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CASTLE KOPPIES AND TORS IN THE BOHEMIAN HIGHLAND (CZECHOSLOVAKIA)

Abstract

This paper deals with the origin of castle koppies and tors, which are typical features of the relief of many areas of the Bohemian Highland. Castle koppies and tors are occurring most frequently in areas consisting of intrusive igneous rocks (granites, syenites), but they are found even in a number of areas formed of metamorphic and sedimentary rocks (especially of block-sandstones). The author explains the origin of tors in two ways. According to the first one, the tors were created by a two-stage development. In the first phase the rocks forming castle koppies and tors weathered deeply. Core stones and less weathered parts were preserved in the thick regolith. In a later period this regolith was stripped from about the unaffected rock and the core stones and unaffected parts are standing as castle koppies and tors. The deep chemical weathering is connected with the period of the hot-humid climate in the Tertiary. The exhumation of castle koppies and tors began already at the end of the Tertiary and it passed mainly at the time of enormous mass wasting in the phases of the transition between the cold and warm periods of the Pleistocene. According to the second mode, castle koppies and tors were formed by the one-stage mode, e.g. by weathering on simultaneous removal of the regolith. The origin of castle koppies and tors in this way is connected closely with the slope development in the periglacial climate and with the origin of altiplanation terraces. The parallel retreat of the frost riven cliffs separating the individual terraces, caused the isolation of castle koppies and tors. The frost weathering went then on modellating their shapes and disturbed them successively, so that we may compose a whole row of development from the extensive castle koppies up to low entirely buried tors below the angular talus blocks. In a rather different way castle koppies and tors are formed in the block-sandstones of the Bohemian Plateau, where the opening of the vertical joints behind the free face is of main importance. This process passed intensively during the Pleistocene and it is passing even at present.

INTRODUCTION

Castle koppies and tors are features common in many areas of the Bohemian Highland. The term castle koppies is used in this paper to designate areally quite extensive, bare-rock forms steeply rising from ground level on all sides. The term tors is used to designate the individual areally less extensive forms. Perched boulders, pinnacles and needle forms are often found.

MAIN LANDSCAPE FEATURES OF THE BOHEMIAN HIGHLAND

The Bohemian Highland has to be considered as a complex mountain, the landscape features of which are the result of a long development under various climatic conditions. The block of the Bohemian Highland being a constituent part of the Meso-European kraton, shows in the vertical direction a structure consisting in general of two units: the platform fundament permanently consolidated by Variscian tectogenesis, and the Neodic platform cover. In the Variscian fundament metamorphic rocks and Paleozoic sedimentary folded rocks, penetrated by numerous plutons (especially granite ones) are prevailing. The younger platform cover is formed mainly of Permo-Carboniferous, Cretaceous and Neogene sedimentary and volcanic rocks.

At the end of the Paleogene the extensive peneplain in the Bohemian Highland reached its maximum development. The rocks of the Bohemian Highland underwent during this period the intensive weathering in the hot-humid climate of savanna type. In connection with the upheaval of the Alpine-Carpathian belt tectonic movements came about, which caused the warping of the original coherent peneplain. The central part of the Bohemian Highland preserved its low altitude, while the marginal parts were uplifted. By the influence of tectonic upheaval the thick regolith was stripped away and the peneplain was rejuvenated. The incision of water streams into the uplifted upland surface caused the origin of more or less incised valleys. In the Quaternary the landscape development passed, influenced by large climatic oscillations. The alternating of cold and warmer periods led on the one side to the origin of system of periglacial forms, on the other side of forms of mild humid climate. The polygenesis of the landscape of the Bohemian Highland is a result of the climatic changes during the Tertiary and Quaternary. Besides the forms created in the warm climate of the Tertiary even periglacial forms and forms of the mild humid climate can be found.

THE CONFIGURATION OF CASTLE KOPPIES AND TORS

Castle koppies and tors are most common in areas consisting of intrusive igneous rocks (granite, syenite); such regions are for instant the Central Moldanubian Pluton, the Central Bohemian Pluton, the Krkonoše massif, the Brno massif, the Žulová massif, the Čistec-Jesenice massif and others. But these forms occur even in some areas consisting of metamorphic rocks (the Hrubý Jeseník Mts., the Žd'árské vrchy Highland, the Šumava Mts. and others) and of sedimentary rocks (in areas of block-sandstones of the Bohemian Plateau). In connection with the lithologic properties of rocks, which they are consisting of, the forms of castle koppies and tors are somewhat different in the individual areas. From the lithologic point of view there can be found on the one side castle koppies and tors formed of distinct-

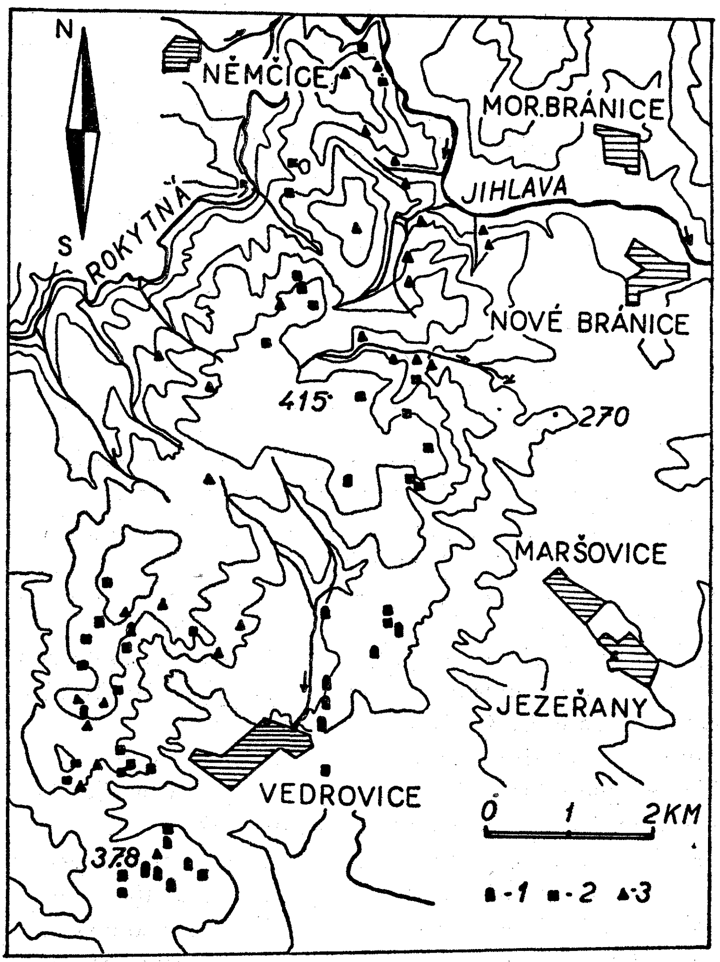

Fig. 1. The map of the Krumlovský-les Highland southwest of the town Brno, formed of granites of the Brno-massif. We can see on the map the dependence of the distribution of tors and boulders on the extent of the denudation of Tertiary regolith (according to J. Demek 1960)

1. well rounded tors and boulders; 2. partly rounded tors and boulders; 3. angular tors and boulders

ly more resistant rocks than the surrounding rocks (to compare with the profile, fig. 2, Komáří Kameny Tor near the village Rejvíz in the Hrubý Jeseník Mts.) and on the other side castle koppies and tors, which cannot be lithologically distinguished from their surroundings (to compare with the profile, fig. 3, Tisá skála Tor in the Českomoravská vrchovina Highland).

Castle koppies and tors are occurring in groups or individually on the summits of hills and ridges or in the upper parts of slopes. There can be distinguished either skyline tors, the tops of which form after connection an imaginary slightly convex plain, which could represent the original surfaces of the peneplain (for instance in the Krkonoše Mts. — M. P r o-

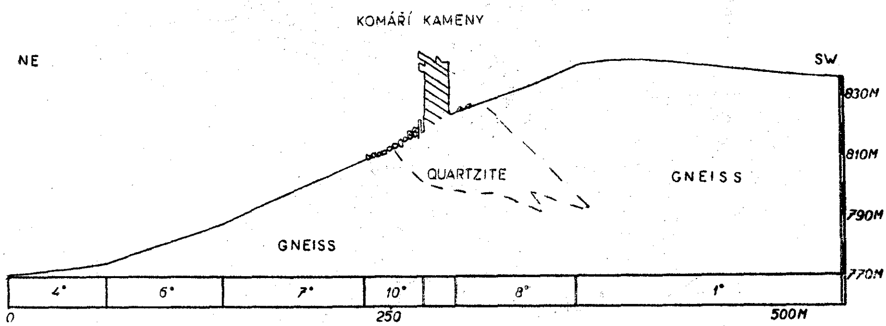

Fig. 2. Profile through the Komáří Kameny tor near the village Rejvíz in the Hrubý Jeseník Mts.

Measured by J. Vařeka and J. Demek; geological structure according to J. Skácel

s o v á 1963, p. 53—54) or sub-skyline tors, which can be found in the lower parts of slopes and are already corresponding to the younger phase of development (compare L. C. King 1962, p. 372).

The size and the area extent of castle koppies and tors vary considerably. The simplest forms have the boulders (for instance the boulders called Dědek and Bába in the massif of Čistec-Jesenice — pl. 1) or the groups of boulders lying one on another. Less frequent are the shapes of towers, pillars (for instance the tors on the Leskoun Hill in the Brno massif — pl. 2) and of needles. More frequently mushroom shaped tors can be found (for instance Petrovy kameny Tors in the Hrubý Jeseník Mts.). In certain cases such stones have such a small area of contact with their supports, that they will move under hand. These are the „rocking stones" or „logan stones" (for instance the „rocking stone" called Husova kazatelna near the village Petrovice in the Central Bohemian Pluton, or the „rocking stone" called Trkal on the hill Kníže near the town Kunžak in the Central Moldanubian Pluton — pl. 3). The massive castellated tors may be considered as forms of transition to castle koppies. The castle koppies are reaching considerable dimensions especially in the Jizerské hory Mts. (pl. 4), Krkonoše Mts. and Žďárské vrchy Highland (for instance the castle koppies on the summits of the hill Oldřichovský Špičák, Frýdlantské cimbuří, Čertovy skály on the ridge of Černá Studnice in the Jizerské hory Mts., Dívčí kameny, Mužské kameny and Violík in the Krkonoše Mts., Drátenícky,

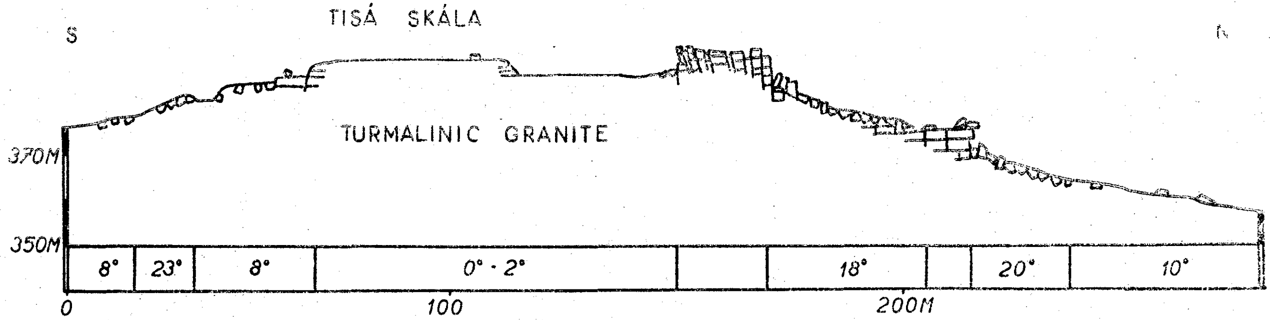

Fig. 3. Profile of the Tisá skála Hill near the town Golčův Jeníkov on the Českomoravská vrchovina Highland

Measured by J. Vařeka

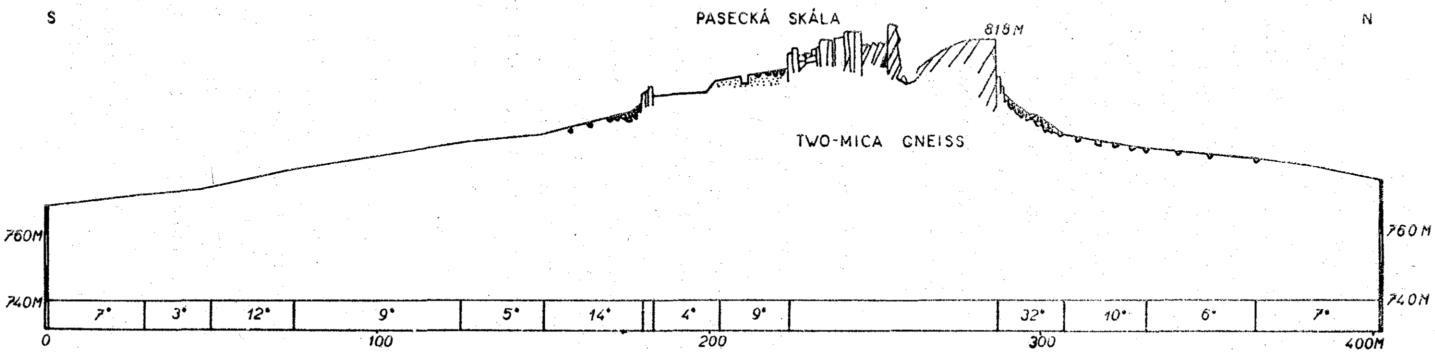

Fig. 4. Profile through the Pasecká skála Hill near the town Nové Město na Mor. on the Českomoravská vrchovina Highland

Measured by J. Vařeka

Devět skal — pl. 5, Pasecká and Malínská skála in the Žd'árské vrchy Highland and others).

Castle koppies and tors have rounded and angular shapes. In granite areas rounded forms are prevailing, especially in the coarse-grained granites (pl. 1). The tors are not seldom woolsack-shaped. The rock is usually traversed by bold and widely spaced near-vertical fissures, and these as well as the bounding walls are clearly the expression of joint planes in the granite. Powerful divisions also traverse the rock more or less horizontally — the so called pseudo-bedding — and give the whole mass the rudely architectural aspect that is well described by the term *cyclopean masonry* (compare D. L. Linton 1955, p. 470). Even in sandstone areas the castle koppies and tors use to be mostly rounded (pl. 6). In areas of metamorphic and some sedimentary rocks (gneiss, quartzite) rather angular forms can be found. But we may not seldom find on one even not large tor simultaneously rounded and angular forms. On many castle koppies and tors microforms (dew-holes, weather pits, lapiés and honeycombs) can be found.

THE ORIGIN OF CASTLE KOPPIES AND TORS

The different modes of the castle koppies and tors formation can be explained in two ways (R. A. Pullan 1959, p. 53; A. Jahn 1962, p. 19—20).

On the first opinion the castle koppies and tors were formed in a two--stage development. In the first period the rocks forming castle koppies and tors weathered deeply. In the regolith core stones and residual parts were preserved. In the later period the regolith was stripped from about the unaffected rock and the core stones and the residual parts standing as castle koppies and tors.

On the second opinion castle koppies and tors were formed in an one--stage development, e.g. by weathering and by the removal of the regolith at the same time.

THE ORIGIN OF CASTLE KOPPIES AND TORS BY TWO-STAGE MODE

On the territory of Czechoslovakia the origin of castle koppies and tors by two-stage mode has been described by R. Kettner (1936) in the granite Čistec-Jesenice massif in Western Bohemia.

The two-stage origin of castle koppies and tors is connected with the intensive chemical weathering during the hot humid climate of the Tertiary period. The various sorts of rocks decayed in a different degree and into a different depth. Intrusive igneous rocks (such as granite, syenite, diorite and gabbro) underwent very easily the chemical weathering. The tropical regolith was preserved in original thickness in a series of basins. The kaolinic weathering reaches, for instance, in the granites in the substratum of the Sokolovská pánev Basin up to the depth of 100 m (O. Kodym, in: Tectonic Development of Czechoslovakia, 1960, p. 130). In the area of the Žulová massif in surroundings of the town Vidnava, the borings were finished in the depth of 57 m below the surface in the kaolinic weathering products of granite. In the Plzeňská pánev Basin the kaolinization reached the depth of 30 m (near the villages Chotikov and Chlumčany) up to 80—85 m (near the villages Horní Bříza, Kaznějov) in arkoses. In areas, which were lifted up during the Neogene and Quaternary, the tropical regolith was partly removed and only its basal parts were preserved. In most areas consisting of igneous rocks the rotting goes down to at least 10—20 m below the surface (R. Kettner 1953, p. 266). But even in the uplifted areas considerable thickness of regolith can be found not seldom. For instance on the Českomoravská vrchovina Highland in the area between the villages Veverská Bitýška, Velká Bíteš, Deblín and Svatoslav, the gneiss of Svratka is decayed to the depth of 110 m and China clay was mined to the depth of 60—80 m (A. Polák in: J. Kalášek *et al.* 1963, p. 194; and pl. 7).

The observations in exposures showed the rocks not to be rotted to the same extent. In the regolith up to this time undecomposed mostly well rounded core stones remain. In the photography 8 well rounded core stones of syenite are in place in decomposed rock exposed by quarrying near the town Třebíč (syeno-dioritic massif of Třebíč). The strong contrast between the sound rock and the rotted syenite should be noted. The reason of the irregular rotting of especially igneous rocks can be found on the one side in the original mineral composition and the texture of rocks (alternating of parts resistant and of parts less resistant to weathering) and on the other side in the irregular jointing of rocks (R. Kettner 1953, p. 267). The rotting begins along the joint-planes and it leads to the origin of boulders and rock-forms. These conclusions were testified in many natural and artificial exposures.

The boulders found in the tropical regolith of Tertiary age are mostly well rounded. They have mostly spheroidal forms or they are woolsack--shaped (pl. 8). These forms are partly caused by the original arrangement of the minerals in the rock, as the intrusive igneous rocks cooled mostly from certain centres, around which mineral parts were arranged in concentric layers. In other cases, especially at metamorphic and sedimentary rocks, these forms are conditioned by the processes of chemical weathering along the joint-planes and by the rounding at the edges and corners of the originally angular blocks (R. Kettner 1953, p. 267).

By the removal of relatively fine grained products of rock decay, castle koppies and tors got to the surface. The greatest removal was on the summits of the narrow watershed ridges and in the upper parts of slopes. This is proved by the location of tors, as can be observed (fig. 1) on the map (J. Demek 1960a). The map shows a part of the Brno massif SE of the town Brno. The territory is lying between the Dyjskosvratecký úval Basin in the east and the Furrow of Boskovice in the west and it consists of biotite- and two-mica granite. It reaches in its central part the altitude of 415 m. The central part is very flat, the margins being dissected by creeks into narrow ridges. From the map it can be seen, that the tors are most common phenomena on the rounded ridges in the northern and especially in the southern part of the area. In the central part tors are either entirely missing, or they are occurring only solitary. This part can be considered as the preserved part of the Paleogene peneplain of the Bohemian Highland. The borings in the central part of the territory showed granite to be decayed here into debris in a depth of more than 10 m. But the rotting is very irregular. In the close vicinity of the boring, which did not reach the unweathered bedrock in the depth of 10 m, unaffected granite appears on the earth surface. On debris the denudation relics of Helvetian sediments are lying, which prove clearly the Paleogene age of the rock rotting in the central part of the territory (J. Demek 1960a, p. 241). On narrow ridges the decomposed rocks were stripped away and tors got to the surface. The greatest denudation was in the convex part of valley slopes, so that tors occur often at their breaks. Owing to the depth of rock rotting and the extent of denudation, the height of tors varies very much. The highest tors reach the height of about 40 m, but their height is varying on average between 5—10 m. For instance tors in the syenodioritic massif of Třebíč in the eastern part of the Bohemian Highland have the average height of 5 m. In contradistinction to it, tors and castle koppies in the granite-Krkonoše massif having the shape of walls, towers and needles are more frequent and reach not seldom considerably greater heights (pl. 4).

The detailed forms of tors are influenced by the rock properties. In coarse grained granite rounded forms are prevailing, while in the fine grained one tors have rather angular forms. This dependence is distinctly shown for instance in the Central Moldanubian Pluton on the contact of the coarse grained granite of the type Landštejn and of the fine grained one of the type Číměř (compare St. Chábera 1961, p. 61). We may observe in other places, that they are occurring as rounded as angular shapes on one tor. On some tors the flat planes cut the rounded shapes and form sharp edges. For instance on the Leskoun Hill in the Brno massif in the upper part of a boulder of middle grained biotite granite traces of loosing of curved scales were found, while in its lower part younger angular forms occurred (pl. 9). The different forms on one boulder cannot be explained by rock properties, but they are a result of two different weathering processes under various climatic conditions. The rounded forms were created by weathering in the hot humid climate of the Tertiary. After the exhumation the boulder was subjected to different weathering processes, operating during the periglacial climate of the Pleistocene period.

In some cases the Pleistocene cryergic processes modificated entirely the forms of castle koppies and tors. On the profile (fig. 4) the cross section of the castle koppie Pasecká skála (818 m above sea level) in the Žd'árské-vrchy Highland can be found. The castle koppie is projecting on the summit of the flat hill, which towers about 30 m above the surrounding terrain. According to the profile the hillsides are expressively stepped. The slopes are formed of gentler sections of an angle of 3°, separated by steeper sections (12—14°). On the steep ones blocks and even unweathered bedrock outcrop in some places directly to the surface (fig. 4). The castle koppie on the top has its maximum height of 18 m and expressively angular forms. It consists of two-mica gneiss and is surrounded with tors having angular forms too. At the NW-foot of the castle koppie a talus slope consisting of angular talus blocks is developed. Angular talus blocks are scattered even on the hillsides. In the upper part of the castle koppie opened joints may be found, which prove the intensive frost weathering. Of the total geomorphologic conditions and the forms of slopes, castle koppies and tors in their surroundings, the question arises, whether the stepped flats are not altiplanation terraces and the castle koppies are not forms created by cryoplanation in the Pleistocene. But the research showed, that in a distance of 200 m of the castle koppie a sand pit in which lateritic weathered gneiss is occasionally mined, can be found. The gneiss is rotted so much, that it can be dug like sand. The wall of the sand pit is 2,60 m high and solid rock does not occur on its bottom. The upper layers of the products of weathering are bent down-slope. For checking, test pits were situated directly at the foot of the castle koppie (see fig. 4), which showed that the relics of the red tropical regolith can be found also directly at the foot of the steep walls of the castle koppies and tors. On some places they are veneered by a more than 3 m thick debris mantle consisting of unweathered angular gneiss fragments.

The above mentioned shows the castle koppie to be formed in a two-stage development too. In the first stage the two-mica gneiss was subjected during the Paleogene hot humid climate to intensive weathering, which created a thick regolith. The decay was irregular and the rock was not rotted to the same depth in all places. In the second stage the upheaval of the Žd'árské-vrchy Highland and likely even the climatic changes led to the exhumation of less weathered parts. Owing to the irregular rotting and the irregular exhumation of the basal weathering surface step-like slopes also developed looking like altiplanation terraces at first sight (see later). The individual tors around the castle koppie protected partly the regolith behind them from removal what supported the development of a part of steps on the slope. The forms of the castle koppie and of tors created by the sub-surface rotting were entirely modelled during the periglacial conditions of the Pleistocene.

The degree of the modellation of castle koppies and tors by periglacial processes depended on the different rock resistance to frost weathering. A high resistance to mechanical weathering showed coarse grained granites and syenites. Around the castle koppies and tors consisting of coarse-grained granite angular fragments created by mechanical weathering use not to be found (compare J. R. F. Handley 1954, p. 207). In contradistinction fine-grained granite, especially the densely jointed one, was much more influenced by periglacial processes. The greatest modellation of the Tertiary forms was then found in tors consisting of gneisses and phyllites, where frost-weathering processes occurred along the joints and even on rock schistosity planes. These facts caused then that in granite and syenite areas tors with the rounded forms of Tertiary age were preserved, while in other areas angular forms of periglacial origin occur most frequently or are even predominating.

The question is put now, when the thick regolith was stripped away and when the tors were exhumated. For the determination of the period, when the castle koppies and tors got to surface, the microforms on the rock surface are important. Some of these are developing even in the present climate (for instance weathering pits), but others are distinctly past-relic forms, created during the former geological periods (pseudo-lapiés, dew-holes). The weather pits are most common on the rock walls, but the pseudo-lapiés and the dew-holes are of much greater importance.

For instance the granite lapiés on the tor called Slouha on the Klepec Hill near the village Přišimasy in the Central Bohemian Pluton (J. Sekyra, in: Geologický slovník naučný, 1961, plate XIV) are typically developed. The tor towers on the southern gentle hillside and is formed by biotite granite (Říčany-type — pl. 10). It has the height of 8,10 m and the length of 11,60 m. On its northern, convex wall, 5 distinct and 3 less visible pseudo-lapiés are developed, the longest one having the length of 7,10 m at the maximum depth 0,19 and the maximum width 0,45 m. At the foot of the tor fragments can be found and in the vicinity of the exposure in the hill top less weathered granite appears. Other granite lapiés are developed on the tor on top of the Vysoký Kámen Hill (831 m) near the town Kunžak in the Central Moldanubian Pluton (J. Demek 1960b; St. Chábera 1962), on the boulder NW of the Jahodník Hill (378 m) in the Žulová massif and elsewhere (T. Czudek, J. Demek, P. Marvan, J. Raušer, Vl. Panoš 1962). The granite lapiés were formed by the mechanical and chemical erosion of rainwater. At present time they are fossil forms. For their origin the hot humid climate of the Neogene period was most favourable. The dependence of the depth of pseudo-lapiés on the declivity of the rock surface shows, that tors on which they occur, had to be exhumated even in the time of their origin (compare P. Macar 1957, p. 295). Even J. Hövermann (1953, p. 9) found in the Harz Mts. traces of Tertiary weathering processes passing on already exhumated tors. Similarly even dew-holes found on more tors in different places of the Bohemian Highland are the proof, that the beginning of the exhumation of tors must be put at least in the end of the Neogene period (compare A. Jahn 1962, p. 32). The exhumation must have passed quickly or under different climatic conditions than were these of the origin of the regolith. The observations of W. Panzer (1954, p. 48) showed namely, that at a slow removal of regolith the core stones and the tors are rotted quickly in the hot humid climate. Especially intensively the regolith was stripped away in periods of transition between the cold and warmer periods of the Pleistocene, when extensive mass wasting took place on slopes.

THE ORIGIN OF CASTLE KOPPIES AND TORS BY ONE-STAGE MODE

The study of castle koppies and tors in the area of the Bohemian Highland consisting mainly of metamorphic and sedimentary rocks showed, that tors may develop even by one-stage mode (compare R. A. Pullan 1959, p. 53).

The origin of tors and castle koppies by one-stage mode is inextricably bound up with the slope development and the inequilibrium of the free-face. An examination of slopes in the vicinity of castle koppies and tors, and a reconstruction of their history of stability and instability yields more substantiation of the nature of castle koppies and tors genesis. The examples given in the paper are resulting of the research in the Hrubý Jeseník Mts., the Českomoravská vrchovina Highland and in sandstone areas of the Bohemian Plateau in Northern Bohemia.

The research showed castle koppies and tors to be often found in these areas on hillsides and ridges having expressively stepped slopes. On the

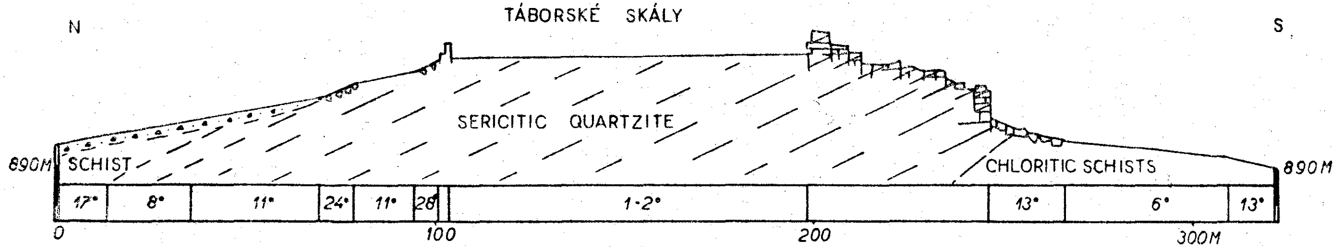

Fig. 5. Profile through the Táborské skály Ridge in the Hrubý Jeseník Mts.

Measured by J. Vařeka and J. Demek; geological structure according to J. Skácel

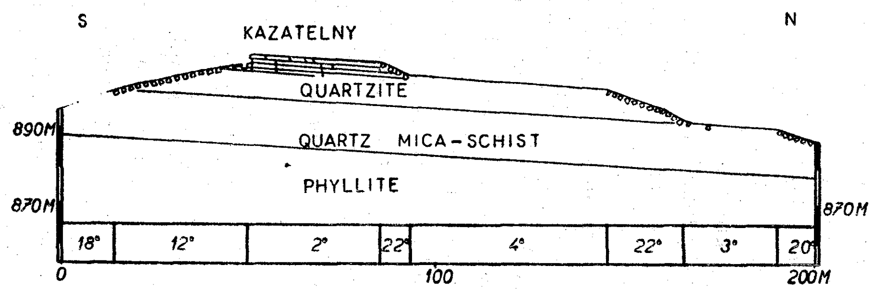

Fig. 6. Profile through the Kazatelny Ridge near the village Rejvíz in the Hrubý Jeseník Mts.

Measured by J. Demek; geological structure according to J. Skácel stepped hillsides gently sloping treads of 5—11° inclination and moderately steep risers alternate (fig. 4—8). The flatter, gently sloping treads have the shape of terraces. The terraces pass on hillsides either coherently on a distance of some hundreds of meters, or they are dying out and beginning again. For instance on the profile (fig. 5) of the Táborské skály Tors in the Hrubý Jeseník Mts. the cross section through a terrace can be found, having an inclination of 6° and the length of 480 m at a maximum width of 65 m. The terraces on slopes use to have an inclination of about 6° (to compare with the profiles). The summit terraces have smaller declivities (1—3°). Besides the inclination in the direction of the total angle of slope, the terraces are often inclined even in their longitudinal direction.

It is obvious from the evidence furnished by various exposures that the terraces are cut in solid rock. In some cases the surface of the terraces is parallel with the strata inclination. This case is shown on the profiles (fig. 6, 7) through the Kazatelny Ridge in the Hrubý Jeseník Mts., where the terraces are developed on gently diping Lower Devonian quartzites and sericitic phyllites. Elsewhere the terraces are levelling the folded or inclined strata (to compare with the profile of the Táborské skály Tors in the Hrubý Jeseník Mts.). The terraces carry variable thicknesses of debris. The terraces on the north slope of the hill Malínská skála on the Českomoravská vrchovina Highland (fig. 8) are covered by angular talus blocks of two-mica gneiss of enormous dimensions (on average 2 × 4 × 1m), which have the thickness at least 3m. The spaces between the boulders are not filled out with finer material. In other borings in this area (for instance at the foot of the castle koppie Drátenîčky) it was found, that the terraces are underlain by fragments mixed with sandy loam. The fragments had a different size (from 0,10 m up to blocks of more than 1 m in diameter) and were unweathered with sharp edges. To the depth of 1,60 m below the surface blocks were lying losely in the sandy loam. Downwards the blocks were lying closely on each other, mutually touching and only the gaps between them were filled up by sandy loam. Some blocks were raising vertically in the loam. There was no sign of stratification in this material. In contradistinction to it the boring in the terrace on the ridge of the Kazatelny Hill (fig. 6) showed, that forest humus 0,20 m thick is underlain by solid rock already (the above mentioned Lower Devonian quartzite) strongly joint and disturbed by mechanical evidently frost weathering. The terraces occur on slopes individually or at another time some steps of terraces are developed (pl. 12).

The individual terraces are backed in the direction towards the line of slope by steeper inclined slope parts. These scarps have a different appearance. In some cases they are covered by soil and vegetation and their

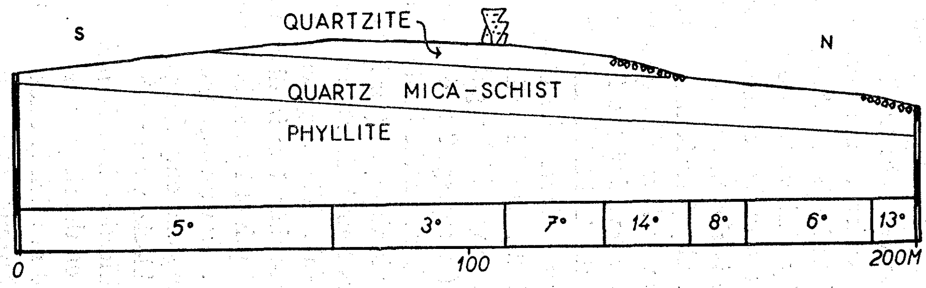

Fig. 7. Profile through the Kazatelny Ridge near the village Rejvíz in the Hrubý Jeseník Mts.

Measured by J. Demek; geological structure according J. Skácel

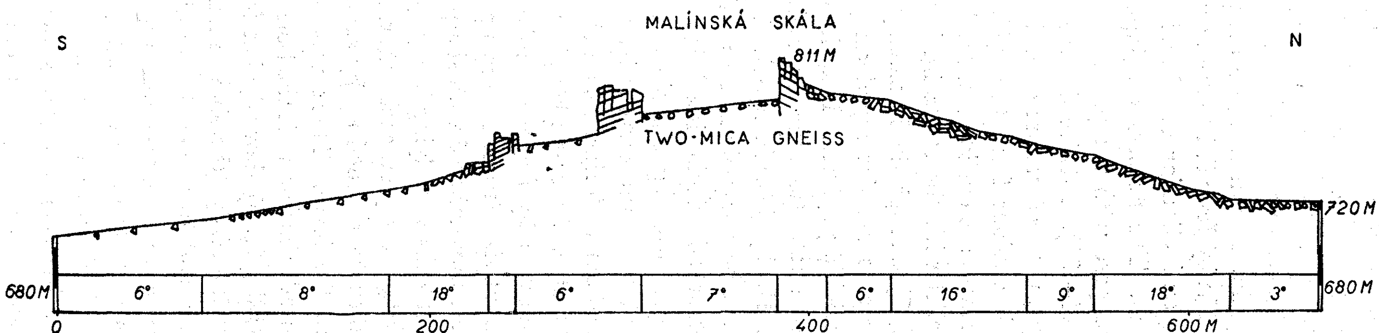

Fig. 8. Profile through the Malínská skála Hill south of the town Svratka on the Českomoravská vrchovina Highland

Measured by J. Vařeka

declivity varies about 16—24°. Examples of the scarp face of this type are on the profile (fig. 5) of the Táborské skály Ridge (18—24°) and on the photo (pl. 12). Steeper scarps veneered by angular talus blocks are standing out already expressively. Fine examples of this type are the scarp faces on the summit of the Břidličná Hill (angle 23°) in the Hrubý Jeseník Mts. (M. Prosová 1954, p. 5), on the north slope of the ridge Kazatelny (fig. 6 — angle 21°), on the north slope of the Malínská skála Hill (fig. 8) and others. In some cases the inclination of these steeper sections is drawing near to the angle of deposition for its component material. The size of the materials composing the scarp varies greatly. In some places talus blocks weighing many tons are included (Malínská skála Hill); elsewhere a scarp may contain only rock fragments measuring not more than a few dm (Kazatelny Ridge). Solid bedrocks outcrop often in the upper parts of these scarps. In many cases they form narrow vertical walls up to rock cliffs, which disappear under blocks forming a talus at their foot. For instance in the surroundings of the Kamenná chata in the Hrubý Jeseník Mts. the rock cliffs in the upper part of the steep section reach the height of up to 6 m. The talus is formed of quartzite blocks of 3 m and more in diameter, sloping 28° at the foot of the rock cliff. In some sections they had an inclination of up to 39°. Another example is the Hill Tisá skála on the Českomoravská vrchovina Highland (pl. 12). In other cases the whole steep section forms a vertical rock wall up to a rock cliff. The wall consists of solid rock and has angular shapes. It is either smooth or more often step-like (fig. 5). Its height varies from about 2,50 m (Kazatelny Ridge — fig. 6) up to rock walls of a height of 20—25 m (fig. 48). Most frequent are cliffs 5—10 m in height (pl. 13). Traces of intensive mechanical weathering are visible on the rock cliffs. The open joints exhibited in every rock cliff are usually clean and unweathered and are products of frost splitting. Some blocks in the upper part of the free-face are loosened. The opened joints have in many cases a considerable width and fissure caves are rising (T. Czudek & J. Demek 1961, p. 58). At the foot of the rock cliffs differently large talus are sometimes found (pl. 12), at another time block streams are running out of them (pl. 13). In other cases we do not find any rock fragments at the foot of the rock cliffs and the foot is sharp, even when the extensive denudation of the rock cliff is evident from its whole appearance. The foots of such walls are usually moderately undermined and the wall an overhanging one. In some cases the material is accumulated as low ramparts and it can be found in a certain distance of its foot below the overhanging wall. Similar ridges of slight-rock, parallel to a steep free-face but separated from it by a longitudinal depression, may be regarded as nivation ridges (C. H. Behre, Jr. 1933, p. 630; winter talus ridges

F. H. Lahee 1931, p. 337; protalus ramparts — K. Bryan 1934). It is obvious that frost weathering was acting in the modellation of walls and the depressions at the foots were formed in places of greater humidity due to snow-melting.

The length of rock cliffs is different. The longest rock cliffs were described up to this time in the Hrubý Jeseník Mts. in the drainage area of the Branná River (R. Netopil 1956, p. 95 — geomorphologic map), where they are 2 km long. Of the same area many rock cliffs of the length of 500—800 m are known. For instance on the SE-slope of the Černý-vrch Hill (1200 m above sea level) a cliff 630 m long and up to 25 m high was found. Walls of a length of about 100 m are common. But steeper back slopes are found most often on these benches, where vertical rock cliffs alternate with sections formed by angular talus blocks and even with soil mantled and vegetated slopes. It should be noted that the marginal scarps of the higher terraces on stepped slopes are generally as steep as, and in some cases even steeper, the scarps of the lower terraces (compare M. T. Te Punga 1956, p. 332).

The steepness and the total appearance of the steeper sections are evidently controlled by geological structure. The steps including the rock walls are found on slopes facing all cardinal points and it does not appear any evident dependence on the facing. The enclosed profiles show the rock cliffs to be formed only under certain geological conditions, most often at the head of the beds or of the cleavage. It appears distinctly in the Kazatelny Ridge, where a vertical rock cliff is at the head of the quartzite bed, while on the opposite side, in the direction of the bed dip (6° to the north) only a steeper section is developed and covered by blocks (fig. 6). In this profile it may be also noticed that the steeper slope-part is built of quartzites, while the less-inclined surface of the terrace — by quartz mica-schists and by quartz phyllites. The quartzites prove to be an extremely hard rock in the present climate, but they were more mobilizable in the cold climate owing to the strong jointing with microscopic joints and they were subjected more quickly to frost weathering than the apparently less resistant mica-schists and phyllites. Of this example the considerable importance of the joints, their density and their mutual distance for the origin of rock cliffs and terraces is evident. The vertical joints are of main importance here. Even in the same rock the steeper sections can have due to local conditions a different appearance and the local conditions are of importance even for the development of terraces. On one hill they may be well developed, while on an equally elevated neighbouring hill they are lacking (H. M. Eakin 1916, p. 78). Variation in hardness of more or less horizontal stratified rock would favour the development of terraces

(O. Stehlík 1960, p. 47), but the terraces are by no means restricted to these conditions, for they commonly truncate steeply inclined strata, and may be cut in massive homogeneous bedrock too (M. T. Te Punga 1956, p. 336). As an example of the terraces in homogeneous rocks the profile of the Tisá skála Hill can be mentioned, near the town Golčův Jeníkov in the Českomoravská vrchovina Highland, built of turmaline granites (the type of Přibyslavice — fig. 3).

It appears from the above mentioned that the terraces separated by steeper sections are corresponding to forms called by H. M. Eakin (1916, p. 79) the altiplanation terraces. The steeper sections, as far as they have the appearance of cliffs or scarps veneered by angular talus blocks, can then be specified as frost-riven cliffs (L. C. Peltier 1951, p. 224). The terraces were developed by the parallel retreat of frost-riven cliffs under periglacial climatic conditions of the cold periods of the Pleistocene.

During the parallel retreat of the opposite frost-riven cliffs their crossing and mutual destruction occurred. The destruction of the frost--riven cliffs and their intersection is seen clearly in the profile through the Kazatelny Ridge. In the profile (fig. 6) a visible bed of quartzite is on the summit of the ridge, on which the above mentioned frost-riven cliffs are bound on both slopes. In the profile (fig. 7) drawn in the narrower part of the ridge, the destruction of a part of the quartzite bed by the parallel back-wearing of the frost-riven cliffs can be found and as the proof of the former higher level the tor remains on the ridge.

With regard to the already mentioned local conditions (the intensity of jointing, the springs of ground water and others) all parts of the frost--riven cliffs do not retreat equally and with the same rate. Due to the irregular retreat, the isolation of the individual parts retreating more slowly and the origin of the castle koppies and tors were caused. The separating passes by the opening of the vertical joints behind the free-face. Tors are towering then in the middle of the altiplanation terraces as proofs of the cryoplanation extent. In front of the rock wall a series of tors can be in many cases noticed as evidence of successive parallel retreat of the frost--riven cliff. In other cases the destruction of the free-face during the retreat of the frost-riven cliff came about and the slope got a smooth shape on the whole. Of the comparatively smooth slope only tors with expressive vertical walls formed by separating along the joint-planes are projecting. The tors of this type are usually surrounded with rock fragments. In the profile (fig. 2), the Komáří Kameny Tor near the village Rejvíz in the Hrubý Jeseník Mts. can be seen. Its maximum height is 13 m and its length 17,30 m. It was preserved evidently due to smaller jointing of quartzite, of which it consists. The foot of the tor is surrounded with rock

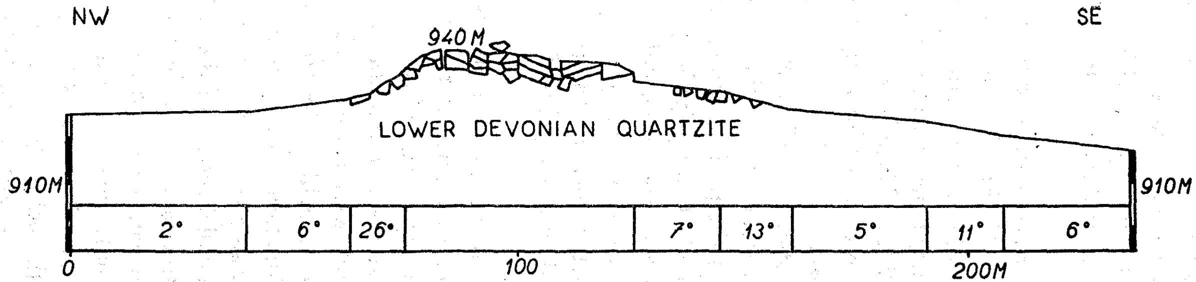

Fig. 9. Longitudinal section of the castle koppie on the ridge between Bílé and Černé kameny, north of the town Rýmařov in the Hrubý Jeseník Mts.

Measured by J. Vařeka

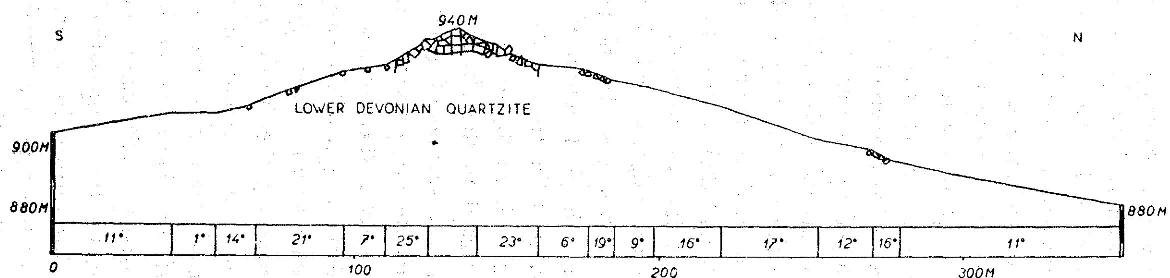

Fig. 10. Cross-section of the castle koppie on the ridge between Bílé and Černé kameny, north of the town Rýmařov in the Hrubý Jeseník Mts.

Measured by J. Vařeka

fragments. In the direction of the slope angle a block stream having the length of 27 m and the inclination of 10° is projecting from its foot. Due to the further frost splitting, the successive destruction of the tors occurred. The frost splitting went on, enlarging joints and loosening angular blocks. In the investigated areas a whole series of transition-forms can be found, when the angular blocks overlap more and more the core of tors formed by solid rock. In the profiles (fig. 9, 10) the long and cross profiles of the castle koppie on the ridge between Bílé and Černé Kameny in the Hrubý Jeseník Mts. can be found (to compare with pl. 14). The boulders surround the rock core entirely, projecting only in the shape of a narrow small wall in the middle. The investigations showed, that it is possible to detect the whole development from the extensive castle koppies changing by successive destruction into tors. In the last stage there remains only a heap of angular boulders on the ridge or on the summits (T. Czudek & J. Demek 1961, p. 58).

Development of the castle koppies and of the tors in the Cretaceous block sandstones of the Bohemian Plateau passed somewhat differently. In Cretaceous sandstones, the free-face was developed even in relatively low slopes. In the origin of tors the weathering along vertical joints is of main importance. The joints are so widened by weathering, that in many cases one can walk behind the free-face (compare the profile, fig. 11). The sandstones usually decay directly into the sand, which is immediately removed. The tors and castle koppies are usually rounded and many microforms (honeycombs and hollows) occur on the walls. Besides tors and castle koppies which originated by parallel retreat of free-face and which do not differ in resistance from their surroundings, occur tors and castle koppies formed of rock extremely resistant to agents of weathering and erosion. For instance on a stripped surface between the rivers Labe and

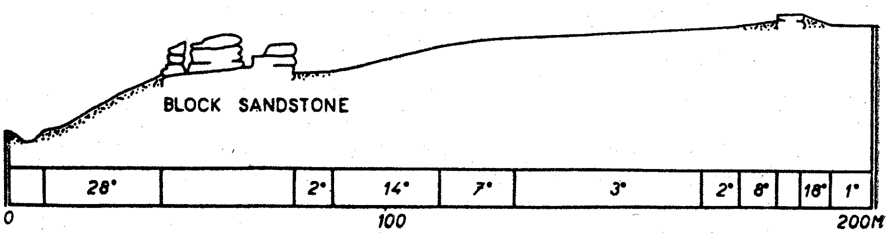

Fig. 11. Profile through the slope with sandstone tors on the valley slope near the village Tupadly in surroundings of the town Mělník in the Bohemian Plateau

Measured by J. Demek

Liběchovka such tors built of harder layers of block sandstones are projecting selectively and isolated of their surroundings. They reach the height of 10 m above the levelling stripped surface and they consist either of individual rockeries or tower-shaped pyramids of fantastic forms, forming in many cases whole groups (B. Balatka, J. Loučková, J. Sládek 1962, p. 203).

A special case of the origin of the tors swerving of the sandstone walls was described by Q. Záruba (1952, p. 163) in the surroundings of the village Podháj near the town Turnov. The sandstone rocks on the rock-spur called Kozlová are divided by two systems of joints: the longitudinal ones (of the direction WSW-ENE), which are approximately parallel to the upper edge of the slope, and the cross ones (of the direction NNW-SSE). Along the joints of the first direction the individual walls and pillars are fanwise swerving downslope. The swerving can be noticed in the length of 150 m and it was caused by the water freezing in longitudinal joints in the Pleistocene. The depth of the cuneate joints, widened by frost, separating the tors is 30—40 m.

The formation of castle koppies and tors in sandstone areas in the above mentioned mode developed intensively during the Pleistocene period, and it is proceeding even nowadays.

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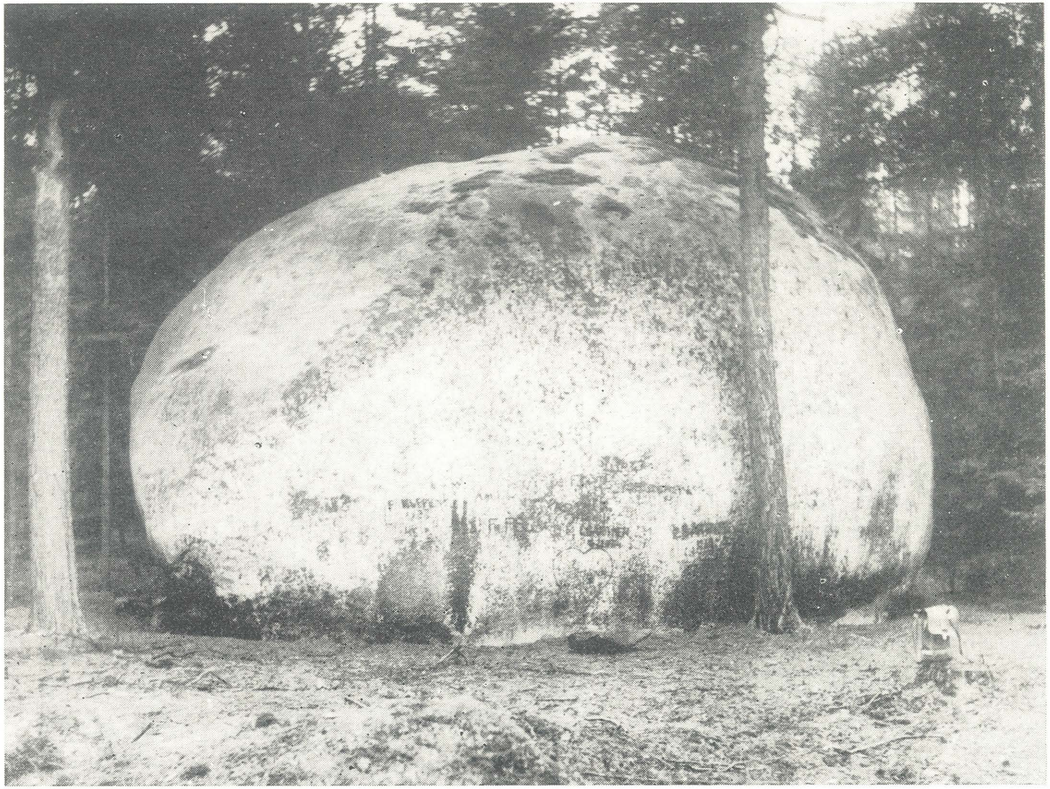
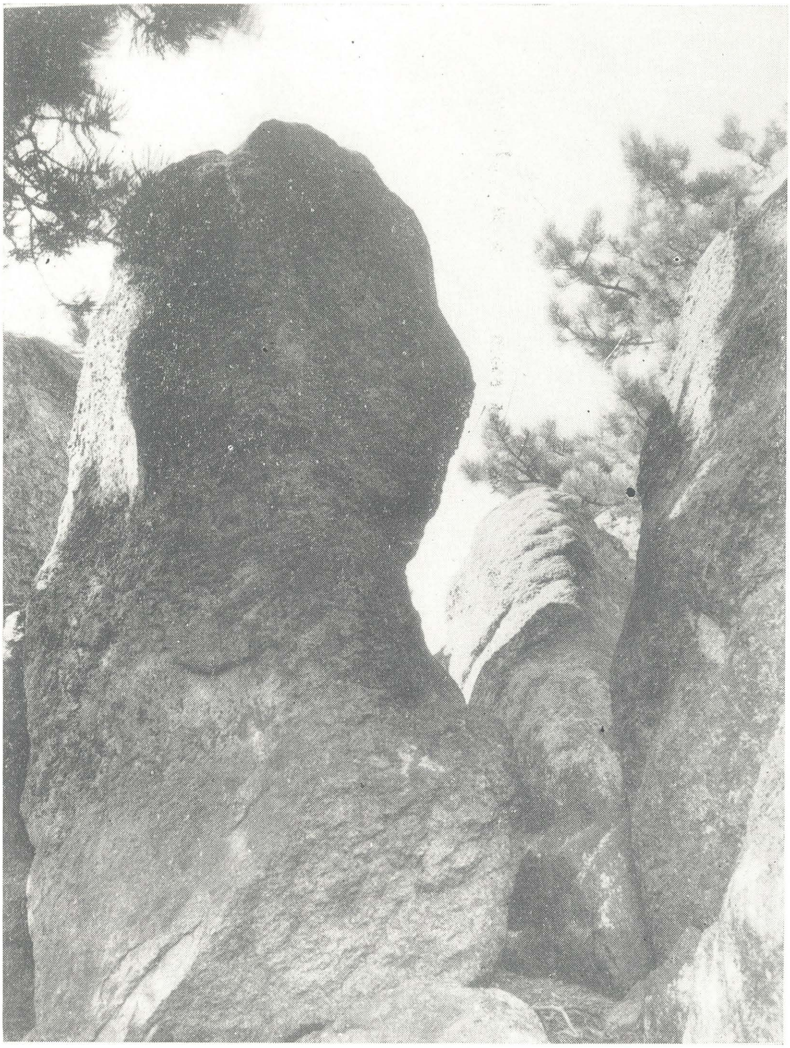


Photo by J. Demek

Pl. 1. Granite boulder called Dědek in the Čistec-Jesenice granite massif



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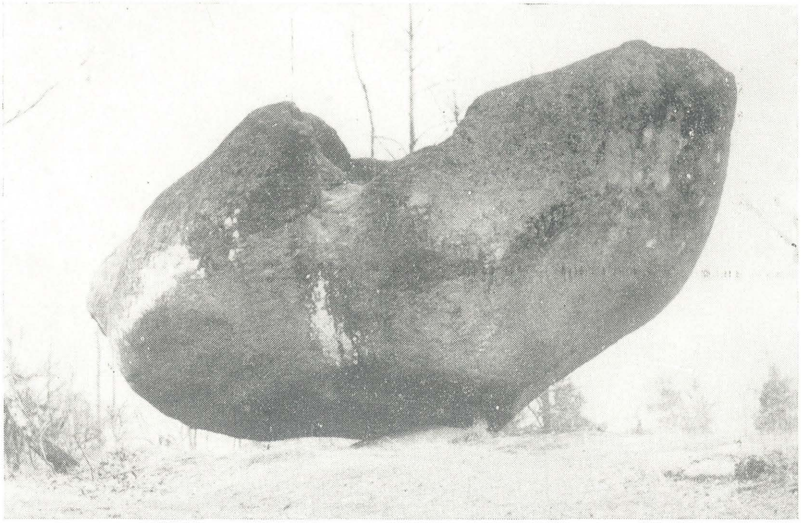
Pl. 2. Granite pillar tors on the slope of the Leskoun Hill in the southern part of the Brno-massif



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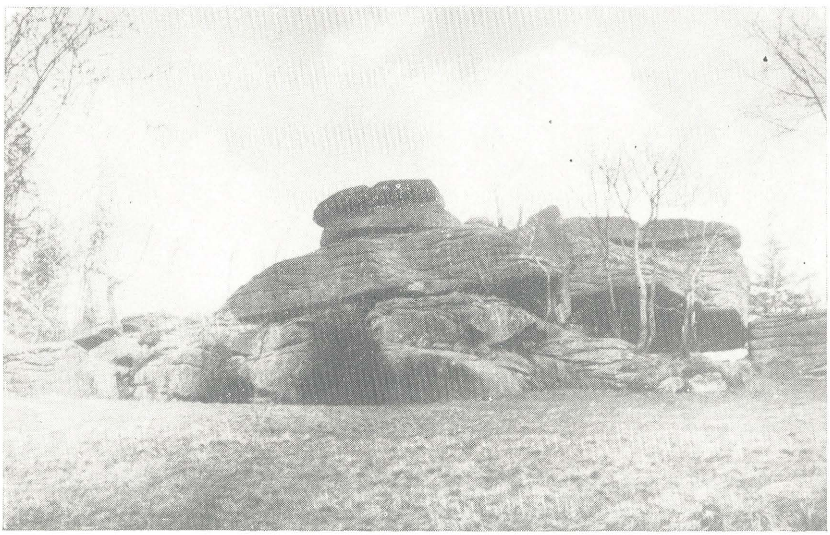
P. 3. Rocking-stone called Husova kazatelna near the village Petrovice in the Central Bohemian Pluton



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Pl. 4. Granite castle koppie on the hill near the village Janov nad Nisou in the Jizerské hory Mts.

Photo by J. Demek

Pl. 5. The upper part of the gneiss castle koppie Bílá skalka in the group of Devět skal in Českomoravská vrchovina Highland

Photo by J. Demek

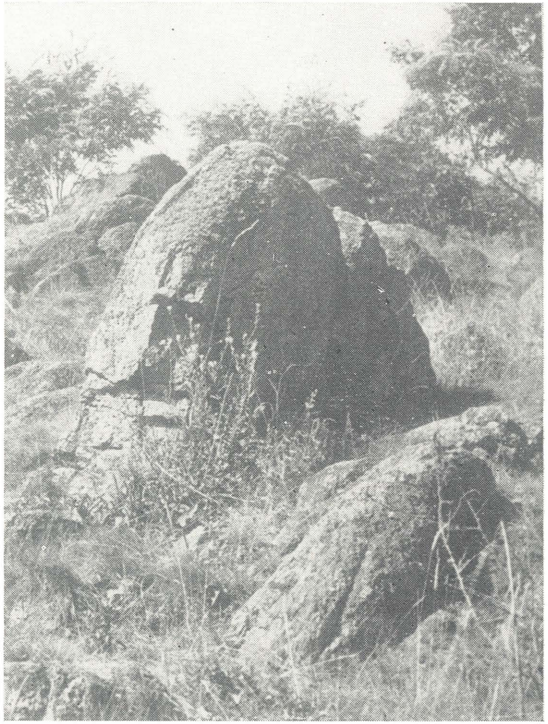
Pl. 6. Sandstone tor in the vicinity of the village Tupadly in the Bohemian Plateau

Photo by J. Demek

Pl. 7. Kaolinic gneiss regolith of Tertiary age bent by periglacial processes in the Pleistocene. Exposure near the village Bačkovice near town Jemnice on the Českomoravská vrchovina Highland

Photo by J. Demek

Pl. 8. Well-rounded core stones of syenite in situ in decomposed rock exposed by quarrying near the town Třebíč in Českomoravská vrchovina Highland



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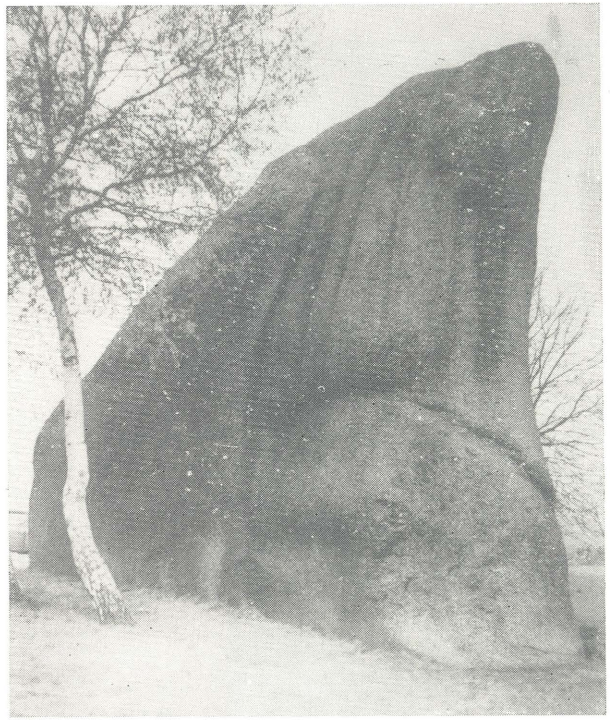
Pl. 9. Boulder on the Leskoun Hill in the Brno-massif with traces of Tertiary weathering in the upper part and of periglacial processes in the lower one



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Pl. 10. Tors on the hill Klepec in the Central Bohemian Pluton with pseudo-lapiés

Photo by J. Demek

Pl. 11. Altiplanation terraces on the summit of Táborské-skály Ridge with a tor. The scarp between terraces is veneered by soil and plants (inclination 22°)

Photo by J. Demek

Pl. 12. Free-face with angular talus blocks on the Tisá-skála Hill in the Českomoravská vrchovina Highland

Photo by O. Bárta

Pl. 13. Frost-riven cliff with a block stream jutting out of its foot. The surroundings of the village Horní Kounice on the Českomoravská vrchovina Highland

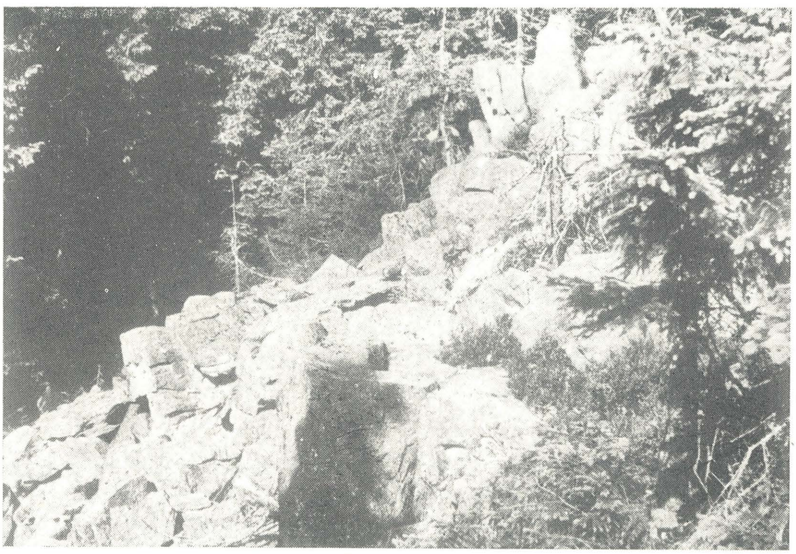

Photo by J. Demek

Pl. 14. Castle koppie on the ridge between Bílé and Černé kameny in the Hrubý Jeseník Mts., which is disappearing entirely below the block loosened by frost weathering

Photo by J. Demek

Pl. 15. The wall of the tor in the group Čtyři palice on the Českomoravská vrchovina Highland, with visible traces of frost weathering and reaching the height of 37,5 m