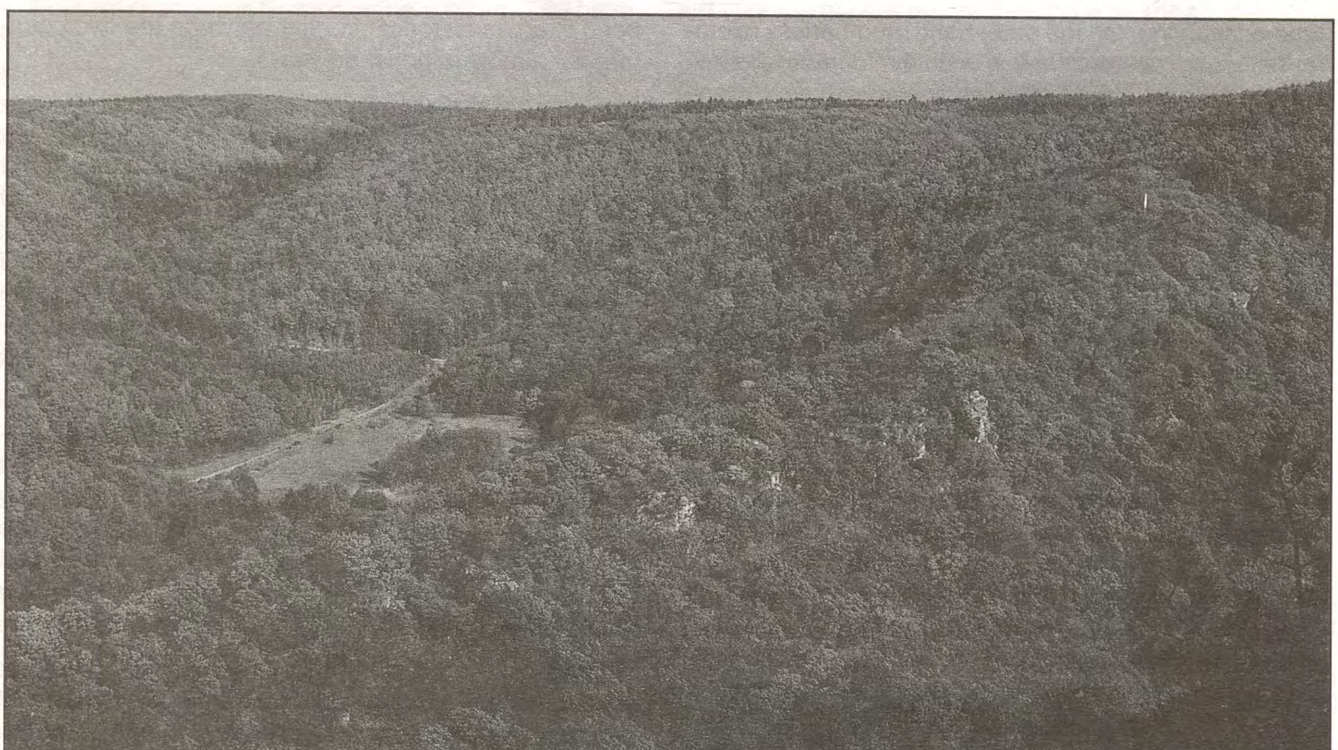
East margins of the Jevišovická pahorkatina (Hilly land) and Podyjí NP, are bounded by a distinct landscape feature, the eastern marginal slope of the Bohemian Massif. The slope faces depression of the Dyjsko-svratecký úval (Graben), which is one of the Outer Carpathians Depressions, situated between the Bohemian Massif and low flysch mountains of the West Carpathians. From geological viewpoint the depression is Carpathian Foredeep composed of unconsolidated Miocene and Quaternary deposits. The Dyjsko-svratecký úval (Graben) is noted for its very flat or gently rolling topography, with prevailing arable land many vineyards and orchards, but little woods.

The Dyje river leaves both the Bohemian Massif and Podyjí NP in the town of Znojmo. Its course is transversal both to the geological structure and relief. The Dyje crosses successively the intermontane depression of the Dyjsko-svratecký úval (Graben), Outer Flysch Carpathians (Pavlovské vrchy Hills and Ždánický les Highland) and Dolnomoravský úval (Graben), where it joins the river of Morava, left tributary of the Danube. From geomorphological and environmental point of view the Pavlovské vrchy (Hills) are both the Biosphere reserve (UNESCO) and the Protected Landscape Area named Pálava. In the confluence area of the Dyje and Morava rivers, a tripartite national park in the floodplain forest is being proposed. In the Austrian part of the Bohemian Massif, the Westliches Waldviertel corresponds to the Českomoravská vrchovina (Highland). In contiguous area of the West Carpathians and Alps, the Wiener Becken (Vienna Basin) and its portion the Westliches Weinviertel are counterparts of the Carpathian Foredeep and Dyjsko-svratecký úval (Graben) of Moravia.

3. Geological structure

3.1 Complexity of basement structure of the SE part of the Bohemian Massif

Crystalline rocks, both igneous and metamorphic, distinctly dominate in the deeply eroded SE part of the Bohemian Massif. Structure of the crystalline basement is very complex and controversial.The territory is believed to be classic area of Hercynian nappe tectonics. From the beginning of this century, the most exciting



1. Canyon of the Dyje river in the western part of the Podyjí National Park, in the foreground incised meander with rock ridge. On the northwest facing slope of this ridge, the locality of the Ledové sluje (ice caves) is situated. Photo: K. Kirchner

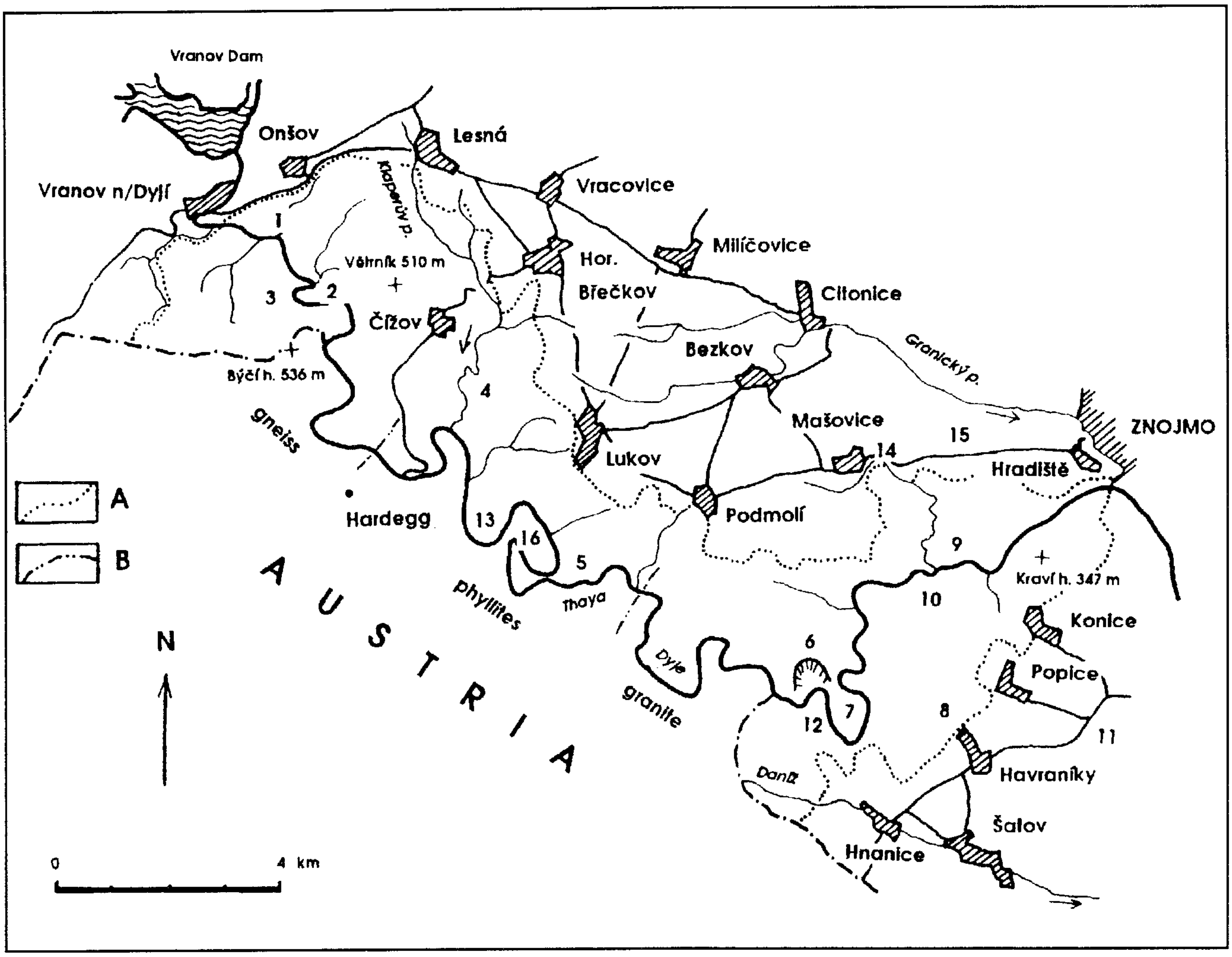


Fig. 2 Important geological and geomorphological localities in Podyjí NP

A - boundary of Podyjí NP
B - lithologic boundaries in Dyje canyon

1 - Vranov - ptygmatic folds
2 - Vranov - fissure ice caves
3 - Býčí hora - gravitational phenomena
4 - Klaperův potok (brook) - incised meander, cryogenic and karst forms
5 - Nový Hrádek (castle) sand pit in Lower Miocene deposits
6 - Devět Mlýnů (Nine Mills) abandoned incised meander
7 - Šobes active incised meander
8 - Havraníky - forms of granite weathering
9 - Králův stolec (King's table) weathering forms, cultivation terraces
10 - Sealsfieldův kámen (Sealsfield stone) - weathering forms
11 - Pustý kopec (Deserted hill) exhumed granite inselberg
12 - part of Dyje valley with distinct low right slope
13 - Gališ (hill) - Vraní skála (Crow's rock) - low river terrace, bluff
14 - Maršovice - kaolinized biotite granite
15 - Hradiště - deposit of kaoline (not exploated yet)
16 - Umlaufberg (core of incised meander)

discussions tackled existence of the Moldanubian nappe, thrusted eastwards over Moravicum and later uncovered by erosion in tectonic windows. At present, after many discussions and modifications, the nappe tectonics is generally accepted, even though different opinions still exist (for references see M. SUK et al. 1984, G. FUCHS 1990). In the course of last decades, the complicated tectonic, petrographic and chronological problems of the area were discussed mainly by P. BATÍK (1984), T. HÁJEK (1985,1990), V. JENČEK - A. DUDEK (1971), M. KRATOCHVÍL - K. SCHULMANN (1984), S. SCHARBERT - P. BATÍK (1980) and G. FUCHS (1990). The nappe structure was most convincingly demonstrated by J. JAROŠ (1992) in the Svratka dome west of Brno.

In present division, three high-order geological units participate in the structure of the Podyjí NP and its surroundings. They are, from the east to the west the Brunovistulicum, the Moravicum (or newly Moravosilesicum) and the Moldanubicum.

The Brunovistulicum (after A. DUDEK 1980), in the eastern part of the Podyjí NP, presents in the structure of the Bohemian Massif a relatively alien element, and is originally thought to be a part of the Fenno-Sarmatian platform (M. SUK et al. 1984). In the west, the Brunovistulicum is separated from the Moravicum by the newly defined Moravian thrust, characterized as terrane boundary by Z. MÍSAŘ - A. DUDEK (1993).

The Brunovistulicum is composed of intrusive rocks of the Dyje Massif (Cadomian, S. SCHARBERT - P. BATÍK 1980) believed to be, together with the Moravicum, a complicated structure of the Dyje Dome. The Dyje Massif is its core. However, the whole of east half of the dome was denuded.

Petrographically, the Dyje Massif is rather homogenous in the area of Podyjí NP. The prevailing biotite granite, called also the Dyje granite, is close to contacts with the Moravicum schistosed and mylonitized. The Dyje Massif was probably deeply eroded already before the Devonian.

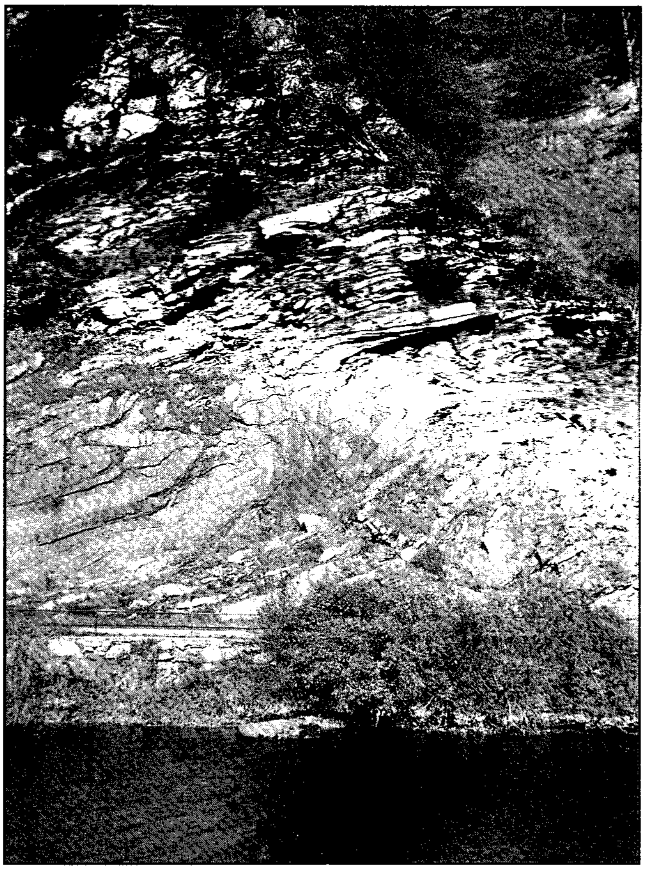
The Moravicum, is an extraordinary complex by its structure, composed mainly of metasediments and gneiss. It consists of three units, all present in the Podyjí NP (see e.g. geological map of the Podyjí NP, 1 : 25 000 in P. BATÍK, 1992).

In the west, there is an east marginal part of the Vranov unit (the Outer Phyllites in the original conception of the Moravicum and the Dyje Dome) built of paragneiss with intercalations of amphibolites and crystalline limestones. Under these rocks, the Bíteš unit composed of two-mica orthogneiss (Bíteš augen gneiss), occupies a zone wide about 6 km. The Bíteš orthogneiss is metagranitoid rock probably of Cadomian or older origin (see M. SUK et al. 1984). The lowest, Lukov unit (the Inner Phyllites) on the east, is composed of two parts. The upper part consists of garnet-staurolit mica schists with crystalline limestones and erlans, the lower part of two-mica schist with quarzites.

Although the crystalline rocks of the Moldanubicum are not present in the Podyjí NP, they form the majority of the drainage area of the Dyje river and crop out relatively close both to the west and north boundaries of the Podyjí NP. Here, important tectonic contacts form the Moldanubian thrust (even though its exact position is controversial) and Kravsko fault (Z. MÍSAŘ - A. DUDEK 1993, K. SCHULMANN - O. MATĚJOVSKÁ - R. MELKA 1992).

West and north of the Podyjí NP, the prevailing Moldanubian rocks are different types of paragneiss and orthogneiss, trending generally to NNE. The Javořická vrchovina (Highland), further to the west, is composed mainly of different types of post-orogenic Hercynian granites of the Central Moldanubian Pluton. The various two-mica granites (the Eisgarn granite) prevail with typical granite relief forms. It is remarkable, that in this so called Bohemian-Moravian part of the Central Moldanubian Plutone, the axis of intrusive structure conforms roughly with the course of main European divide.

The nappe structure in the eastern part of the Bohemian Massif was demonstrated most convincingly in the Svratka Dome west of the town of Brno (J. JAROŠ - Z. MÍSAŘ 1974, J. JAROŠ 1992). There, two nappes in



2. Rock wall of the Bíteš gneiss near town of the Vranov nad Dyjí with ptygmatic folds. Photo: K. Kirchner

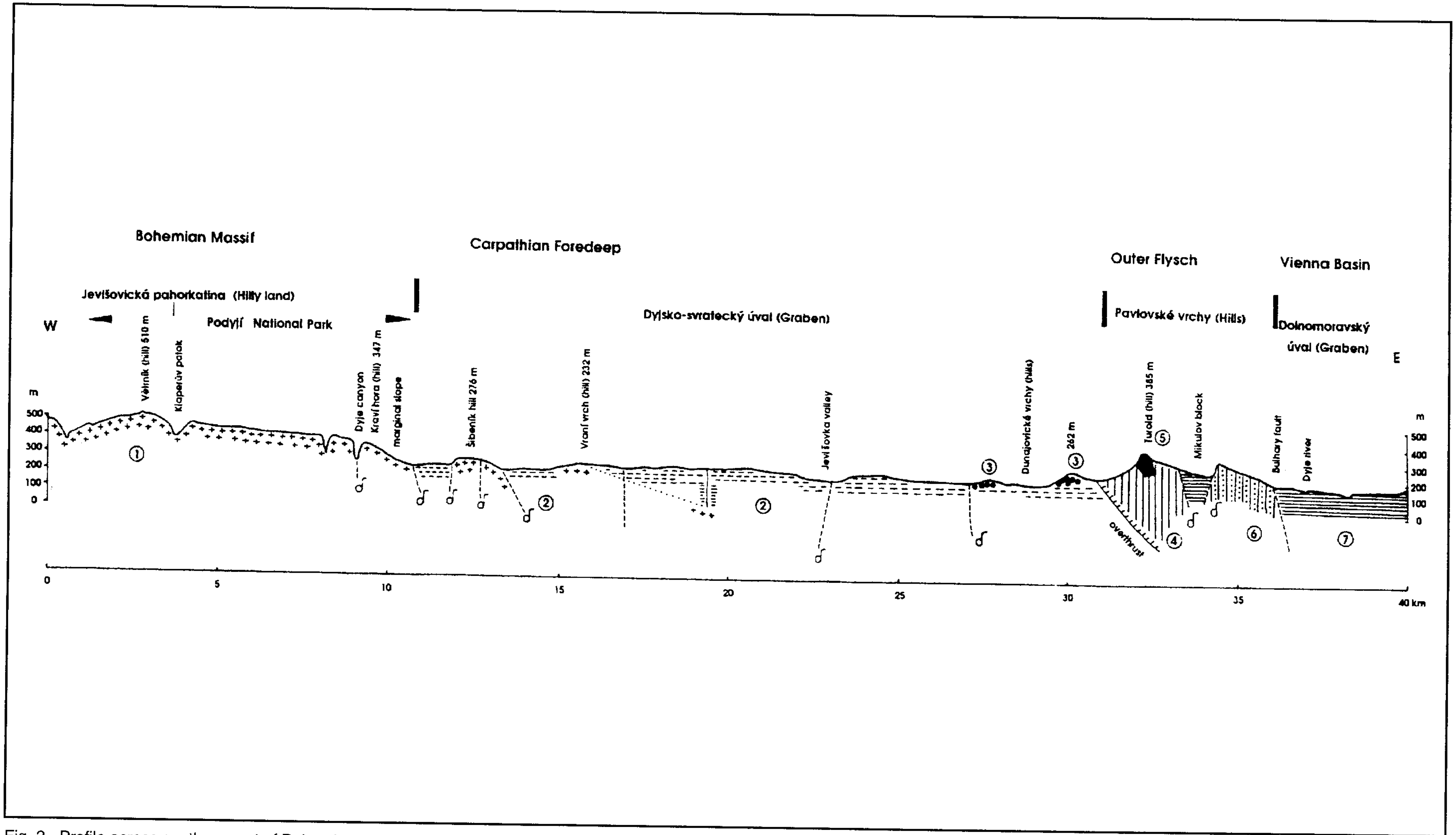


Fig. 3 Profile across southern part of Bohemian Massif and adjacent part of West Carpathians

1 - biotite granite
2 - Miocene sediments in Carpathian Foredeep
3 - Miocene basal conglomerates (Lower Badenian)
4 - Cretaceus - Lower Paleogene flysch
5 - Jurassic limestone (klippes)
6 - Upper Paleogene flysch
7 - Miocene sediments in Vienna Basin

superposition, composed of different metamorphic rocks have been distinguished. Both the nappes, the higher Moldanubian and the lower Moravian, were thrusted eastwards over the Brunovistulicum, consisted of granitoid rocks. After long denudation, metamorphic rocks of the Moravian nappe as same as the Brunovistulian granites have been uncovered in the tectonic windows and half-windows.

The structure of the Dyje Dome is rather similar. Both in the Svratka and Dyje domes the autochtone (the Brno and Dyje granite) and parautochtone (Bíteš orthogneiss, two-mica schists and phyllites) are strongly influenced by dynamometamorphosis. This fact is of primary geomorphological importance.

The differences in resistance of crystalline rocks of the Podyjí NP are well visible in the 40 km long canyon of the Dyje river. But even minor differences led to diversity of slope profiles, microforms assemblages and intensity of weathering. Nevertheless, the structural control is a significant but only secondary factor in the present topography. The most resistant rock is the Bíteš orthogneiss, forming the highest points in the area of national park (Býčí hora - hill 535.9 m, on the right side of the Dyje canyon and Větrník 510 m, on the left side), close of the western boundary of the park. The strip of this orthogneiss, sandwiched into metasediments, forms a flat convex elevation, with the west boundary more distinct than the east one. High resistance is partly obscured by moderate general dip of the area towards the east. The granites of the Dyje Massif, although schistosed,are resistant, too. Less resistant are phyllites and mica schists in the middle part of the Podyjí NP, but not only owing to petrographic composition, but also to tectonic shattering and presence of many faults and fissures.

3.2 Geomorphological aspects of platform tectonic regime in the SE part of the Bohemian Massif

The Hercynian orogenesis was followed by a period of transition to stabile platform regime lasting about 70 million years (J. VACHTL 1974) accompanied by intensive subaerial denudation. In the SE part of the Bohemian Massif, depth of denudation was enormous owing to general dip of the area to the north. In the south of Moravia, this inclination is apparent from 1) the more deep erosion of the Dyje Dome in comparison with the Svratka Dome, 2) the absence of Upper Carboniferous and Lower Permian continental deposits along the Boskovice-Diedendorf fault in the surroundings of Znojmo, and 3) the fact, that in half- graben structure of the Boskovice Furrow the conglomerates are more abundant in its southern part than in the northern part. The steepening of the more gentle west limb of the Boskovice Furrow (to 30-50° and in some places even to 80°, J. JAROŠ in J. KALÁŠEK et al. 1963) resulted probably from uplift of the Svratka Dome at that time.

As to the role of post-Hercynian platform tectonic regime in relief evolution of SE part of the Bohemian Massif, two aspects were important. First, the ancient block structure of the massif was accentuated and the NW-SE trending faults became most important. Second, formation of the Tethys took place and its margin in South Moravia was determined by faults of SW-NE direction. In opinion of Z. ROTH (1978, p.350), this margin of the Bohemian Massif "had experienced since the Late Cretaceous more conspicuous and more differentiated vertical displacements than other parts of the platform". The SE part of the Bohemian Massif influenced by tectonic processes in the Tethys was defined as a block of the Moravian foredeeps by Z. ROTH (1980). The area under study belonged to the South - Moravian block. A. DUDEK and V. ŠPIČKA (1975) named this block as Waschberg-South Moravian, and three subblocks, Nikolčice, Pavlov and Waschberg, distinguished. In this detailed division the surroundings of Znojmo belongs to the Waschberg block.In structure of this block take part faults of direction SSW-NNE (Boskovice-Diedendorf fault) and N-S (Miroslav fault and part of Velké Pavlovice fault north of the town of Mikulov).

The South-Moravian block was in a very low position and in connection with several marine transgressions it was submersed in the Late Jurassic and Cretaceous periods. In the epicontinental sea platform carbonates were deposited on the sub-Hercynian planation surface in Jurassic (M. ELIÁŠ 1981, 1992, M. ELIÁŠ-G. WESELY 1990). The present west limits of these autochtone Jurassic limestones, now buried under Miocene deposits of the Carpathian Foredeep, are about 15 km east of the topographic margin of the Bohemian Massif in surroundings of Znojmo. The limit of limestones is erosional and some authors (J. OPPENHEIMER 1932, K. JÜTTNER 1940) suggested that Jurassic sediments were extended originally far much westwards.

In the Tertiary the topographical margin of the Bohemian Massif has been brought near both to the Eastern Alps and the Carpathians as a result of subduction in the Tethys. Fronts of nappes were shifted towards the north in the Alps and towards west in West Carpathians and margins of the Bohemian Massif subsided. Between the Bohemian Massif and Carpathian nappes, foredeeps originated in which molasse sediments were deposited. Orogenetic phases in Alps and Carpathians have been evidenced (R. TRÜMPY 1973) and migration of orogenic phases, both in the radial and longitudinal directions (R. JIŘÍČEK 1979) influenced relief in a part adjacent to the platform. In the SE part of the Bohemian Massif these effects were stressed by wandering of orogenetic phases and their action from the south at first and later from the west.

Both the sedimentation and tectonic processes in the adjoining mobile areas together with tendency to quasi-permanent uplift in the Bohemian Massif have resulted in deformation of marginal parts of the massif into a large monocline complicated by longitudinal and cross faults. The present marginal slope of the massif which is only the uppermost part of this monocline originated in the south Moravia in Mesozoic and Tertiary. However, like in Jurassic and Cretaceous, the Miocene transgressions have spread extensively and rests of marine sediments occur far inside of the massif, at present. During formation of monocline the ancient basement faults were reactivated.

The eastern limit of the South-Moravian block coincides with Peripienine lineament that contacts the Bohemian Massif with Western Carpathians.The lineament is hidden under flysch and Neogene sediments. This deep contact with the West Carpathians system was much discussed from the point of view of geotectonics and geophysics (M. DLABAČ - E. MENČÍK 1964, Z. ROTH 1980). On the other hand, the western or inner limit of the South Moravian block is rather arbitrary and would be connected with the foot of the marginal slope related to fault (see the tectonic map in M. MAHEL - O. KODYM - M. MALKOVSKÝ 1984). The Outer Carpathians Depressions (Carpathian Foredeep) in front of the slope are composed of unconsolidated Miocene sediments. The profile of the slope is very variable. In the South-Moravian block this slope is distinct in granites. In the area between the towns of Brno and Moravský Krumlov the slope is built of granite of the Brno Massif and in the surroundings of Znojmo of the Dyje granite. On the other hand, in metamorphic rocks this slope is very undistinct or absent.

The low position of South-Moravian block and probably also the fact, that its regional dip was not only toward E, to the Carpathian Foredeep, but also towards S to the Alpine Foredeep, caused that the sea transgressed in the SE part of the western part of Bohemian Massif and South Moravian block already in the Paleogene and the Lowest Miocene. The Lower Miocene sediments (Eggenburgian) are more preserved than in other parts of the Bohemian Massif (P. ČTYROKÝ 1991). In contradistinction to the Middle- and North-Moravian blocks, in the South-Moravian block it is not possible to differ distinctly the Carpathian and Badenian foredeeps. This can also help to explain the very flat planated relief of the Jevišovická pahorkatina (Hilly land) that is, in fact a western continuation of the South-Moravian block.

In the Moravian part of the Carpathian foredeep adjacent to the Jevišovická pahorkatina (Hilly land) the Egerian, Eggenburgian, Ottnangian Carpathian and Badenian predominantly marine sediments occur (R. JIŘÍČEK - P.H. SEIFERT 1990). The sediments of the younger stages, the Sarmatian and Pannonian, are present only in the Austrian part of the foredeep. In the Austrian territory, close to Moravian borders and only about 15 km from the margin of Bohemian Massif the hill Buchberg (416 m), with the top composed of the Lower Badenian Lithothamnion limestone, is the highest point in this part of the foredeep and whole of the Dyjsko-svratecký úval (Graben).

In the Jevišovická pahorkatina (Hilly land) the many remnants of Miocene sediments of different age and in different altitude are preserved (M. DLABAČ 1976). They rest on bare or weathered crystalline rocks. This suggests only feeble effects of marine abrasion processes. Some authors believed that the whole of the Českomoravská vrchovina (Higland) was covered with Miocene deposits. No detailed research of the Miocene sediments in the national park itself was made.The polymict gravels and sands are supposed to be Ottnangian by P. BATÍK (geological map, 1992). West of the Podyjí NP, in surroundings of the villages Šafov and Langau (the latter in Austria), also the rests of downfaulted Lower Miocene (Eggenburgian) coal-bearing sediments in thickness of up to 50 m occur (A. DUDEK et al. 1962, V. JENČEK et al. 1984).

4. Relief of the Podyjí National Park

4.1 Regional planation surface

4.1.1 The problem

The flat or moderate rolling surfaces in interfluvial areas are rests of originally extensive regional planation surface and present the most distinct topographic feature of the SE part of the Bohemian Massif. Owing to absence of pre-Miocene deposits in the whole of SE part of the Bohemian Massif, the problem of origin and age of this surface, referred previously to as Paleogene peneplain, is very difficult and impossible to resolve in the small area of the national park.

The platform limestones of Jurassic age as well as the Cretaceous sediments buried under Tertiary sediments in the Carpathian Foredeep on the South-Moravian block (partly incorporated in flysch nappes) indicate a very planated relief in the adjacent land at that time. Also the Upper Cretaceous sediments in the present South Bohemian Basins were deposited on weathered surface of low relief. Thus, it is very probable that the whole of southeast part of the Bohemian Massif was covered by Mesozoic sediments. After regresssion, the planation processes have continued without any perceptible intervention of tectonism in progressive downwearing of subdued relief up to Upper Paleogene (the acyclic development after C. KLEIN 1974). With regard to the fact,that in platform stage the Moldanubicum was the most stabile part of the Bohemian Massif, we agree to designate the planation surface as Mesozoic-Paleogene (M. SUK et al. 1984).

In the W-E cross profile from the main continental divide on the Bohemian- Moravian border to the eastern margin of the Bohemian Massif, the planation surface truncates different rocks and dips unperceptibly eastwards, down to the upper edge of the marginal slope near of Znojmo. The planation surface is continuous and smooth. An undistinct break is only at the contact of the Javořická vrchovina (Highland) with the Křižanovská vrchovina (Highland), corresponding probably to contact of the Central Moldanubian Pluton granites with the Moldanubian paragneiss or with the zone of the Přibyslav deep fault trending to SSW. In the Central Moldanubain Pluton typical granite relief evolved with inselbergs, tors, corestones and different microforms. Therefore we believe that rests of only one, originally widespread planation surface are preserved in the SE part of the Bohemian Massif. The present diferences in extent and altitude of surface resulted from the Late Paleogene or post- Paleogene moderate differential tectonic movements and lithologic control of denudation.

In the area of Moldanubian paragneiss, the planation surfaces are more dissected owing to their lesser resistance. The resistant quarzite and orthogneiss form only narrow strips. On the other hand, in Moravicum, the resistant Bíteš orthogneiss and Dyje granite prevail and the area of relatively weak mica-schists is small.

4.1.2 Planation surfaces in the Podyjí National Park

4.1.2.1 Regional planation surface

Although in the surroundings of the Podyjí NP the planation surface truncates both the granites and steeply dipping crystalline schists, some parts of planation surface are almost perfectly flat and we found no strict structural control. But lithologic contacts are perceptible in the relief and also weathering products of rocks are different. Generally, two types of weathering mantle occur. The first are rests of fossile deep chemical weathering, the second consists of products of physical weathering of firm rocks. Here, the weathering mantle is mostly thin, composed predominately of loamy and sandy debris. Some parts, especially in low altitudes, are covered with loess which smoothed down the small superficial irregularities. Whereas in inner parts of the Českomoravská vrchovina (Highland) the second type is dominating, in the eastern marginal part numerous denudation relics of fossile kaolinic weathering crust are very important and some of them are mined (see M. KUŽVART 1965, M. KUŽVART et al. 1983).

The rests of planation surface, underlain by various types of crystalline rocks, sound or weathered, but also by unconsolidated Miocene and Quaternary sediments, are in the Podyjí NP, in our opinion, the polygenetic forms. The surface is somewhat monotonous, some parts are rather very moderate slopes. Forms as tors, boulder accumulation or corestones are exceptional on the surface.

In the west part of the national park, the rests of planation surface are in altitude 450-535 m, in the east, above the marginal slope of the Bohemian Massif only in 300 m. In generalized NW-SE profile, the surface is smooth and dips eastwards with inclination of 0.2-0.3^{o} only. The lithologic and structural control of topography is apparent partly also in the adjacent part of Austria (profile in H. NOWAK, 1969). The altitude of planation above the high eastern marginal slope south of the town Retz is 460-480 m. Thus, difference in altitude of planation surface in surroundings of the PNP is surprisingly almost 200 m.

4.1.2.2 Importance of deep chemical weathering

The many remnants of deep weathering crust in the SE part of the Bohemian Massif, their distribution and contrast with the crusts in higher altitudes attracted attention of geologists and geomorphologists already long ago. They were discussed in detail especially by L. SÝKORA (1949). Recent inquiry of J. KARÁSEK (1985) into problems of areal distribution of weathering products, their genesis and relations to the Miocene sediments and planation surface aids substantially in understanding of relief evolution.

There are many localities of remnants of fossile weathering crust also in the surroundings of the Podyjí NP. Detailed research of kaoline deposits in last decades has confirmed both climatic and areal (non-linear) character of kaolization. In opinion of M. KUŽVART (1965, for references see also J. VACHTL ed., 1969 and M. KUŽVART et al. 1983), the Moravian kaolines in eastern part of the Bohemian Massif originated in warm humid climate, and are pre-Upper Miocene, probably of Oligocene age. In handbook by J. KONTA (1982), the South Moravian kaolines are mentioned to be originated mainly in Cretaceous, partly in Paleogene. Their origin was probably connected with brown coal or lignite seams, existing at that time in their neighbourhood.

However, how M. KUŽVART and other authors have stressed, in some places the kaolization was preceded and facilitated by dynamometamorphism or cataclasis and the problem of origin is not quite unambiguous. In this connection it is very interesting, that the South Moravian kaolines occur predominantly in the Moravicum, both in the Svratka and Dyje Domes, characterized by Variscan nappe tectonics. In the last modification of structure of the Svratka Dome (J. JAROŠ 1992), in which the important kaoline deposit of Lažánky occurs, even two nappes are in superposition. Both nappes, the lower Moravian and the upper Moldanubian, were thrusted over Brunovistulicum. The largest known deposit in the centre of the Svratka Dome originated by kaolization of cataclased granite of the Brunovistulian autochtone, which was uncovered by denudation in a tectonic window. Less important occurences of kaoline are present also in the Moravicum (Bíteš orthogneiss and phyllites), which is a tectonic half-window originated by denudation of the Moldanubian nappe. The depth of kaolization in the Lažánky deposit is about 110 m (M. KUŽVART, 1965).

Kaolinization in the area of the Dyje Dome was prepared, too. However, tectonic development was different here (e.g. absence of eastern half of the dome could indicate the deeper denudation). Main kaoline deposits are again on granite (Dyje granite) in the centre of dome. In the deposit Únanov the depth of kaolinization is more than 80 m (M. KUŽVART 1965). According to L. KRYSTKOVÁ (1971) thickness of kaolines at the deposit of Plenkovice (about 6 km north of Dyje NP) attains 81 m. Here, the kaolines originated on the Bíteš orthogneiss and importance of tectonics is also emphasized.

In the past, the processes like diapthoresis of phyllites (retrograde metamorphism) were connected (but later refused) with overthrusting in the both domes. However, it is more probable, that it was dynamometamorphism, which prepared very different rocks for kaolization.It it also possible, that unusual great depth of chemical weathering also connects with this process.

The largest kaoline deposits in the surroundings of Znojmo, Únanov and Plenkovice, are close to the margin of the Bohemian Massif, in the altitude of about 300-350 m, only. Here, in short segment of margin, instead of distinct marginal slope, only an undefinable, very long and gentle slope passes the Carpathian Foredeep. The absence of slope connects probably with the cross fault trending to SE (A. DUDEK-V. ŠPIČKA 1975). Here the kaolines probably were thicker and their denudation was delayed owing to the low altitude.

The well-known deposit Únanov in the altitude of 300 m is in a very shallow depression trending to NE in the head of the first-order valley. The potential deposit Hradiště, 2 km west of the town of Znojmo at the boundary of the Podyjí NP, is in the altitude of about 350 m. It is situated on an almost ideal flat surface underlain with Miocene sediments and Quaternary loams.

The Austrian deposits in surroundings of the Thaytal National Park are in the altitudes of above 400m. Niederfladnitz (5 km NW of the town Retz) originated on the Dyje granite, the Mallersbach (4 km WSW of the town Hardegg) on the Bíteš orthogneiss (H.F. HOLZER - P. WIEDEN 1969).

The kaolines were found and studied also in the area of the Podyjí NP, especially near the villages of Hradiště and Mašovice - Podmolí (J. NEUŽIL - M. KUŽVART, 1972, J. PAVLÍK 1987), or in their immediate vicinity. Results of the recent research were published also by L. KRYSTKOVÁ (1971) and P. BATÍK - M. GABRIEL - P. ŠEBA - O. LUBINA (1979).

In the paper about kaolines of the discovered deposits in the surroundings of Znojmo, J. NEUŽIL - M. KUŽVART - P. ŠEBA (1980) found, that biotite of the Dyje granite is primary chloritized by dynamometamorphosis and its fine scales parallel with dynamometamorphic foliation facilitate deep weathering at many places. Another interesting aspect is that alternation of potash feldspars started after complete weathering of plagioclas.

As to comparison with granite weathering products in Hercynian Europe (J.P. BAKKER - Th.W.M. LEVELT 1964, J.P. BAKKER 1960), the detailed analyses of kaolines from the localities of Hradiště and Mašovice-Podmolí, in the immediate vicinity of the Podyjí NP, published by J. NEUŽIL, M. KUŽVART and P. ŠEBA (1980) have shown different proportions of clay, silt and sand fractions, with 2.4-17.4 % of clay particles, predominately kaolinite, 10-15 % of illite and a few percent of montmorillonite. J. PAVLÍK (1987) has found in the Mašovice-Hradiště deposit of 87 % kaolinite in primary kaoline and 86 % kaolinite and 9 % montmorillonite in redeposited kaoline. As concerns weathering of two-mica schist or phyllites in the Dyje Dome, M. KUŽVART (1965) has only mentioned decay of phyllites into black plastic clay at the deposit from Únanov.

There are great differences in thickness of kaolines and the basal surface of weathering is not well defined in most of the cases. Without a doubt, the existing rests of kaoline weathering crust are only the deepest roots of an originally thick, probably almost continuous mantle. Absence of corestones near kaoline deposits is significant, too. Regardless of these facts, the deep chemical weathering and stripping (etchplanation) was very probably the major planation process in Mesozoic and Paleogene.

In the opinion of authors, the prevailing portion of kaoline weathering crust was denuded in the southeastern part of the Bohemian Massif already before Lower Miocene marine transgression. The products of deep chemical weathering were washed out into shallow erosion or tectonic depressions. Gravels and boulders in the Lower Miocene sediments suggest that also bare rocks of adjacent elevation such as inselberg (Schildinselbergs of J. BÜDEL 1978) were strongly attacked. Thus the sea trangressed over topography which was a low hilly landscape rather than a perfect flat plain. The landscape consisted of weathered and bare rock surfaces with forms such as inselbergs (e.g. Býčí hora, 536 m). In the conception of F.E. THOMAS (1974) it could be a partially or dominantly stripped etchplain. The local height differences could attain more than 100m and clearly, the relief evolution was controlled by resistance of rocks and climatic changes. As A.VELDKAMP and A.P.OOSTEROM (1994) point out, "etching and stripping processes tend to increase relief instead of reducing it". But the relief evolution since the marine trangression in Lower Miocene was too complex, to consider present relief to be an etchplain, although processes of etchplanation were cooperating in certainty in morphogenesis (T. CZUDEK - J. DEMEK 1970).

In discussing geodynamic evolution of the central Paratethys and its climatic implications, I. CICHA and M. KOVÁČ (1990, p.72) refer, that "within Ottnangian humidity gradually decreased and climate became drier with continental features". In connection with application of plate tectonics in the West Carpathians region, the paleogeographic changes are thought to be very important for changes of climate. The content of montmorillonite in several profiles would indicate a possibility of some drier climate, too. Further, global climatic changes in Late Tertiary and Quaternary have influenced relief evolution and we must pressupose also other types of weathering of granite and crystalline rocks.

4.1.2.3 Position and importance of Lower Miocene deposits

In the middle part of the Podyjí NP, 2.5 km south of the village Lukov and at the road to the castle Nový Hrádek, the planation surface forms a flat topped ridge in the altitude of 390-400 m, about 130 m above floodplain of the Dyje. The flat surface is composed of polymict gravels and sands, about 3 m thick, with distinct dominance of quartz. The sediments are occasionally mined in the shallow pit. The deposits contain predominantly well-rounded pebbles and also badly rounded or angular fragments of different rocks. The sediment is not sorted,some rounded boulders are more than 50 cm in diameter, requiring long transport and rapid rash accumulation. The gravel and sand have character of basal clastics and rest uncorfomably on sligtly weathered chloritized mica schist of the Lukov unit. According to the geological map of P. BATÍK, the sediments are of Ottnangian age (Lower Miocene). In opinion of V. ŠPALEK (1935a) the gravel is of Pleistocene age.

The palynological analysis of sands and clays (up to 25 m thick) of near-by deposit Únanov has shown the Eggenburgian - Ottnangian age (P. BATÍK - M. GABRIEL - P. ŠEBA - O. LUBINA 1979), too. However, the last mentioned authors have noted in the locality Únanov also quarzite (Oligocene ?) in one of the drills.

A less instructive locality, also underlain by two mica schists, is about 1.5 km west of the Lukov village on the flat-topped ridge in the altitude of 400 m. Here, the residual quartz pebbles, very well rounded, mixed with resedimented kaoline clay are present.

It seems, that the Miocene sediments occur prevalently in the area of some lower altitude underlain with less resistant micaschist. Towards the NE they extend up to the local drainage divide north of the Lukov. The sands and gravels fill a shallow depression between the flat ridge composed of the Bíteš gneiss on the NW and the less distinct elevation with flat rock-bare surface built of the granite of Dyje massif on the SE. It is interesting in this context, in spite of intensive research, among a lot kaoline occurences, the only mention of deep weathering crust on the less resistant phyllites is in the paper of (M. KUŽVART 1965 and J. KARÁSEK 1985). No relation both of the depression and Miocene sediments to the present drainage lines is apparent.

In Austria, in the SW extension of the zone of micaschists, the depression is also visible.Owing to the greater altitude of granite relief east of micaschist, the depression is more distinct there (see also the profile in H. NOWAK 1969). Lower Miocene sediments are also occuring in the depression.

Very interesting is also the position of Lower Miocene sediments on the bottom of a structural and topographic depression in the surroundings of villages Šafov and Langau west of the Podyjí NP. In the flat depression trending to SW the Lower Miocene sediments were downfaulted in a zone of non-resistant two-mica schists. (The geological map of CSSR 1 : 200 000, sheet Jindřichův Hradec, A. DUDEK a kol. 1962). The bottom of depression in the altitude of 430-450 m corresponds well with sediments near Nový Hradek. The height difference between the bottom of depression and planation surface in adjacent part of the Podyjí NP truncating the resistant Bíteš gneiss is about 100 m.

Different, but a very instructive locality of Miocene sediments is on the east margin of the Podyjí NP above the marginal slope of the Bohemian Massif. Here, at the village of Konice and at the elevation point of Kraví hora (347 m), the pavement of perfectly rounded quartz pebbles originated on the flat granite surface in the altitude of 335 m. Northeast of the Kraví hora, in the lower altitude of some 310 m, rests of gravel of the same type are preserved on the rather irregular surface of sandy weathered granite. The sediment is thought to be of Eggenburgian - Ottnangian age (geological map 1 : 25 000, sheet Znojmo, 1983). Similar sediments crop out also on the marginal slope of the Bohemian Massif.

4.1.3 Buried planation surfaces in the adjacent part of the Carpathian Foredeep

In addition to analysis of planation surface in the Bohemian Massif itself, additional but important information is also provided by the buried relief in the Carpathian Foredeep. In front of the marginal slope of the Bohemian Massif, the planation surface truncating various crystalline rocks and Upper Paleozoic sediments continues under Miocene sediments of the foredeep eastwards. Here, however, the surface is more affected by young tectonics. The planation surface is block-faulted (J. KARÁSEK 1985), but in generalized profile almost horizontal in forefield of the marginal slope. However, some protrusions of basement occur here. The thickness of Miocene sediments does not usually surpass 200 m. The basement surface dips to the east at the rate of 9-25 m per km and in depth about 400-500 m and 20-25 km from the marginal slope passes over on Jurassic limestone. Thus, eastwards of the village of Jaroslavice there are under Miocene sediments two buried planation surfaces. The younger one, truncates in the same level both the crystalline rocks and gently inclined Jurassic limestone. With its moderate basinward dip, the carbonate structure is potential for formation of cuesta, but details of buried topography are not known.

The latter planation surface, buried under Jurassic sediments and underlain with crystalline rocks, dips eastwards gently at first but approaching to the front of Carpathian flysch nappe, its basinward dip is steeper (some 200 m per km) and is both downwarped and faulted. In our opinion, this planation surface on crystalline rocks is very probably of post-Hercynian age. Further eastward, under flysch nappes, the Jurassic sediments are thicker and together with basinal facies of Upper Cretaceous sediments are present. The projection of the sub-Hercynian planation surface towards the west anticipates a relatively great height difference (and also intensive post-Jurassic denudation), compared to altitude of the present planation surface in surroundings of the town of Znojmo.

4.2 Marginal slope of the Bohemian Massif and relief in its eastern forefield

4.2.1 The marginal slope

The SE marginal slope of the Bohemian Massif faces the Dyjsko-svratecký úval (Graben), which originated after regression of Miocene sea coming to the SW part of the Carpathian Foredeep. As stated above, the SE marginal slope of the Bohemian Massif between Brno and the Moravian-Austrian border is distinct in granites of the Brno and Dyje Massif, while in metamorphites (between towns of Miroslav and Znojmo) transition to the Dyjsko-svratecký úval (Graben) is very gradual and in some places the slope is practically absent. There, the margin is also masked with thick cover of loess, deposited on the leeward.

Eastern limit of the Podyjí NP is situated in the upper part of the marginal slope of the Bohemian Massif between the towns of Znojmo on the N and the state boundary on the S. Morphology of the slope, its height, profile, structure as well as of its piedmont are very variable. The marginal slope is about 8 km long and 1-1.5 km wide in this section. Its upper edge is not quite distinct everywhere and this applies also to the foot.

In the short section immediately south of Znojmo, the slope is 40-100 m high, composed mostly of Eggenburgian-Ottnangian sediments. As mentioned above, near the village of Konice, remnants of quartz gravel rest on granite. The gravel can be seen also in old inactive gravel-pit in the uppermost part of the marginal slope. At foot of the slope, however, granite protrudes above surrounded fine grained sand with silt. In the middle section of the slope also fluvial sediments called "younger gravel cover" assigned to Lower Pleistocene (Günz)

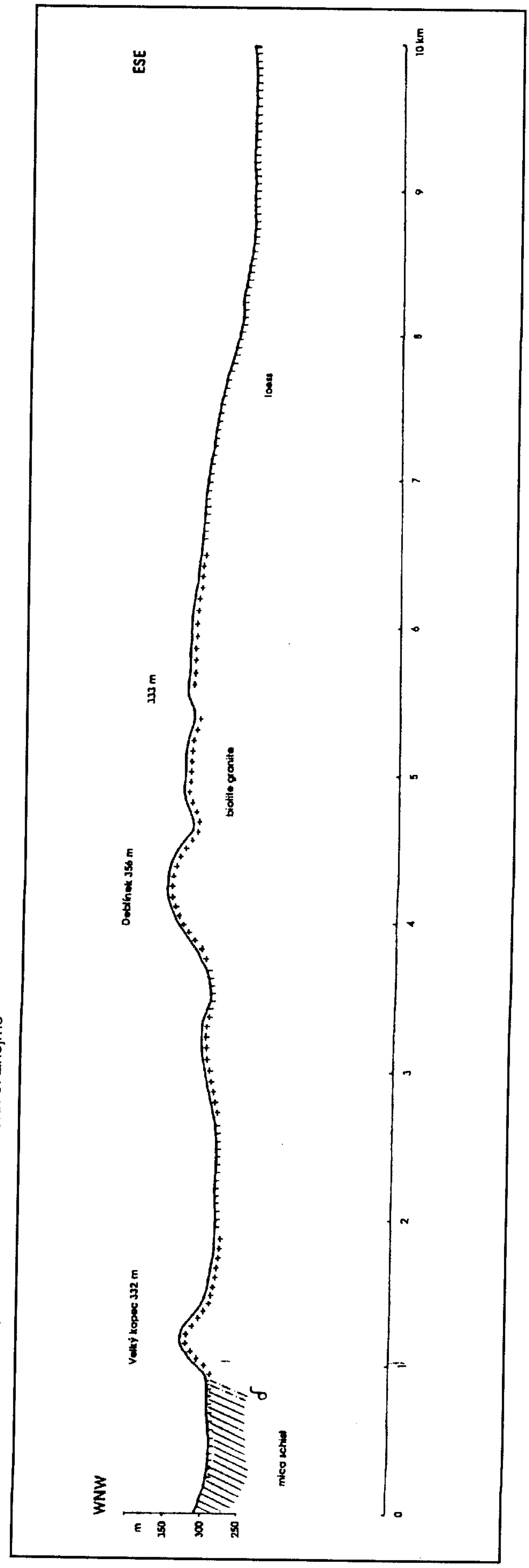


Fig. 4 Profile of marginal slope of Bohemian Massif north of Znojmo

are mapped, too. The slope dips only 4-9°, the foot being in the altitude of 230-270 m.

Between the villages of Konice and Hnanice morphology of marginal slope is even more complex . In the uppermost part of the slope, in the altitude of 300-330 m, some tors and boulders protrude from sandy weathered biotite granite, some of them in the protected heather. The marginal slope is more gentle, rarely more than 5° inclined. On the slope, the low rocky ridges, tors and boulders occur, too. Whereas general direction of the slope is NE, the rocky ridges and other forms prefer the N or NNW direction, related to schistosity of granite. The foot of slope in the altitude of 270-290 m is rather arbitrary. At the foot of slope, about 15 m high granite inselberg (Pustý kopec - Deserted hill, 263,7 m) projecting from the very flat bottom of shallow first-order valley is a very striking form.

Most distinct is the marginal slope in Austria. Towards SW from the village of Hnanice to the rivulet of the Pulkau (in Austria), the marginal slope is higher (up to 200 m, see profile of H.NOWAK 1969). Foot of the marginal slope is in the altitude of 270-370 m, planation surface above the slope in 370-480 m. In front of the slope many granite elevations are present, some of them of inselberg type.

Origin of the marginal slope and its evolution are difficult problems. Austrian authors support the idea, that the marginal slope was created by tectonic movements in the Oligocene or Lower Miocene. Then, following subaerial erosion the sea transgressed over the very dissected shore with many embayments (one of the largest is the Eggenburg Bucht-embayment) in Eggenburgian time. During the repeated transgressions , the thick sediments were accumulated and have buried dissected erosion relief under Egenburgian-Ottnangian, Carpathian and Lower Badenian sediments, in opinion of Austrian geologist up to the altitude of 420 m. After sea regression, the relief on crystalline rocks was ressurected step by step. The denudation levels in the forefield of Bohemian Massif as well as on its marginal slope are explained by this mechanism. H. NOWAK (1969) recognized 8 post-Badenian denudation levels in NW part of Weinviertel and marginal part of the Bohemian Massif. Thus, in concept of Austrian geologists and geomorphologists, the marginal slope is Late Oligocene or Early Miocene form, partly denuded, then buried and exhumed. R. GRILL (1958) recognized a less important tectonic phase in Lower Miocene (Helvetian and Lower Tortonian) yet. Some authors have admitted queer elevation in the SE-NW direction.

In the Czech literature, there is no mentioning of how the marginal slope originated. Only J. KARÁSEK (1985) in general review of relief evolution of the surroundings of Znojmo stressed the importance of post-Badenian faulting, especially with graben-like structure of this part of Carpathian Foredeep.

In our opinion, the evolution was rather complex and the differences in structure basement were significant.

In Austria a very important tectonic disturbance in the structure of SE part of the Bohemian Massif is the zone of Mailberg fault trending to NE. This fault with the amplitude of 3000 m separates the subsided Hollabrunn-Laa Depression(or block) with very thick Jurassic and Cretaceous sediments from the uplifted Sitzendorf block, where only 360 m thick Tertiary sediments rest on the basement rocks. The Mailberg fault was most active in Jurassic. On the uplifted block the marginal slope originated, too, but now is about 15 - 20 km from the buried fault-line.

As to geomorphological importance, the Mailberg fault rises two questions. The first is a problem of renewed fault movement of Mailberg fault zone in Miocene and its amplitude. The second problem, the large, some 15 - 20 km, parallel retreat of marginal slope from the fault-line.

The basement structure of South Moravian block, in front of marginal slope of the Bohemian Massif is even more complex. The Velké Pavlovice fault system (V. ŠPIČKA 1976) very probably corresponds with Mailberg fault zone. Addition to parallell to this fault system, the Ždánice flexure is suggested under marginal part flysch nappes. The Mailberg fault zone branches out in the surroundings town of Mailberg. The main fracture named the Velké Pavlovice fault system, has a complicated course and runs under Carpathians nappes, some 40 km from the margin of the Bohemian Massif (Z. STRÁNÍK - J. ADÁMEK - V. CIPRYS 1979). The others are subsidiary branches, the East Dyje and West Dyje faults dislocating the Lower Miocene, Carpathian and Lower Badenian sediments Carpathian Foredeep (M. DLABAČ - M. MOŘKOVSKÝ 1963). Thus, the marginal slope of the Bohemian Massif is on no account connected with Velké Pavlovice fault system.

More acceptable explanation is presence of a parallel fault situated close to the foot of marginal slope, as suggests the Tectonic map of CSSR (M. MAHEL - O. KODYM - M. MALKOVSKÝ, 1984). In the surroundings of Znojmo this marginal fault crossed with the Boskovice -Diedendorf fault. In our opinion, the main fault movements along these disturbances occured in Oligocene or Lower Miocene with some repetition after Lower Badenian. The crossing of the marginal fault with the Boskovice-Diedendorf fault resulted in a block-faulted relief (J. KARÁSEK 1985), in front of the marginal slope of the Bohemian Massif. The differences in height of marginal slope areas have been caused probably by undulations along quer axes. Thus, absence of marginal slope of the Bohemian Massif north of Znojmo connects with fault trending to SE, which separates the partial Pavlov and Waschberg blocks inside of South Moravian block (A. DUDEK - V. ŠPIČKA 1975).

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As to geomorphological importance, the Mailberg fault rises two questions. The first is a problem of renewed fault movement of Mailberg fault zone in Miocene and its amplitude. The second problem, the large, some 15 - 20 km, parallel retreat of marginal slope from the fault-line.

The basement structure of South Moravian block, in front of marginal slope of the Bohemian Massif is even more complex. The Velké Pavlovice fault system (V. ŠPIČKA 1976) very probably corresponds with Mailberg fault zone. Addition to parallell to this fault system, the Ždánice flexure is suggested under marginal part flysch nappes. The Mailberg fault zone branches out in the surroundings town of Mailberg. The main fracture named the Velké Pavlovice fault system, has a complicated course and runs under Carpathians nappes, some 40 km from the margin of the Bohemian Massif (Z. STRÁNÍK - J. ADÁMEK - V. CIPRYS 1979). The others are subsidiary branches, the East Dyje and West Dyje faults dislocating the Lower Miocene, Carpathian and Lower Badenian sediments Carpathian Foredeep (M. DLABAČ - M. MOŘKOVSKÝ 1963). Thus, the marginal slope of the Bohemian Massif is on no account connected with Velké Pavlovice fault system.

More acceptable explanation is presence of a parallel fault situated close to the foot of marginal slope, as suggests the Tectonic map of CSSR (M. MAHEL - O. KODYM - M. MALKOVSKÝ, 1984). In the surroundings of Znojmo this marginal fault crossed with the Boskovice -Diedendorf fault. In our opinion, the main fault movements along these disturbances occured in Oligocene or Lower Miocene with some repetition after Lower Badenian. The crossing of the marginal fault with the Boskovice-Diedendorf fault resulted in a block-faulted relief (J. KARÁSEK 1985), in front of the marginal slope of the Bohemian Massif. The differences in height of marginal slope areas have been caused probably by undulations along quer axes. Thus, absence of marginal slope of the Bohemian Massif north of Znojmo connects with fault trending to SE, which separates the partial Pavlov and Waschberg blocks inside of South Moravian block (A. DUDEK - V. ŠPIČKA 1975).

4.2.2 Crystalline elevations in forefield of the marginal slope

In front of the marginal slope of the Bohemian Massif, solated elevations, some of them rather larger, composed of predominately crystalline rocks protrude from the weak Miocene sediments. Some small hills, situated at the foot or close to the marginal slope and composed of the same rocks are certainly inselbergs. However, large rectangular elevations in some cases composed of very different rocks are supposed to be fault blocks.

The largest block, the Krhovice horst, about 3x5 km in size, lacks distinct margins and in NW it is attached in little depth with the basement rocks of the Bohemian Massif. Only in the W it is separated by a 2 km wide depression, trending and dipping to the N, from the marginal slope of the Bohemian Massif. In the depression the S trending fault is supposed. The flat bottom of the depression is in the altitude of 205-250 m. The depression is crossed by the Dyje river. In two boreholes on the bottom of the depression, the Dyje granite was found in the depth of 118 m and 147 m respectively (approximately 100m above sea level) under Lower Miocene sediments.

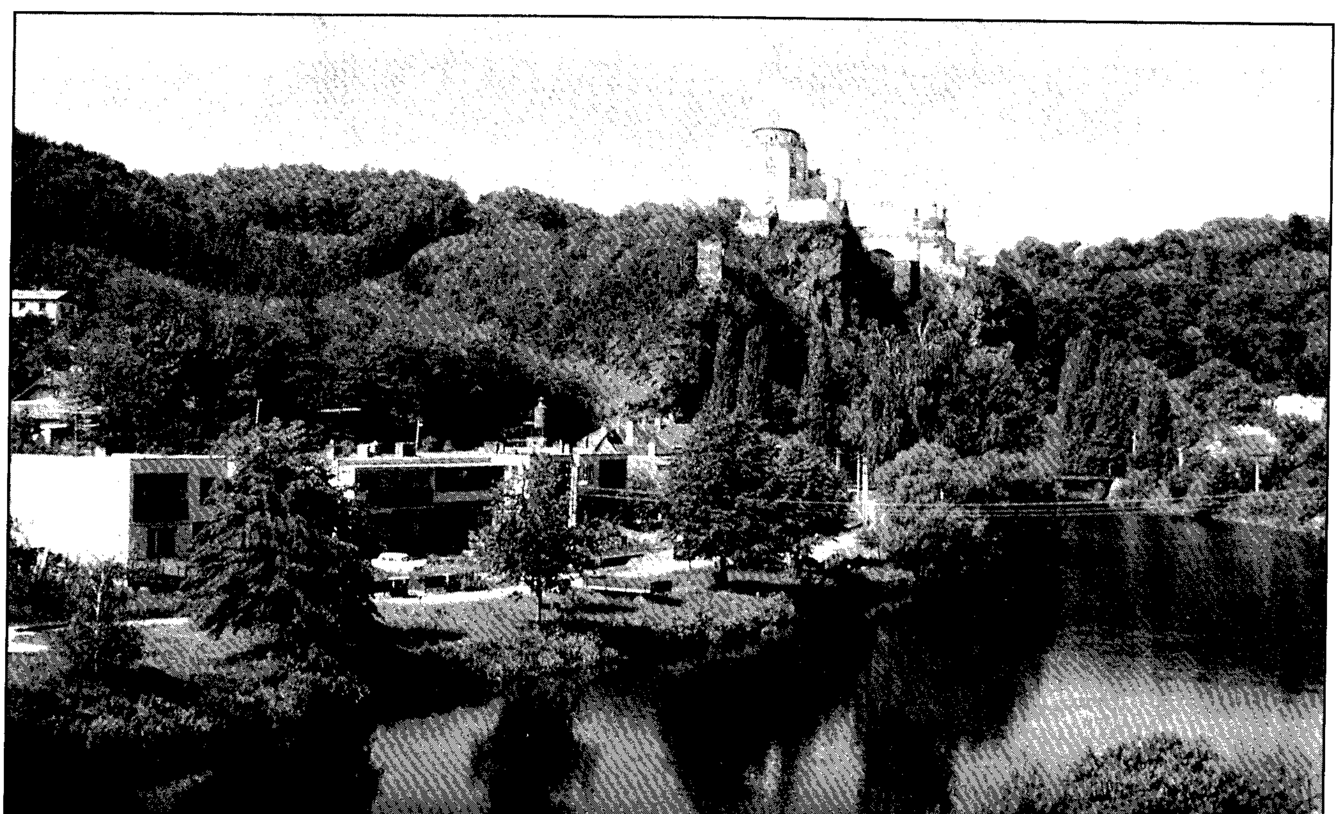
The intrusive rocks, the Dyje biotite granite and quarz diorite form the western part of the horst. They are separated by downfaulted block of Lower Devonian conglomerates from metamorphites, which were enigmatic for geologists for long time. The different gneiss and mica-schist and phyllite are believed to be a volcanic-sedimentary unit belonging to Moravicum (P. BATÍK in J. DORNIČ and al. 1984).

The Krhovice horst dips gently to the east, conformably with the marginal part of the Bohemian Massif. Thus, the highest point of the horst, the Načeratický kopec (hill), attains 290 m above sea level and is situated in the flat granite terrain in the western part. The rests of fluvial gravels in the altitude of about 230 m are thougt to be younger gravel cover of Lower Pleistocene age (Günz). The most interesting form of the horst is the gorge of Dyje, 5 km long and about 50 m deep, incised into crystalline rocks, at present intensively mined.

4.3 The Dyje canyon and valley pattern of the Podyjí NP

4.3.1 Position of the Podyjí NP in the drainage area of the Dyje river

The Dyje river (Thaya in Austria, L-305, 6 km, A-13.418 km^2) is a major water course in the SW Moravia and the largest tributory of the Morava river. Generally, the Dyje river flows towards ESE,down the regional slope. From its unregular, zig-zag or meandering course follows the anomalously high sinuousity connected possibly - at least partly - with prevailing dips of metamorphic rocks to the W or NW.



3. Valle of the Dyje river in town of the Vranov nad Dyjí, the Vranovský zámek (Vranov chateau) is slanding on the rock ridge.
Photo: Mojmír Hrádek

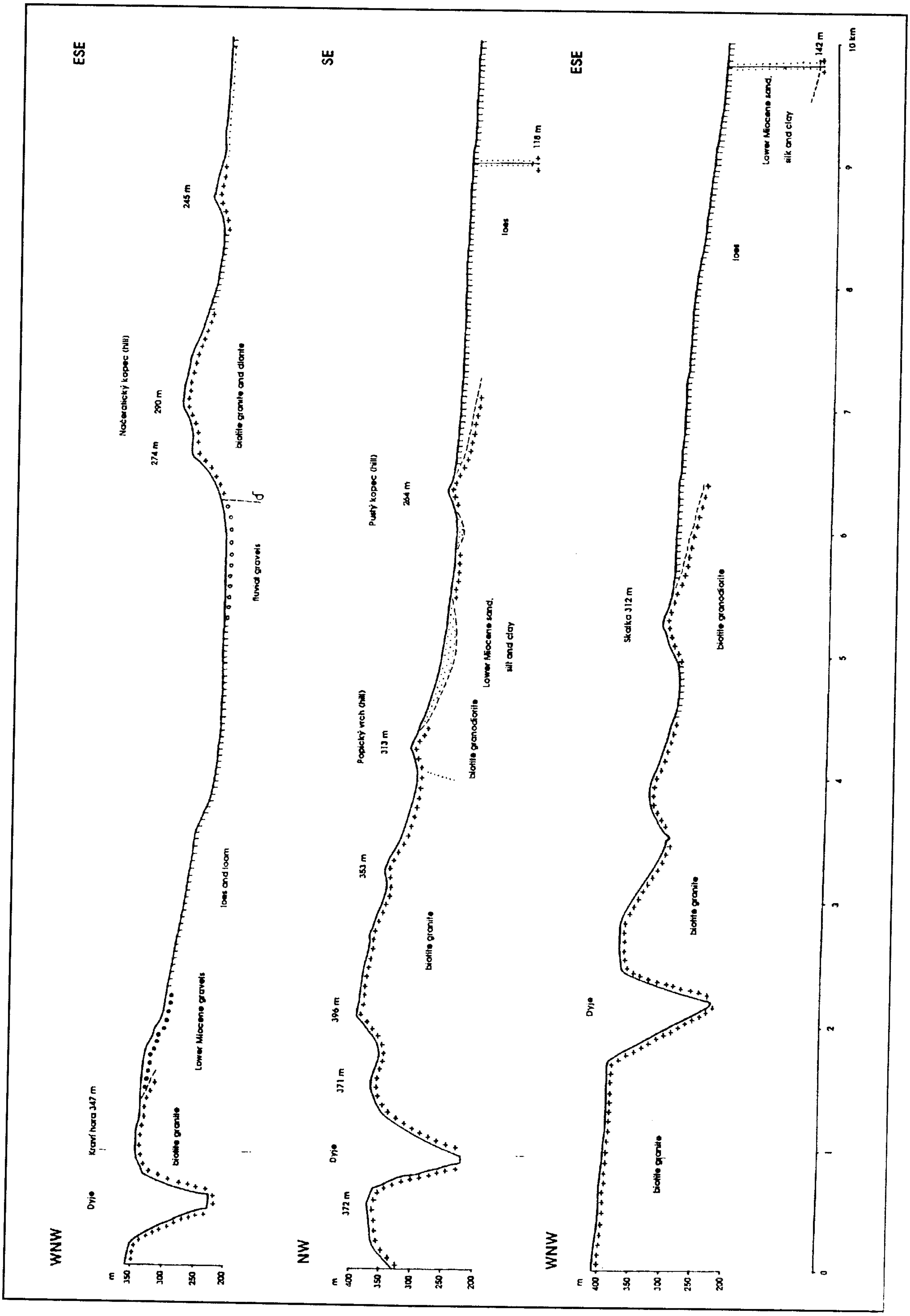


Fig. 5 Profiles of east marginal slope of Bohemian Massif south of Znojmo

Sources of the Dyje river are the Moravská Dyje in Moravia and the Deutsche Thaya in Austria, the first trending to the South, the latter to the North. Both sources join together in the Dyje river near the town of Raabs an der Thaya in Austria. The Dyje river is followed in several sections by the Czech-Austrian border and joins the river of Morava in the Dolnomoravský úval (Graben, geologically in the Vienna Basin) at the contact of Austria, Slovakia and Czech Republic.

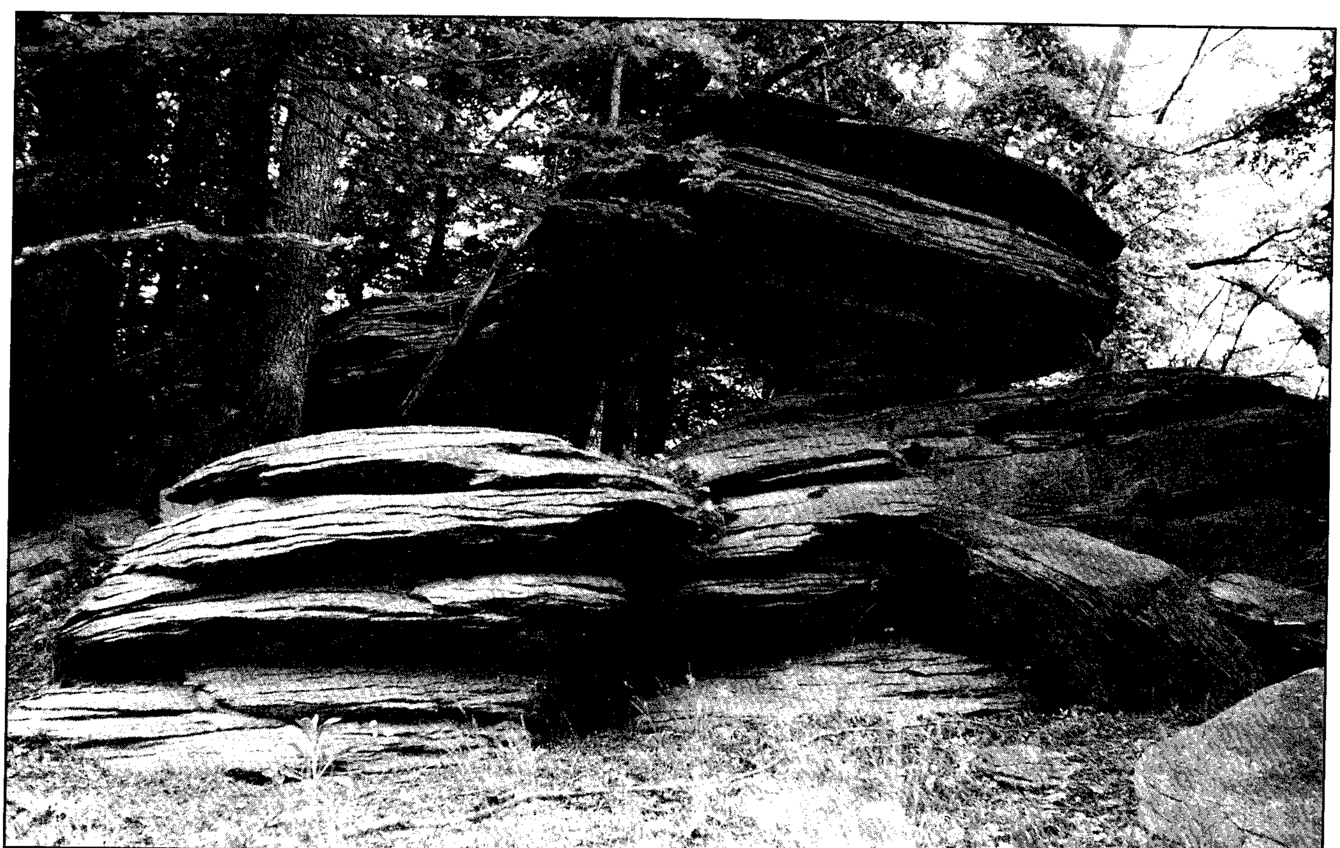
Complicated course of the Dyje river is characterized by four large bends each being some tens of kilometers long. These bends are not regular in form, but broken and composed of reaches of SW-NE and NW-SE direction. The Podyjí NP is situated in the lower part of the second bend and in the uppermost part of the third bend. In these bends, the Dyje river has created many meanders, incised in the bedrock (in the Bohemian Massif, in the upper and middle course) or free alluvial meanders (in the Carpathians, in the lower course). Although the river course is generally independent of structure and lithology, their influences are apparent in detailed morphology of canyon as well as the pattern of low-order tributaries.

4.3.2 The Dyje canyon

The complicated and predominantly meandering canyon of the Dyje river, between the towns of Vranov nad Dyjí and Znojmo is the main and unique landscape feature of the national park. Whereas, the air distance between the river channel at the beginning of the Podyjí NP and its end in Znojmo is only 17 km, actual length of the Dyje river is 41.6 km. The anomalously high sinuosity ratio (2.4) resulted partly from sharp change direction about 9 km upstream of Znojmo, too.

The Dyje river enters the Podyjí NP at Vranov nad Dyjí about 2 km downstream of the Vranov Dam in the altitude of 305 m. The downstream end is at the Znojmo Dam at 215 m. From the vertical difference of 90 m follows an average slope of 2.16 m per km. The cross profile of the canyon, its depth, width and form of slopes, are rather variable, being controlled by gelogical structure. Thus, in harmony with the main geologic units, we distinguish in the Dyje canyon three sections with different morphology.

1) The western section in Bíteš orthogneiss,between the towns of Vranov nad Dyjí and Hardegg. In the surroundings of Vranov nad Dyjí, before entering the Podyjí NP, the Dyje river is incised in lesser resistant paragneiss to the depth of 130 - 150 m. Here, small riverine basin is filled with the Vranov Dam. Downstream of Vranov the Dyje river enters the deepest section composed of Bíteš orthogneiss. On the right side, below the highest point of the Podyjí NP, the Býčí hora (hill) 535.9 m, the depth of valley is almost 250 m. Slopes of the valley are very steep up to vertical at some places. Many tower-shaped tors up to 20-30 m high are accompanied by ledges, steps, boulders and in lower parts of the slope by



4. Tors of the Bíteš gneiss modelled by selective weathering (locality of the Býčí hora, hill - eastern slope). Photo: K. Kirchner

talus and boulders accumulations. The slopes are densely forested and partly inaccessible. Whereas the tors or tor-like forms crop out in several levels, the rock walls rise from the bottom of the valley only in very rare cases.

In this valley section two remarkable geologic and geomorphologic features occur, namely ptygmatic folds in bluff near the entrance to the Podyjí NP and fissure ice caves about 1 km downstream.

The strip of resistant Bíteš orthogneiss between the town of Vranov and Hardegg is 6 km wide, but owing to crookedness, the length of the river is 9.3 km in this rock. Due to high resistance the river bends are rectangular rather than bow-shaped. The meanders are principally symmetrical in cross profile (entrenched type). The sinuosity of 3 successive bends is 1.9. As to relation to bedrock structure the Dyje is up-dip stream. The Bíteš orthogneiss trends NE and dips 20-40^{o} NW. Form of the bends seems to be depending on resistance rather than on structure of the rock.

2) In the middle second section only the left valley side is on the Czech territory. The Dyje is incised in less resistant two-mica schists of the Lukov unit (with the important intercalations of cristalline limestone). The strip of mica-schists is about 5 km wide, however length of the valley (talweg) is 12.9 km (sinuosity in the whole reach being 2.3). The river maintains general canyon-shaped forms, but some valley features are rather different here.

   Large untypical meanders elongated in groundplan in NW-SE direction with very long and narrow necks are the most remarkable forms of the section. The sinuosity of meandering part of the section is very high (2.9). In the cross profile meanders are assymetric and thus belong to ingrown type. Smooth meander curves suggest lesser importance of bedrock structure than in Bíteš orthogneiss. Narrow meander necks, one in Moravia with the castle Nový Hrádek, the other "Umlaufberg" in Austria, demonstrate initial cutting off. The Dyje is predominantely up-dip stream here. As to trend difference between bedrock dip and flow direction (D.R. HARDEN, 1990), anti-dip relation trend difference of 180^{o} prevails, however in short sections in meanders also difference of 90^{o} occur.

   The canyon in the mica-schists is mostly of about 120 - 150 m deep. Very steep rock slopes or bluffs which rise above the river bank are present only at undercut of meander slopes. Distinct rock-walls and bluffs, some tens of meters high, are present particularly upstream of junction of the Dyje river and Klaperův potok (brook), at the locality of Vraní skála (Crow's rock) and between the castle of Nový Hrádek and the mouth of Žlebský potok (brook). At the opposite valley side of the section, in Austria, the canyon of Fugnitz, is the most interesting form of the longest tributary of the Dyje river in the Podyjí NP.

3) The third, eastern section of the Dyje canyon, incised in the biotite Dyje granite is almost 20 km (18.35 km sinusoity 2.1) long. Depth of the canyon does not surpass 160 m, however the canyon-like features are in all respects unique also here. Steep slopes with many tors and exfoliation phenomena especially in the upper parts are accompanied by surprisingly large blockfields and screes. In the lowest part of the section the Dyje river is impounded for 5.5 km behind the Znojmo Dam.

   The Dyje granite is schistosed or cataclased, mainly close to contacts with Moravicum. The schistosity planes trending to NE dip about 70^{o} NW. There is a tendency of the granite to disintegrate into large blocks or boulders.

   Wealth of granite forms in the Podyjí NP is surprisingly large particularly in comparison with Brno granite. There, in deep valleys of Svitava and Svratka rivers, in surroundings of the town of Brno, the weathering granite forms are rather exceptional, as same as the traces of deep chemical weathering. In our opinion explanation of this difference consists in more intensive tectonic shattering rather than cataclasis in the Brno Massif, where depth of denudation is also lesser.

   Course of the Dyje river in the section is very complicated, different from upstream sections. Downstream of the junction of the Dyje river and Žlebský potok (brook), the river flows for about 9 km down the regional slope in tortuous course with some undeveloped incised meanders (sinuosity 1.9). At apex of the last of them, termed Šobes, which is of entrenched type, the Dyje turns at first to the N for 3 km and then to the NE up to the eastern margin both of the Podyjí NP and Bohemian Massif. In this slightly winding course trending to NE the Dyje river is impounded. Thus, in spite of the regional slope the Dyje river flows from the Šobes meander approximately in parallel with marginal slope of the Bohemian Massif.

The floodplain of the Dyje river in the Podyjí NP is well developed mainly in the section of two-mica schists and in meanders.

Quaternary fluvial terraces are very rare in the Dyje canyon. Hopeful places as slip-off slopes, e.g. the Šobes meander, are transformed in agricultural terraces cultivated for centuries. At the Gališ meander,in the middle section of canyon composed of mica-schist, we found the rest of fluvial accumulation, destroyed by slope processes.

The most hopeful profile has been found,for the time being, in lower part of the left valley slope below Králův stolec. In the altitude of 256 m, about 30 m above the floodplain we found fluvial, mostly coarse-grained grales with slightly rounded pebbles of quartz and orthogneiss. Sediments of loess type occur in the gravel intercalations. Known thickness of the sediments in the profile is 2.45 m. According to its elevation and relation to the Dyje river terraces in adjacent part of the Dyjsko-svratecký úval (Graben), gravel is probably analogous to the young gravel cover of Early Pleistocene age (A. ZEMAN 1974).

4.3.3 Pattern of tributary valleys

Tributaries of the Dyje river in the Podyjí NP are mostly low-order streams. The Granický potok (brook) as the longest left tributary of 13.3 km in length is the stream of the 3rd order. The Klaperův potok (brook) is only 8.6 km and Mašovický potok (brook) 5.6 km long. Other streams are no more than 2-4 km long. Some short watercourses are episodic and disappear in the bottom or in slope sediments.

On the right side, no tributary is longer than 3 km in the Moravian part of the Podyjí NP. In Austria, on the other hand, the Fugnitz is 21 km long and flows in deep canyon incised in mica-schist of the Lukov unit. The abandoned incised meander is another interesting form of its course.

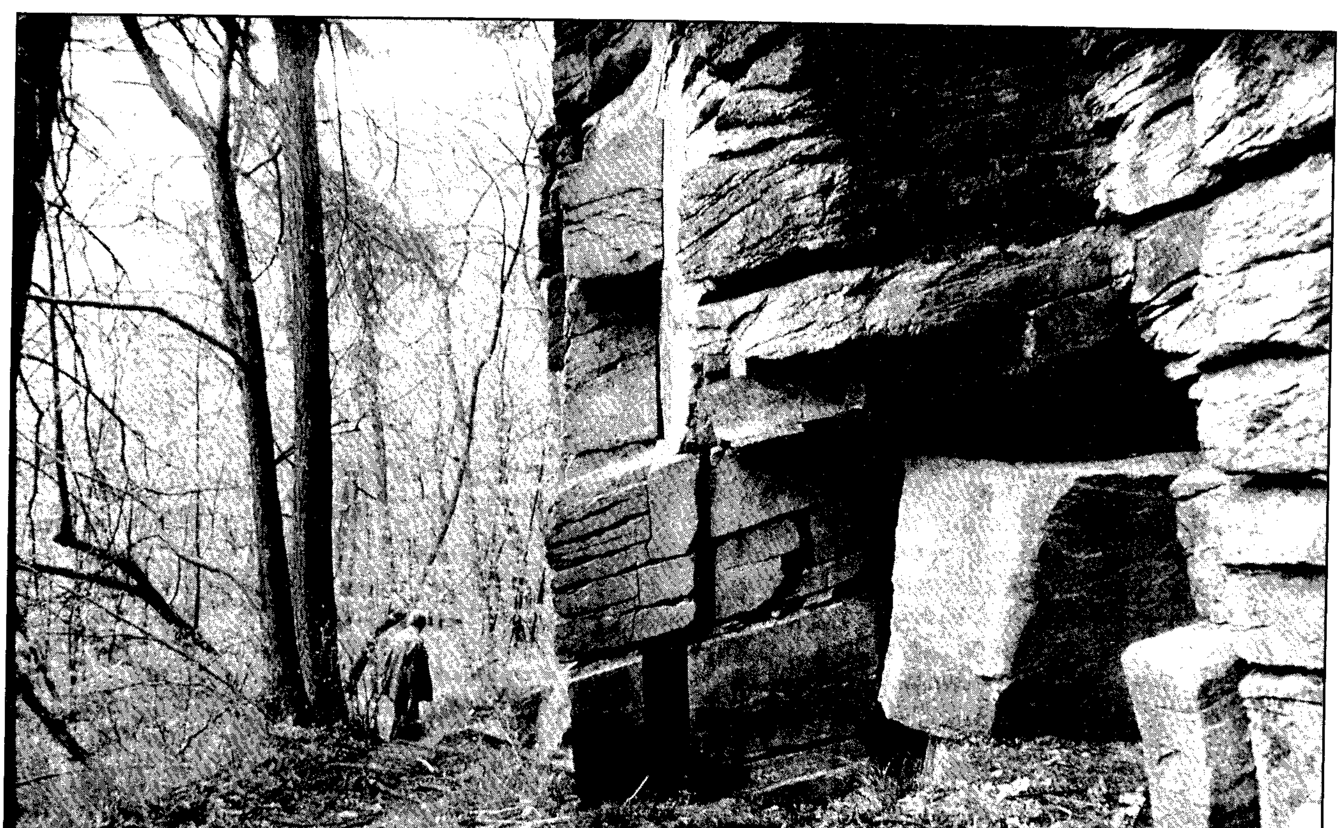
Headwaters of the longer tributaries are trending to SE, suggesting the direction of original drainage straight to the Dyjsko-svratecký úval (Graben). The Granický potok (brook), as the best example flows towards SE for the most part of its course and only some last hundred metres turn suddenly to the SW.

In the source areas valleys are both open and very shallow, channels being straightened up artificially in the mostly agricultural landscape. In the middle and lower courses both the slopes and gradients are steeper. Nickpoints are mainly in granite. Alluvial fans are mostly neglectable.

5. Some interesting geomorphological localities

In the Podyjí NP many interesting relief forms occur. Here only a very short information is given about forms developed predominately by processes of erosion and denudation.

1. Vranov - fissure ice caves and gravitational phenomena
   The fissure ice caves are situated on the narrow rock ridge in core of a deep incised meander of entrenched type. The ridge composed of Bíteš orthogneiss is almost 1 km long, 130 m high and it narrows towards SW to the tip of spur. The ridge is trending to ENE, the rock dips 15 - 30° NW. Thus NW facing the concave undercut slope of meander is well predisposed to gravitational loosening, cambering and desintegration. Thin intercalations of biotite schists were important for realizing of movements, too



5. Rock walls of the Bíteš gneiss afected by gravitational processes (failure) on the locality of the Ledové sluje (ice caves).
Photo: Mojmír Hrádek

(V. ŠPALEK 1935b). As a result, the whole slope from the top to the foot has been affected. The rock walls, pillars, deep opened fissures, huge angular blocks and coarse debris are very main features of the slope. In the rock and block accumulation tens of meters deep and some hundred meters long fissures occur, known by year - long preservation of ice.

At present, dynamics of block movements is monitored (J. ZVELEBIL - B. KOŠŤÁK - J. NOVOTNÝ - P. ZIKA, 1993).

The form has been classified mostly as rock slide (J. KOUTEK, 1934, V. ŠPALEK, 1935b), however some features resemble rock glacier (cf. H.E. MARTIN - W.B. WHALLEY 1987). Age of slide movements is obscured.

In front of the slide slope and the block accumulation the valley of Dyje (river) is somewhat wider, also owing to erosional activity of two short left tributaries. On the flat valley bottom an unusual isolated rock protrudes. The rock is about 75 m long, 30 m wide and flat-topped, composed of bare rock. The top is 12 m above the floodplain surface. The rock was interpreted as cutoff meander core or severed spur by V. ŠPALEK (1935a). In his opinion, the cuttingoff took place when 9 m terrace of the river Dyje was formed. However, the terrace gravel mentioned in the ŠPALEK's paper is in fact a sediment of alluvial cone of two left tributaries.

However, another explanation of the isolated rock is also possible, connected with loosening of the slope. In our opinion, the isolated rock was separated from the opposite meander spur not by lateral erosion from opposite sides, but more probably by breaking or overspilling of the spur due to updamming of a part of the valley bottom by catastrophic slope failure.

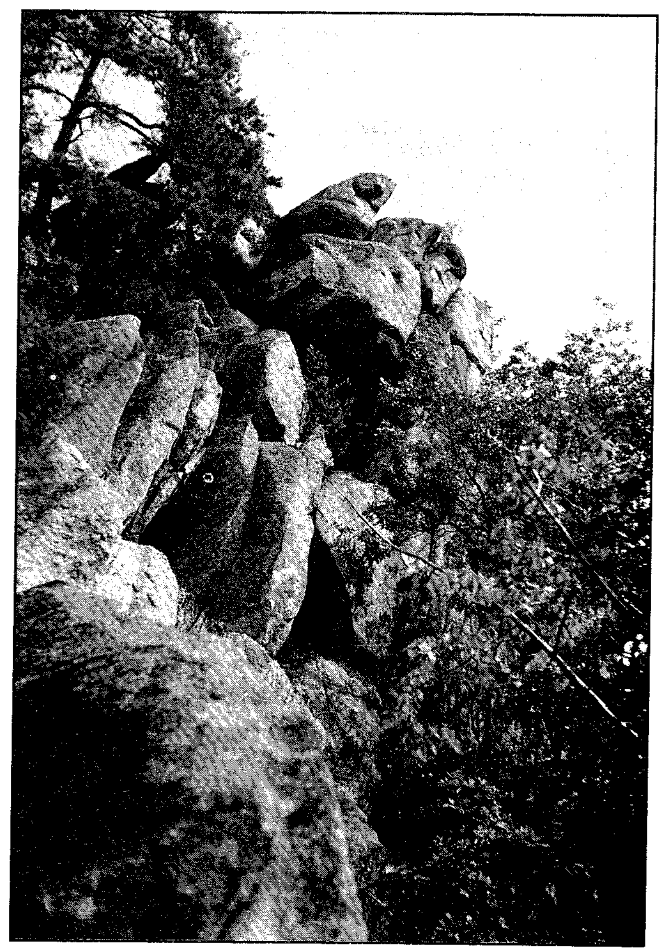
The features indicating the slope loosening have been found also on the right valley slope, about 250 m high,especially near its upper rim. This slope is remarkable by many tower-shaped tors and scree accumulations.

2. Valley of Klaperův potok (brook). In its upper course the brook is incised in Bíteš orthogneiss. Here, incised meanders and many cryogenic forms on valley slopes occur. In the middle and lower course the valley is incised in mica schists with intercalations of crystalline limestone. This is important for studying Upper Pleistocene and Holocene landscape evolution. Cave entrances, corrosion microforms and loess with two interglacial soils are regarded by V. CÍLEK (1993). The Klaperův potok (brook) is the only left tributary with the continuous floodplain and steps indicating several episodes of erosion and accumulation. In the lowermost course direction changes occurred probably.

3. Šobes. The local name includes vineyards on a slip-off slope of the (ingrown) meander of the Dyje river incised in biotite granite. Several very interesting forms are in its surroundings. In neighbourhood of the Šobes, some hundred meters upstream, an incised cut-off meander with amphitheatre facing southeast is very remarkable. Bend of the abandoned meander is about 600 m wide. Walls of the amphitheatre are up to 100 m high. The neck is 400 m long and forms a sharp-topped ridge (291 m) with tors and boulders. The floodplain surface is in the altitude of 250 m, the saddle between the neck and amphitheatre wall in 280 m. The neck separates the former valley bottom into two parts. The planation surface above abandoned meander as well as on opposite valley side is in the altitude of 400 m.

The Šobes meander is rather rectangular, elongated in the direction of NNW-SSE. The narrow neck, more than 800 m long, connects with mutual position the Šobes meander with the above mentioned abandoned meander. Undercut slopes are very steep with tors and screes. The floodplain of Dyje river around the slip off slope of meander is wider and ruins of several mills are preserved (this locality is termed the Nine Mills).

At the apex of the Šobes meander an important direction change of the Dyje river course takes place. Here the Dyje river flowing towards SE turns suddenly to the north. It is interesting, that the change was



6. Weathering forms of granite on the southern slope of the Králův stolec (King's table) Photo: K. Kirchner

made possible owing to lesser height of the undercut concave slope of meander. Although both the right and the left valley slopes are mostly up to 150 m high, height is only 50 - 60 m in the short reach of the undercut concave slope (about 450 m long). The reach is delimited by two short right tributary valleys trending to SE. This direction suggests that the former course of Dyje continued from Šobes to the SE, probably in position, used by Daníž brook at present. The shallow heads of both tributary valleys pass upstream into undistinct cols in the altitude of 295 - 300 m, only 50 m above the river. These cols are practically in hanging position above marginal slope of the Bohemian Massif.

Šobes is the last incised meander in the Dyje canyon. Downstream of the meander the valley is extremely rocky with rudimentary floodplain only, many tors, blockfields and exfoliation forms. Above the right valley slope we found the fissure paralell with the river. The fissure is some hundred meters long suggesting potential gravitational loosening.

4. Havraníky. The village of Havraníky is situated in the upper part of marginal slope of the Bohemian Massif. In the uppermost part of the slope several groups of granite tors composed of subangular boulders with microform such as weather pits occur.
5. Králův stolec (King's table, 339 m) is a viewpoint at the rim of Dyje canyon with many sub-skyline granite tors, ledges, ribs, exfoliation slabs, weathering pits, pseudolapiés and perched boulders. On the opposite slope similar forms occur near Sealsfieldův kámen (Sealsfield's stone, 373.6 m).

   In the surroundings of Králův stolec many cultivation terraces on the south facing slope occur, mostly abandoned at present. In the small steep rocky valley or ravine we found up to 12 artificial steps and terraced fields, every few m^2 only (K. KIRCHNER - A. IVAN 1994). These petty fields with very favourable microclimate were probably used for vineyards.

6. *Drainage and relief evolution*

As a result of long denudation an extensive post-Hercynian planation surface has become a basic topographic feature in the whole SE part of the Bohemian Massif in Lower Mesozoic. Probably no substantial change due to differential tectonic movements took place in its position. Thus this area belongs to the most stabile part in the Bohemian Massif. Its geotectonic evolution from light block of sialic type into heavy and more persistent simatic block (after J. ZEMAN's classification 1978, see IVAN, 1990) also corresponds, at least partly, to cratogenic regime with its implications for relief evolution (R.W. FAIRBRIDGE, Ch.W. FINKL, jr. 1980).

Information about longterm deep post-Hercynian denudation is scarce. Rests of kaolinic weathering crust, Miocene sediments as well as bare-rock surfaces, loess and periglacial covers suggest polygenetic origin of the regional Meso-Ceinozoic planation surface. Pre-Miocene evolution was characterized by deep chemical weathering in warm climates. However, most of the kaoline weathering crust was denuded before Lower Miocene transgression.

The Dyje river flows down regional slope to the E and SE only with little regard for lithology or structure, nevertheless in a rather zig-zag course. The southeast trend was predestinated probably in Paleogene already and was only slightly modified by orogenic events in adjacent parts of the Carpathians and Alps. The effects of Alpine orogenic movements north of the Danube are apparent in drainage changes of some rivers. In Austria, the Kamp river flowed originally eastwards, up to the Horn or Eggenburg Basin, where it joined the Dyje and Pulkau rivers (F. MACHATSCHEK 1958). Later, perhaps owing to tectonic activity in the Eastern Alps, the Kamp turned southwards to the Danube in the south surroundings of the town of Horn.

Although the main drainage direction was down regional slope to the E or SE, lithologic control of tributaries (SSW-NNE and S-N directions) was important. This is evidenced by the rivers of Moravská Dyje, Deutsche Thaya, Želetavka and Vápovka. The NNE-SSE direction is characteristic for tributaries of the Dyje river in the Podyjí NP, too.

We agree with P. BATÍK (1992) and V. ŠPALEK (1935a), that the Dyje river was superimposed from a sediment cover of unknown thickness. In opinion of V. ŠPALEK vertical erosion and canyon development started in Pleistocene. However timing of this incision is unclear. The incised meanders are thought to have developed from free meanders. However, it is difficult to explain the incised meanders of short tributaries such as Klaperův potok or Fugnitz. The thickness of Miocene sediments must attained at least 130-150 m to process of superposition could start.

ŠPALEK's view of the direction changes is partly in consistence with Machatschek's view. The redirection of the Dyje river could have been caused by uplift movements on quer axis of SE-NW or E-W direction or by repeated movements along the marginal fault. This suggests higher altitude of the marginal slope between the town of Retz and Pulkau river, too.

Distribution of Miocene sediments in the Podyjí NP, mainly in the area of two mica schists also suggests southtrending depressions and possible local and temporary drainage directions in the past. Weak post-Lower Miocene (?) fault tectonics, recognized at kaoline deposit Únanov (P. BATÍK - M. GABRIEL - P. ŠEBA - O. LUBINA 1979) was a possible contributing factor, too. Approximately same direction is characteristic for subsided Lower Miocene sediments between Šafov and Langau.

The Eggenburg Basin situated at the margin of the Bohemian Massif and connected broadly with the Carpathian Foredeep (Outer Vienna Basin) is in a similar position as the Brno Basin and Bránice-Ivančice Basins in Moravia. These basins, related both to the graben structures in the Carpathian Foredeep and to present or ancient rivers, are partly filled with Miocene sediments. East of Eggenburg Basin, there is the Zaya Graben trending to east and filled with sediments of Ur-Donau (Paleo-Danube) of Middle Badenian to Pannonian age (R. JIŘÍČEK - H. SEIFERT 1990). It is supposed, that the river Zaya had an important role in pre-Quaternary evolution of drainage of the SE part of the Bohemian Massif and speculation includes also middle course of the Dyje river and its tributaries (K. JÜTTNER 1940, B. BALATKA - J. SLÁDEK 1962). It is also a question, if the Zaya graben is not analogous to Nesvačilka and Vranovice grabens in Moravia to a certain extent.

Appendix

The regional chronostratigraphic stages of Central Paratethys and their approximate equivalents in Mediterranean region (in parantheses). Compiled from M. SUK et al. (1984) and D. VASS - K. BALOGH (1989)

	Quaternary	
1.8 m.y.		----------
	Romanian	
3.7 ± 0.1		----------(Tabian, Plainsancian, Astian)
	Dacian	
5.6 ± 0.2		----------
	Pontian	(upper Tortonian - Messinian)
7.0 ± 0.2		----------
	Pannonian	(upper Tortonian)
11.0 ± 0.5		----------
	Sarmatian	(upper Serravallian-lower Tortonian)
13.6 ± 0.2		----------
	Badenian	(Langhian-lower Serravallian)
16.6 ± 0.5		----------
	Karpatian	(upper Burdigalian)
17.5 ± 0.5		----------
	Ottnangian	(middle Burdigalian)
19.0		----------
	Eggenburgian	(upper Aquitanian-lower Burdigalian)
22.0 ?		----------
	Egerian	(Chattian-lower Aquitanian)
25		----------

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