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PERIGLACIAL SLOPE DEVELOPMENT IN THE AREA OF THE BOHEMIAN MASSIF IN NORTHERN MORAVIA

Abstract

In the present paper the author gives the results of the research of slope development under Pleistocene periglacial conditions in the Hrubý and Nízký Jeseník Mts. After an introductory summary of the geologic and geomorphic conditions he describes the frost riven cliffs, tors, altiplanation terraces, block-fields, talus, periglacial processes on gentle slopes, the asymmetry of valley sides and the dells.

The periglacial geomorphic processes are reflected by their strong modelling on the slopes of the areas studied which led to the rise of the present slope forms. These forms vary from place to place depending on local geologic and geomorphic conditions.

INTRODUCTION

During the last years within the scope of a basic geomorphologic research I paid special attention to the periglacial forms and deposits and in connection with them to slope development under Pleistocene periglacial conditions. Investigations were concentrated especially in the area of the Nízký and Hrubý Jeseník Mts. In the Hrubý Jeseník Mts. I referred to the detailed research of M. Prosová (1954, 1963). Smaller zones were studied even in the area of the Žulovská-pahorkatina Hilly-land (T. Czudek, J. Demek, P. Marvan, V. Panoš & J. Raušer 1962), of the Rychlebské hory Mts. (V. Panoš 1960, 1961), of the Králický Sněžník Mts. and of the Highland of Úsov. The present study is dealing with periglacial slope development in the Hrubý and Nízký Jeseník Mts., as these areas are today among the best investigated. Some conclusions drawn in it are valid even for the larger region of the Bohemian Massif.

THE HRUBÝ JESENÍK MTS.

GENERAL GEOLOGIC AND GEOMORPHIC CHARACTERISTICS

In the geologic structure of the Hrubý Jeseník Mts. there are distinguished two domes — the Keprník and the Desná consisting of a core and of its sedimentary cover, with many cross faults running NW to SE, along which tectonic movements occurred even during the youngest geological periods (Zd. Pouba & Zd. Mísař 1961, and others). The young tectonics are of a fault character and the fundamental characteristics of the relief and the geologic structure of the domes are considerably influenced by their effects (Zd. Pouba in: Zd. Pouba *et al.* 1962). The smaller Keprník--dome in the west is separated from the larger Desná-dome in the east by the dislocation zone of the Červenohorské-sedlo pass. The Hrubý Jeseník Mts. form in petrologic respect a variegated complex of rocks represented by Proterozoic and Paleozoic crystalline schists. These are mainly gneisses, mica schists, phyllites, amphibolites, quartzites and crystalline limestones.

The Hrubý Jeseník Mts. area is of a mountainous character with narrow watersheds, deep (more than 300 m) valleys and high straight slopes. The much dissected mountainous character of the region is supplemented by deep passes, basins and high stream gradients. The Hrubý Jeseník Mts. reach their highest altitudes in the central part (Praděd 1491 m, Vysoká hole 1464 m, Keprník 1423 m). South of the village Klepáčov, and in the surroundings of the village Rejvíz the terrain is considerably lower. Its altitude does not exceed 960 m.

In the top parts of the relief, there are watershed ridges, passes and very slightly undulating planations. The planations represent partly remnants of the Tertiary erosion surface more or less lowered by younger denudation processes (especially by periglacial ones), and partly altiplanation terraces formed under Pleistocene periglacial conditions. The remnants of the Tertiary surface of levelling lifted up and broken by tectonic movements occur seldom, only in the top parts of the mountains (e. g. on the Vysoká hole 1464 m, on the altitude of Máj 1384 m, Jelení hřbet 1367 m, Orlík 1203 m). Otherwise, there are here more or less extensive altiplanation terraces below the frost-riven cliffs and in the vicinity of isolated rocks. In the top parts of the terrain altiplanation terraces can be found depending on the Tertiary relief, on the geologic as well as local topographic conditions at various altitudes.

Uplifting of the Hrubý Jeseník Mts. the beginning of which is commonly referred to the Upper Oligocene, caused an intense linear erosion, the results of which are the deep valleys of the present-day streams. These are more or less widely open V-shaped valleys with scarps grading sometimes more than 30°. They are following the tectonic lines, the stripes of less resistant rocks and the gradient conditions of the area. The valley heads are very often cirque-shaped and formed in the periglacial periods of the Pleistocene (M. Prosová in: Zd. Pouba *et al.* 1962; M. Prosová 1963).

Exogenic and endogenic processes in the younger Tertiary caused the origin of the macroforms of the relief in the Hrubý Jeseník Mts. The Neogene tectonic movements, which caused the breaking up of mountains into a series of blocks, reflected on the general configuration to such an extent that the area described must be defined as block-mountains.

The processes of the periglacial geomorphic cycle affected very strongly the development of the relief during the cold periods of the Pleistocene. Evidence of the activity of these processes can be found nearly throughout the whole Hrubý Jeseník Mts.

SLOPE DEVELOPMENT IN THE HRUBÝ JESENÍK MTS. UNDER PLEISTOCENE PERIGLACIAL CONDITIONS

In the Hrubý Jeseník Mts. the slope profiles are predominantly convex--concave. In the short convex upper parts the slopes have a smaller gradient (averaging up to 10°). The mid-slope parts are the longest and their declivity varies on the whole some 20° reaching in several places even more than 30°. The down slope parts are usually short, commonly with an angle of about 10° and these are often well defined talus slopes. All the slopes show conspicuous traces of intensive periglacial modelling. In the area described the author distinguished according to the surface three main types of slopes controlled by local geological conditions. These are: step-like slopes, more or less smooth slopes, slopes with both step--like and smooth profiles.

Step-like slopes

These slopes are characterized by alternating segments of more or less grading surface (fig. 1). The more sloping segments are composed of bed-rock outcrops exhibiting traces of periglacial frost weathering along joints, which should to be considered as frost riven cliffs and isolated rocks. The frost riven cliffs are reaching a height of about 20 m, they have always sharp forms and are developed on variously facing slopes. This proves that the properties of the rock were of a primary importance in their development (especially the jointing and the sedimentation conditions) while the exposure of slopes was of a secondary importance. The frost riven cliffs have a different appearance even in petrologically similar rocks. These cliffs are vertical up to the overhanging walls; sometimes only the steeper slope segments have an average inclination of about 10—20°, and are more or less covered with boulders (pl. 1) up to the block-fields or overgrown with coherent forest humus.

Overhanging rock walls occur commonly in the lowest cliff parts, where the frost weathering was, owing to the greatest moisture due especially to snow accumulation, most effective (R. S. Waters 1962). For instance the length of the overhang on the cliff north of the altitude 1015 m west of the village Ludvíkov is over 3 m.

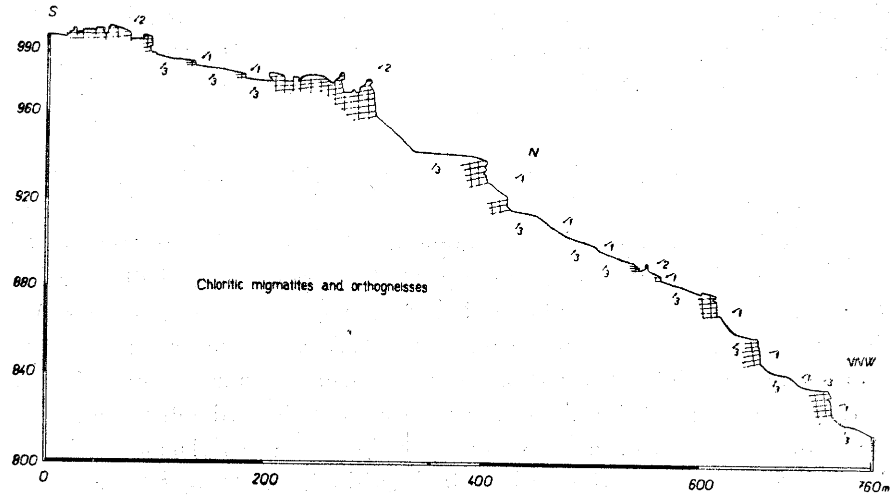

Fig. 1. Upper part of the step-like slope of the Střední Opava river, N of the altitude 1015 m, W of the town Vrbno p. Pradědem in the Hrubý Jeseník Mts. with frost riven cliffs (1), tors (2) and altiplanation terraces (3); petrologic composition: alternating layers of chloritic migmatites and orthogneisses. Measured by J. Vařeka, J. Malínek, T. Czudek

Evidence of boulders split along frost-widened joints and of a greater or lesser displacement of boulders along them are numerous (D. L. Linton 1955; J. Palmer & J. Radley 1961). A fine example is that of a boulder of 5,0 × 4,4 × 2,6 m in size, displaced along joints intercrossing at right angles which forms part of an isolated rock, 30 m NE of the altitude 1019 m, west of the village Ludvíkov. The length of the displacement is in this case of up to 0,55 m.

At the foot of the vertical up to overhanging rock walls talus occur very often, consisting in some places of angular boulders even more than 3 m in the longer axis. The talus show various dimensions and have generally a smaller gradient than the frost riven cliffs. In some places they are spread over a major part of the cliffs. But in some cases (for instance on some cliffs in the farther surroundings of the hill Žárový vrch — 1094 m — WSW of the town Vrbno p. Pradědem) these are rather single boulders on the low, gentler part of the rock wall, which is overgrown with vegetation. There are frequently cases, where the foot of the frost riven cliff is very sharp, without any heaped up boulders, even though may be clearly noticed that they were split off the rock walls along joints. The presence of boulder talus at the foot of cliffs depends on local geomorphic conditions and these being equal it is determined by the quantity of material supplied by the frost weathered steep rock walls. Where the periglacial processes (in this case solifluction and snow activity) were able to remove all the material, no talus was formed.

The length of the frost riven cliffs varies from some tens up to some hundreds of meters. The longest (2,3 km) frost riven cliff hitherto described occurs in the river basin of Branná (R. Netopil 1956). Frost riven cliffs some hundreds of meters in length are common in the Hrubý Jeseník Mts. (T. Czudek & J. Demek 1961). Watershed areas show a combined intersection of frost riven cliffs. This fact is here the most frequent reason of the origin of isolated rocks with steep up to overhanging walls, their altitude reaching in some places as much as 20 m, so that they are towering above the surrounding flat surface (fig. 2; pl. 2—4). Isolated

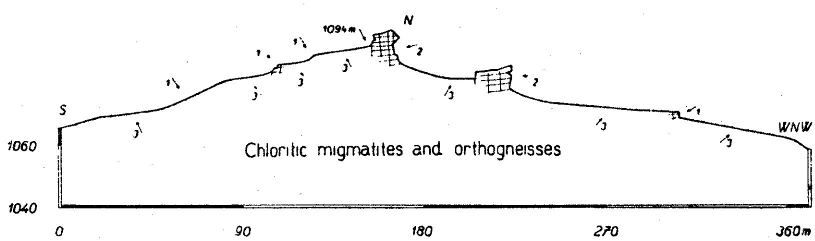

Fig. 2. Frost riven cliffs (1), tors (2), altiplanation terraces (3) in the summit part of the Hill Žárový vrch, WSW of the town Vrbno p. Pradědem in Hrubý Jeseník Mts.; petrologic composition: alternating layers of chloritic migmatites and orthogneisses. Measured by J. Vařeka, J. Malínek, T. Czudek

rocks may be considered as tors. Boulders forming talus up to block-fields (pl. 5) of different dimensions are often found at their foot and fissure caves (pl. 6) formed by frost weathering and removal of weathering products under periglacial Pleistocene conditions occur especially in the lower tors parts. An example of such caves are those in the SW-wall of the tor 60 m NE of the altitude 1094 m — the hill Žárový vrch. The larger has 9,7 m in length, 3 m in maximum width and 2,4 m in maximum height (pl. 6). Tors are as compared with frost riven cliffs less frequent on the valley-sides and marginal slopes of the Hrubý Jeseník Mts.

In the area of the Hrubý Jeseník Mts. frost riven cliffs and tors vary in appearance and clearly show here certain stages of development (Czudek & Demek 1961). The observational data hitherto collected by the present author show that these stages were not only of a chronologic nature but were in many cases (probably even in most of the cases) due to local conditions geologic as well as geomorphic, hydrologic and microclimatic. Rock formations having a various degree of development may be of the same age and others showing a more advanced stage of development may be even younger than those having the appearance of cliffs and tors at a less advanced stage of development. This problem will be discussed in an independent study.

In the area of the Hrubý Jeseník Mts. altiplanation terraces (described for the first time from Alaska by H. M. Eakin 1916) are often found below frost riven cliffs and in the vicinity of tors (fig. 1—3; pl. 2—4). On slopes, their length depends on that of the frost riven cliffs reaching — sometimes — several hundreds of meters. The width of the altiplanation terraces averages some tens of meters and only in a few places more than 100 m. On the whole, their inclination is greater on slopes than on watershed parts. This angle varies often 1—12°. Gradients of more than 14° are relatively rare while the declivities of about 2—5° are common.

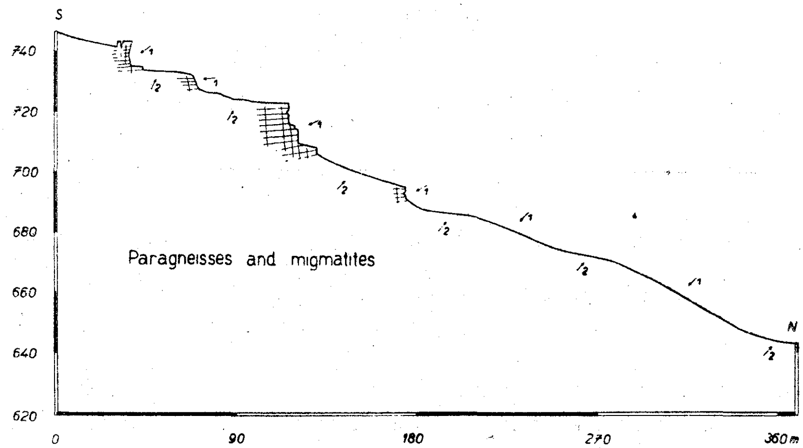

Fig. 3. Frost riven cliffs (1) and altiplanation terraces (2) in the lower part of the step-like slope, of the Střední Opava river, N of the altitude 1015 m, W of the town Vrbno p. Pradědem in the Hrubý Jeseník Mts.; petrologic composition: alternating layers of paragneisses and migmatites. Measured by J. Vařeka, J. Malínek, T. Czudek

The border of altiplanation terraces, frost riven cliffs and tors is either very abrupt or gentle in the investigated area. The solid rock of these terraces is often covered with angular material having in some places more than 1,5 m, but sometimes the bedrock crops out on the surface of the terraces. The long profile of the altiplanation terraces occurring on slopes is either nearly straight, slightly undulating, or clearly sloping down in one direction.

The altiplanation terraces originated undoubtedly as a result of the more or less parallel retreat of the frost riven cliffs under the conditions of the Pleistocene periglacial climate (R. S. Waters 1962 and others). This back-wearing was caused by the breaking away of boulders along joints and the removal of weathering products. The more or less vertical joints were of prime importance of the breaking away of blocks (J. Palmer & J. Radley 1961). The terraces described were a surface, over which the material supplied by the frost riven cliffs was removed. This transportation was chiefly performed by solifluction and the activity of snow (freezing of snow between boulders and their consequent displacement) and had no greater corrasive effects. Frost weathering on the altiplanation terraces and the removal of its products led to a down-wearing of the terrace surfaces. As compared with the retreat of the frost riven cliffs the lowering of the surface of altiplanation terraces had a considerably lesser extent (S.G. Boch & I. I. Krasnov 1951).

The present-day appearance of the frost-riven cliffs, tors and altiplanation terraces in the area of the Hrubý Jeseník Mts. shows all the characteristics of forms produced by one-stage development under conditions of a periglacial Pleistocene climate. There is so far, no evidence indicating that the forms in question may have arisen beneath the Tertiary regolith and would emerged at the terrain surface, owing to its denudation, which case described mainly by D. L. Linton (1955) may be found for instance in the granitic areas of the Bohemian Massif. The most favourable conditions for the production of frost riven cliffs pre-existed, wherever small steps were formed on slopes prior to the Pleistocene. The frost riven cliffs, tors and altiplanation terraces were developing during every cold period of the Pleistocene. But their present basal appearance dates from the end of the last glaciation. The development of step-like slopes proceeded owing to a more or less parallel retreat of the frost riven cliffs and to simultaneous moderate down-wearing.

More or less smooth slopes

More or less smooth slopes occur very often in the Hrubý Jeseník Mts. They are covered with a mantle of coarse-grained periglacial deluvial deposits of an average thickness of 1—3 m. These deluvial deposits often are merging in talus at the slope base. Only seldom, small breaks of declivity can be found on these slopes. The surface of the slopes described is overlain in some places by a compact cover of forest humus, and elsewhere angular boulders occur on it. The number of boulders varies from place to place — from single ones up to typical block-fields and block--streams.

Block-fields are a frequent phenomenon on the slopes described. They occur in the upper convex slope part and even in the steep midslope segments. A fine example is that of the block-field on the NW slope below the hill Břidličná (1357 m), described in detail by M. Prosová (1954) and the block-fields on the valley slope NE of the altitude Bílé Kameny (922 m), WNW of the village Rejvíz (pl. 7). These block-fields consist of angular boulders more than 2,5 m across which are often heaped up above one another. Their surface is undulating (M. Prosová 1954) and their general inclination is according to the line of slope in their vicinity.

The formation of block-fields depends on the properties of the rocks, climate and geomorphic processes. The block-field boulders are a result of intensive frost weathering during the cold periods of the Pleistocene. In the Hrubý Jeseník Mts. these forms are more or less autochthonous (in contrast to the block-streams occurring in flat slope depressions) and the solifluction movements of the whole individual block-fields cannot be assumed (compare M. Prosová 1963). It is indisputable, that the removal of finer-grained waste from the block-fields took place already under the periglacial conditions of Pleistocene. But it is very likely that in some cases they are removed as late as during the more humid periods of the Holocene and in consequence of deforestation resp. of a change in the specific composition of the forest during the historical period. On the whole, under present climatic conditions penetration of the forest can be noticed (especially into the low parts of the block-fields) to have been considerably more rapid than the very slight displacement of individual boulders down--slope produced by gravity and snow activity.

Slopes with a step-like and smooth profile

This type of slopes is most widespread in the area of the Hrubý Jeseník Mts. The slopes in question are either distinctly step-like in their upper parts and more or less smooth in the lower ones or show an alternation of both these segments. The origin of the surface of these slope segments was induced under periglacial Pleistocene conditions, chiefly by the specific rock properties (such as density of joints, conditions of deposition and petrologic composition). The step-like segments have the same appearance and the same genesis as the step-like slopes (see above), smooth segments as more or less smooth slopes.

In the Hrubý Jeseník Mts. more or less conspicuous talus are often found at the foot of steep slopes. Good examples are the talus at the foot of the Opava river sides in the farther surroundings of the town Vrbno p. Pradědem and that at the foot of the right valley side of the river Bílá Opava in the village Karlova Studánka. The talus gradient is always lesser than that of the slope, at the foot of which they occur. So for instance in the village Mnichov, north of the town Vrbno p. Pradědem talus grades at maximum some 10°, while the slope angle is over 20°. The talus consist predominantly of coarse-grained debris of notable thickness. The boulders included are angular and have sometimes more than 1,5 m across. The talus were formed through the combined accumulation of material derived partly directly from the slopes and partly from the valleys. At the foot of the right (SW) valley slope of the Bílá Opava river in the village Karlova Studánka the thickness of the talus attains more than 30 m. From the enclosed profile (fig. 4), it can be seen that before the formation of the talus the valley was deeper and the valley bottom in closer proximity to the right valley side than it is today. The main supply of material was from the right valley side which is, in the village Karlova Studánka, higher and longer than the opposite one. Solifluction, gravity and sheet-wash contributed in particular

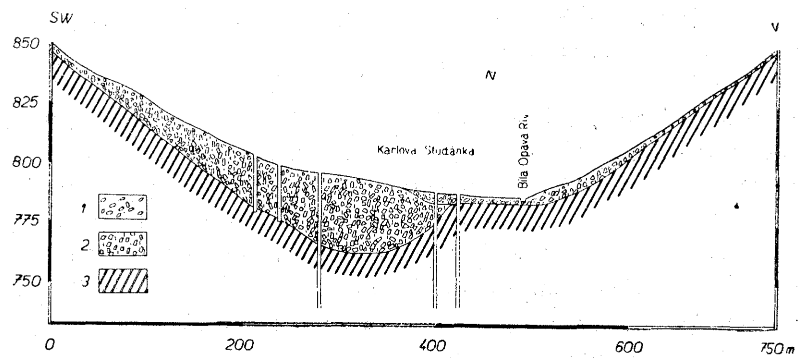

Fig. 4. Valley of the Bílá Opava river in the village Karlova Studánka in the Hrubý Jeseník Mts.

1. slightly rounded boulders, predominantly phyllites; 2. talus formed in the substratum of Holocene soil by angular boulders, predominantly phyllites with sandy loam; 3. solid rocks (phyllites with layers of diabase)

to the formation of the talus, especially during the warmer periods of the periglacial climate of the Pleistocene (mostly in the transition periods between the cold and warm phases of the Pleistocene). But their uppermost layers are of Holocene age.

THE NÍZKÝ JESENÍK MTS.

GENERAL GEOLOGIC AND GEOMORPHIC CHARACTERISTICS

The Nízký Jeseník Mts. consist predominantly of Lower Carboniferous (Culm) rocks, which are represented by a flysh series of strata, in which graywackes and schists alternate. These beds contain intercalated beds of the Culm conglomerates. In some places graywackes are prevailing over schists, elsewhere again schists over graywackes. The strike of the beds is generally NNE—SSW. The direction and extent of their inclination vary rapidly from place to place owing to intense folding. Of other rocks it is necessary to mention the Devonian shales, diabases and diabasic tuffs occurring within the narrow stripe of Šternberk — Horní Benešov, the reduced number of Devonian limestones, the denudation remnants of Lower Tortonian deposits, the basaltic effusions (especially south and SE of the town Bruntál) and the denudation remnants of continental glacial deposits in the narrow stripe along the northern and eastern margin of the Nízký Jeseník Mts.

The Nízký Jeseník Mts. form an extensive geomorphic area, east of the Hrubý Jeseník Mts. They are generally bordered from adjacent terrain by well-defined, steep and straight slopes, often of fault origin. The area described is a Highland reaching the greatest altitudes in its western part (Slunečná 800 m, Dobrečovská hora 809 m), and the lowest on the steps of the villages Plinkout, Řídeč, Tršice and south of the town Hlučín (altitudes of about 320 m). The surface of the terrain shows an inclination trending West to East. The relief of the Nízký Jeseník Mts. as compared with that of the Hrubý Jeseník Mts. is lower, considerably flatter and less dissected. Its basal features consist of planations and widely rounded ridges on the watershed, valleys of various depths, straight slopes and basins. The configuration of the terrain is supplemented by rectangular valley bends, gaps and young volcanic forms.

The planations on the watershed of streams levelled the surface of the folded and variously resistant Culm and Devonian rocks. They occur at various altitudes and are widespread especially in the eastern part of the area. These are remnats of the old surface of levelling uplifted by tectonic movements, which acquired its present fundamental features by very intensive modelling during the Pliocene. During the cold periods of the Pleistocene, cryoturbation was operating in the central parts of the nearly flat planations while solifluction failed to take place (T. Czudek 1960, 1962). Solifluction combined with sheet-wash took however part in the modelling of the more or less undulating, sloping and, in the marginal parts, almost flat planations. Wind which was at that time, an important factor of denudation on all planations blew away part of the fine waste.

The valleys of streams in the Nízký Jeseník Mts. are on the one hand widely open in cross section with variously sloping sides, and on the other they are deep (in some places more than 150 m) the cuts being either V- or trough-like in shape. The widely open valleys occur in the area near the towns Horní Benešov and Rýmařov and in the short valley heads of nearly all deeply cut valleys. In some places in deep valleys river terraces of a little area can be found. The present stream pattern was essentially formed in the Neogene. Formation of many of the valleys started already in the period preceding the Lower Tortonian marine transgression (H. Hassinger 1914 and others).

The origin of the valleys of Tertiary age was caused by the subsidence of the base level of erosion, due to repeated tectonic movements. The fault lines reflect morphologically even inside the area of the Nízký Jeseník Mts. During the Pleistocene, the old valleys in the area described were vigorously modelled. In many places even short valleys were formed and the main valleys deepened.

The basal relief features of the Nízký Jeseník Mts. are a result of the combined activity of endogenic and exogenic processes during the Neogene. Periglacial processes in the cold periods of the Pleistocene led subsequently to intensive modelling of the Neogene macroforms and to the production of some typical forms of the periglacial geomorphic cycle.

SLOPE DEVELOPMENT IN THE NÍZKÝ JESENÍK MTS. UNDER PLEISTOCENE PERIGLACIAL CONDITIONS

It is possible to distinguish in the Nízký Jeseník Mts. gentle and steep slopes according to their gradient. The gentle slopes (with a maximum angle of about 10°) are more or less smooth, the steep ones (with a predominant angle of about 20°, in some places even more than 30°), are mostly smooth too. Less frequent are step-like slopes and slopes with smooth and step-like segments. Like in the Hrubý Jeseník Mts. convex-concave slope profiles with long central segments are prevailing in this area.

Periglacial processes on gentle slopes

The periglacial slope deposits, which make it possible to become better acquainted with the course of the periglacial geomorphic slope processes were studied by the present author on the gentle slopes (about 2—5°) of watershed ridges, on more undulating and sloping planations, on passes

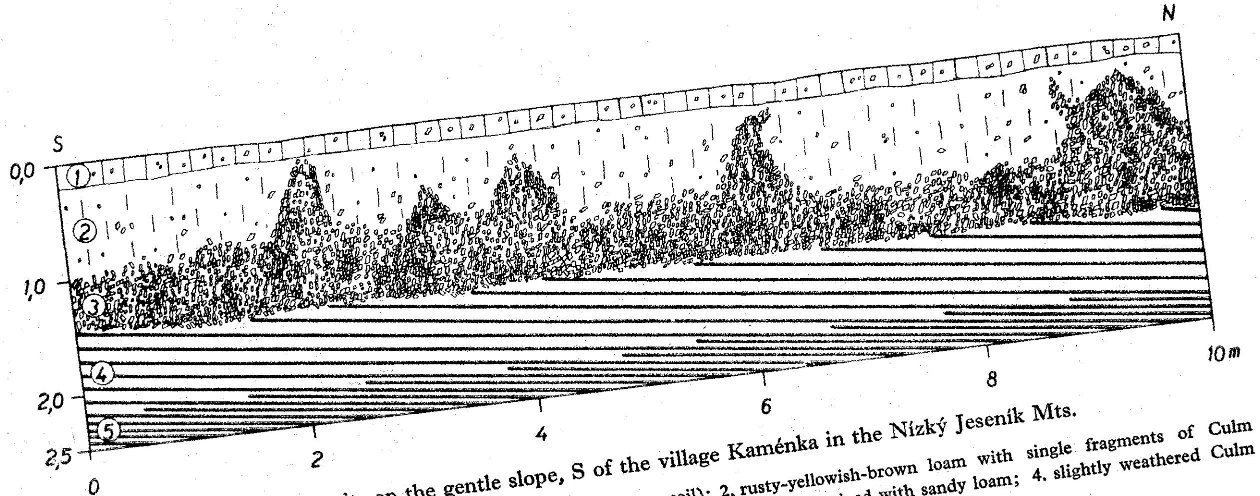

Fig. 5. Deposits on the gentle slope, S of the village Kaménka in the Nízký Jeseník Mts.

1. greyish brown clayey loam with single fragments of Culm rocks (Holocene soil); 2. rusty-yellowish-brown loam with single fragments of Culm graywackes and schists; 3. debris composed of fragments of Culm graywackes and schists mixed with sandy loam; 4. slightly weathered Culm graywackes and schists; 5. solid rocks (Culm graywackes and schists)

and flat valleys in many places in numerous excavations having more than 50 m in length. Periglacial slope deposits are represented here in the substratum of the Holocene soil by loams and debris. The upper border of the debris is clearly undulating (fig. 5, 6) in the form of festoons (see J. P. Schafer 1949; A. Jahn 1951; J. Dylik 1952; J. Sekyra 1960). These festoons are more or less bent according to the maximum slope angle especially in their top parts. The greater the slope inclination, the more well-defined is the bending which takes in some places a tongue-like shape (fig. 7).

The debris includes fragments of Culm and Devonian rocks mostly up to 15 cm across, the surface of which is only very slightly weathered. In some places they constitute some 40%, elsewhere even more than 90% of the whole material (fig. 5—7). Their surfaces (less frequently their edges) are closely spaced and the intersecting fissures are filled with sandy loam up to strongly loamy sand. On the whole, the debris consists of unbedded and unsorted material. A series of rock fragments runs according to the maximum angle of slope (K. Richter 1951; J. Hövermann 1953; A. Suchel 1954; T. Czudek 1960, 1962 and others) especially in the upper part of the debris. This proves that the downslope movement was greater in the upper part of the debris than in the lower one (J. Büdel 1959). Many rock fragments are subangular (J. Hövermann 1953); this is again most frequent and well-defined in the upper part of the debris (fig. 5—7). Such degree of rounding cannot possibly be attributed to intense weathering of edges, but only to down-slope movement. This may be assumed for the reason, that the fragments of Paleozoic rocks on the nearly flat planations of the watershed parts of the terrain and the fragments of the weathered rock substratum with undisturbed structure of the parent rock on slopes (in the substratum of debris), where there is no evidence of horizontal movements, are angular even in places consisting of absolutely equally resistant rocks. But schists with a clearly developed parallel structure (especially roofing slates) are always angular (even in the solifluction waste cover of slopes). This can be explained by the fact, that the fragments of the above mentioned schists were broken at slope movements, which led to the origin of sharp edges. The depressions in the surface of the debris are filled with slope loams with solitary fragments of local rocks. In the direction to the substratum the debris merges gradually into weathered rock which retains the structure of the parent rock (pl. 8).

On the basis of a study of the excavations it may be said, that on gentle slopes (with a gradient of about 2—5°) solifluction and even intensive vertical movements took place. The vertical movements were caused as

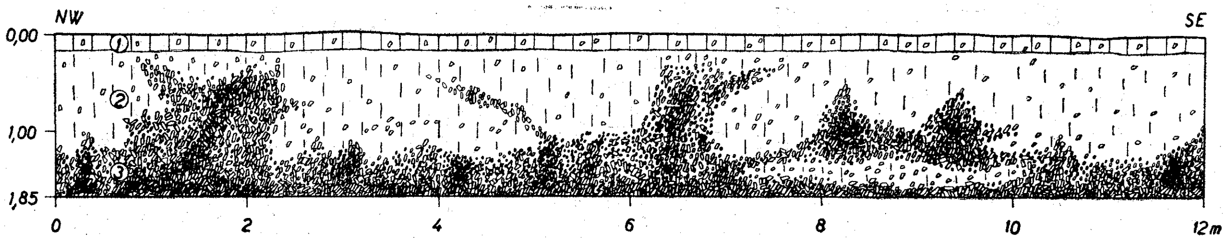

Fig. 6. Deposits on the gentle slope, W of the village Zbyslavice in the Nízký Jeseník Mts.

1. grey loam with single fragments of Culm rocks (Holocene soil); 2. yellowish-brown in the upper part greyish-brown clayey loam, in some places faintly sandy with single fragments of mostly Culm schists; 3. debris composed of fragments of Culm schists mixed with greyish brown sandy loam

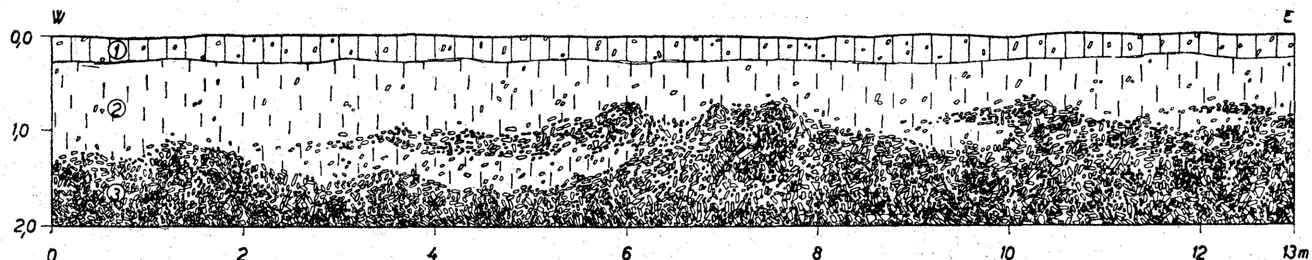

Fig. 7. Deposits on the gentle slope, SE of the village Hrabství in the Nízký Jeseník Mts.

1. brownish-grey faintly sandy loam with single fragments of Culm rocks (Holocene soil); 2. rusty-yellowish brown clayey loam with single fragments of predominantly Culm schists; 3. debris composed predominantly of fragments of Culm schists mixed with brownish grey loam

well by lateral pressures connected with the origin of the depressions in the surface of the debris as by frost heaving of rock fragments towards the surface. Solifluction operated in two different ways. One of them was movement of the thin uppermost part of the weathering products, and the other that of the thicker layer (more than 1 m). Movement of the thin bed down-slope occurred every year, at every melting of permafrost (periodic solifluction according to J. Büdel 1959). Down-slope movement of the whole or nearly whole bed of weathering products took place only during very favourable periods, of deep melting of the permafrost, i.e. only sporadically (episodic solifluction according to J. Büdel 1959).

The writer had no opportunity to study the deposition conditions of periglacial slope deposits in longer excavations in a larger number of places on steeper slopes (angle of about 10°). But the, so far, unique longer test pits and rock exposures show, that periglacial debris in the substratum of deluvial loams is not so strongly undulating as on gentle slopes and that its upper border fails to produce festoon-like patterns. This tends to support the opinion, that with a growing slope gradient, horizontal movements prevail increasingly over vertical ones. Many fragments of Paleozoic rocks included in the debris on the slopes in question have slightly rounded edges and their majority follows the direction of the maximum slope angle. Even on these slopes, movement of the thin uppermost detritus layer was seasonal and that of the whole or nearly whole waste layer only induced by favourable climatic conditions — i.e. episodic. Its velocity as compared with that on the gentler slopes was naturally greater.

On the slopes in question the most intensive solifluction and sheet-wash operated under milder periglacial climatic conditions (especially in the initial and terminal phases of periglacial climate). It was impossible to establish so far the presence on the gentle slopes of the area investigated of periglacial deposits older than those of the last glacial period. This is due to disturbance of the older deposits and by their inclusion into the younger periglacial cycles. Wherever the material supplied by solifluction and sheet-wash was not removed at a sufficient rate, even in periods of increased efficiency of the water streams, it accumulated progressively. This fact may be observed at the foot of slopes, in flat watershed passes and in short flat valleys, the depth of which does not usually exceed 10 m, where periglacial deposits, formed during several periods of the Younger Pleistocene and having a few meters in thickness can be found. Fine-grained material often alternates here with coarse-grained one, thus indicating alternate denudation processes on slopes depending on climatic changes. The occurrence of the displaced fossil weathering products in the basal beds of these deposits shows that solifluction and sheet-wash operated first on the fossil Tertiary weathering products which it removed on suitable places and subsequently on the weathering products formed during the Pleistocene. It may be seen in many places, watershed passes had a greater depth before the Pleistocene, than they have today. So for instance in a pass on the watershed of two short valleys south of the village Staré Těchanovice (north-west of the town Vítkov) the Pleistocene — mostly periglacial — deposits have a thickness of up to 16,20 m (pl. 9). They consist of loam beds with an unequal percentage of Culm shale fragments and graywackes. It is evident, from the profile (fig. 8), that the pre-Pleistocene

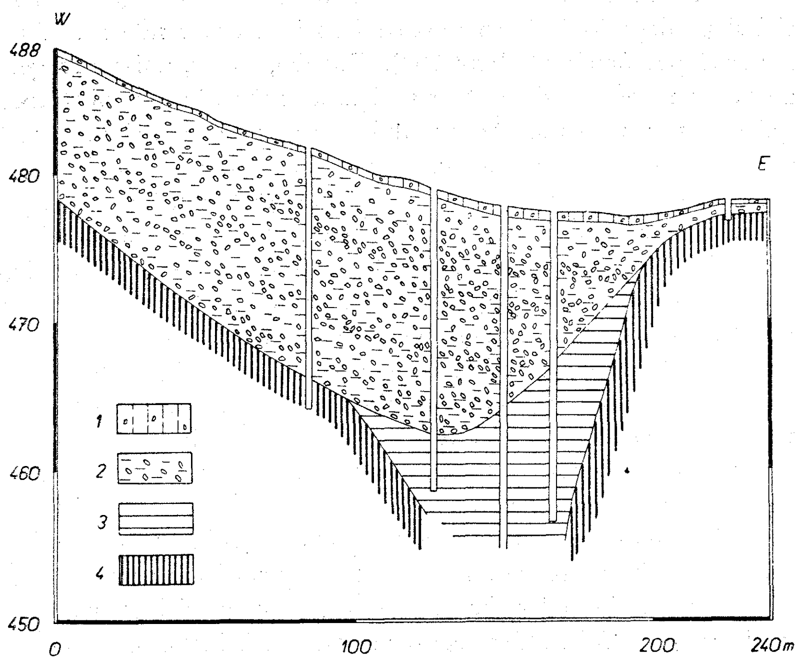

Fig. 8. Flat pass S of the village Staré Těchanovice in the Nízký Jeseník Mts.

1. brownish-grey sandy loam with single fragments of Culm rocks (Holocene soil); 2. predominantly periglacial loams (brown in colour) with fragments of Culm schists and graywackes; 3. Lower Tortonian calcareous clay greyish-green and bluish-grey in colour, filling out the old valley; 4. slightly weathered Culm schists

pass south of the village Staré Těchanovice as compared with the present one, was considerably deeper and its lowest place was advanced more westward than at present. The main supply of material was from the western slope which is longer and steeper than the opposite one.

Asymmetric slope development in valley heads

One of the typical forms created during the cold periods of the Pleistocene is — in the Nízký Jeseník Mts. area — the periglacial climatic asymmetry of the valley sides. This asymmetry occurs in widely open flat valley heads and even at the issues of deep valleys, the bottom of which are now dry over the major part of the year. The asymmetry in question is developed most often and best defined in valleys of more or less meridian trend, predominating notably in the valley heads and short stream valleys of the Nízký Jeseník Mts. The steeper valley slopes are facing west, even in the uppermost segments of the valleys. There is no noticeable change of exposure in the valley heads of the steeper slope in down stream direction. The gentler valley slopes are always longer, their inclination being mostly twice up to three times lesser than that of the opposite steeper slope (fig. 9, 10; pl. 10). Their merging into the valley bottom, like their border (separating them from the surrounding relief) is less pronounced than on steeper slopes.

In order to determine the genesis and age of valley-slope asymmetry, some geological exposures were investigated and in some selected profiles test pits were carried out. The test pits were nivellated and the geological cross profiles of the valleys were worked out on their basis. The test pits and rock exposures proved that in the valley heads the deluvial deposits on the opposite slopes have an appreciably different thickness (fig. 9, 10). On slopes grading at a lesser angle the slope deposits are always thicker than on the steeper ones (F. Fezer 1953 and others). The structure of slope deposits in the substratum of the Holocene soil proves conclusively their periglacial origin. These are various loams, sands and fragments of Paleozoic rocks mixed more or less with sandy loam up to loamy sand and reaching in some places at the foot of slopes east-facing a thickness of about 5 m. Sometimes, are periglacial deposits thicker even at the foot of steeper valley slopes. They either rest in a substratum of periglacial deposits of the valley bottom or interpenetrate with them. The Pleistocene deposits of the valley bottoms in valley heads consist predominantly of angular and sub-angular fragments of Paleozoic rocks mixed with loam and strongly loamy sand. The valley bottoms are often deepened by Holocene ravines, showing in the valley heads a trough-like shape (fig. 9, 10). Thus the slope asymmetry in the valley heads of the Nízký Jeseník Mts. is very closely connected with the asymmetric development of slope deposits. As these deposits date from the periglacial period, it is possible to share the opinion of the scientists, who believe that asymmetry of valley heads and its present features were caused by the

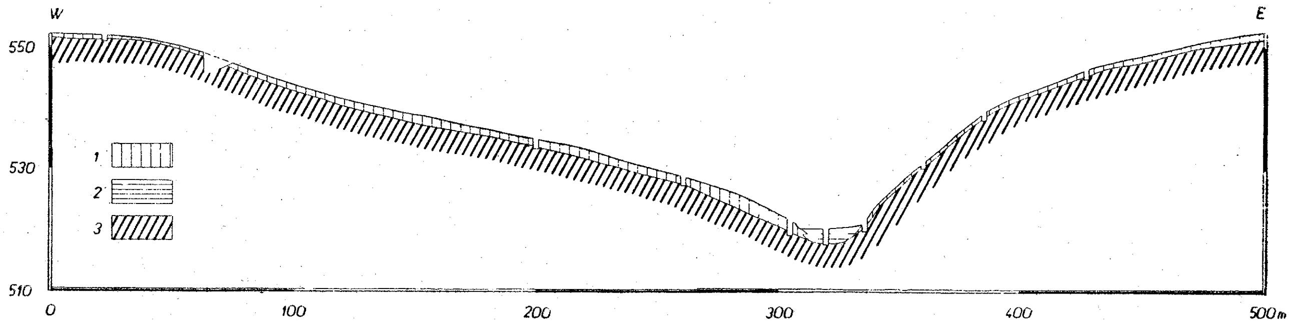

Fig. 9. Slope asymmetry of the valley head, N of the village Svatoňovice in the Nízký Jeseník Mts.

1. periglacial slope loams (brown in colour) and debris composed of fragments of Culm schists mixed with yellowish brown sandy loam in the substratum of Holocene soil; 2. periglacial sandy-clayey loam and debris consisting generally of fragments of Culm schists mixed with sandy loam (in the upper part displaced in the Holocene); 3. lightly weathered Culm schists

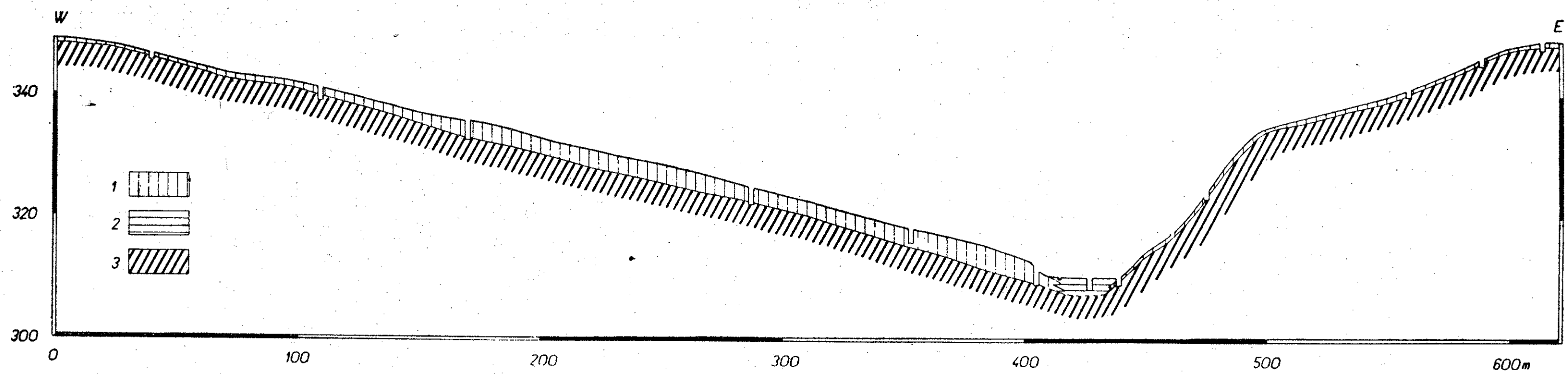

Fig. 10. Slope asymmetry of the valley head at the W outskirts of the village Velká Polom in the Nízký Jeseník Mts.

1. periglacial slope loams (brown in colour) and debris consisting of fragments of Culm graywackes and schists mixed with sandy loam in the substratum of Holocene soil; 2. periglacial sandy clayey loams and debris composed of fragments of Culm graywackes and schists mixed with yellowish brown and greyish-brown strongly sandy loam (top part displaced in the Holocene); 3. slightly weathered Culm graywackes and schists

asymmetric course of slope processes under the periglacial conditions of the Pleistocene.

It is now necessary to elucidate question, which processes are responsible for the development of asymmetric slope. Whether it has been lateral erosion by water streams, eolian sedimentation, the varying intensity of geomorphic processes on the opposite valley slopes conditioned by their different insolation or the effect of snow.

At the present state of research it may be said, that lateral erosion by water streams cannot possibly be regarded as the main agent of asymmetry in the valley heads of the area investigated. This assumption is especially based on the following facts. Asymmetry occurs in the valley heads, where under periglacial climatic conditions the water streams were inapt to remove all the material supplied by slopes, all the less they were able to cause lateral erosion. In humid periods the activity of streams was confined to the removal of periglacial deposits from the valley bottoms. The possibility of lateral erosion was at that time equal on both valley sides and rather reduced by the relative resistance of the component rocks and sluggishness of the water streams. In the case under consideration, sedimentation of loessy loam by prevailing westerly winds can be ruled out as a presumptive agent of the development of asymmetric valley slopes, though such sedimentation supported the effects of solifluction. This view seems the more convenient as asymmetry occurs even in places, from where these deposits are absent (see H. Poser & T. Müller 1951; Ł. Pierzchałko 1954; A. Jahn 1956 and others).

The author's research on asymmetric valley slopes chiefly in the area of Nízký Jeseník Mts. but also in other regions of the Bohemian Massif shows, that in the present case the main cause of an asymmetric development of valley sides in the valley heads should be viewed in the light of the geomorphic effects of periglacial processes on the opposite valley sides. The different proportions of denudation on the opposite valley slopes were caused by their different insolation and the process was effectively supported by the snow cover.

At the onset of each separate cold period the periglacial denudation processes (in our case solifluction and sheet-wash) began to operate sooner on the east facing slopes, but their intensity decreased rapidly. On the other hand, on „warmer" slopes (facing west) the periglacial slope processes began to operate somewhat later, but regelation was here as compared with the east facing slopes acting longer. Owing to this, denudation on these slopes was more intensive than on the „colder" slopes. This can be noticed even in the top phases of periglacial climate. During the end-phases of the periglacial periods and under milder periglacial climatic conditions (farther away from the front of continental ice-sheet) the „colder" slopes (facing east) were subjected to more vigorous processes of periglacial denudation than the slopes facing west, which sooner acquired the features of non-periglacial morphology (J. Tricart 1950; A. Jahn 1956). At that time the operations of periglacial slope processes were here both more frequent and more long-lasting. Therefore these slopes are more denuded than those facing west, on which solifluction and sheet-wash ceased earlier. During these periods, the development of gentler slopes was effectively promoted by the snow cover. On east facing slopes snow accumulated more often and with greater thickness than on the opposite ones. A higher degree of moisture on the west slopes (facing east) during the melting of snow intensified the action and prolonged the duration of periglacial slope processes and caused a greater denudation (see F. Taillefer 1944; J. Büdel 1944; H. Maruszczak 1958 and others). Consequently geomorphic processes operating in the end phases of periglacial climate and under warmer periglacial conditions (farther away from the front of the continental ice-sheet) may be said to have decisive importance for the formation of valley slopes asymmetry of valley heads in the Nízký Jeseník Mts. area. Hence its present-day features are a result of periglacial geomorphic processes of the last glacial period.

Periglacial processes on steep slopes

The steep slopes of the deep valleys and the marginal slopes of the area described are covered with periglacial deposits and typical forms of the periglacial geomorphological cycle. The development of each individual slope-type whether step-like, more or less smooth (which are most frequent in the Nízký Jeseník Mts.) or such, on which step-like and smooth segments alternate — progressed in the area described in the same manner as in the Hrubý Jeseník Mts. But the top parts of the relief in the Nízký Jeseník Mts. do not exhibit any frost riven cliffs and tors, except in some isolated cases occurring in the western part of this area.

The periglacial deluvial deposits on steep slopes consist of angular fragments up to boulders of local rocks, mixed with sandy loam up to loamy sand, thinly veneered with Holocene soil. On these slopes their thickness is insignificant, averaging 0,50—2,0 m. The angular fragments composing the major part of the deluvial deposits are generally smaller as compared with those occurring in the Hrubý Jeseník Mts. The fragments of the boulder-size are often lying on the slope surface or projecting out of the Holocene soil.

As to periglacial forms, the following ones occur on the slopes described: dells (which may be found even on gentle slopes), frost riven cliffs, tors, talus and altiplanation terraces at the foot of frost riven cliffs and tors, block-fields, block-streams and talus at the slope bases. These forms — with the exception of the talus at the slope bases — are in the Nízký Jeseník Mts. of considerably lesser dimension than those in the Hrubý Jeseník Mts.

Dells are very common periglacial forms in both of the areas investigated. They are widely open in cross cut, more or less straight in trend and their bottoms are generally cut by Holocene ravines. Solifluction and running water were the chief agent in their development (see J. Hövermann 1953). The most suitable conditions for their formation were provided by places with most frequent rock jointing and those with pre-Pleistocene flat rills on slopes (see T. Czudek 1960).

Frost riven cliffs, tors, talus and altiplanation terraces at the foot of frost riven cliffs and tors, block-fields and block-streams have in the Nízký Jeseník Mts. a similar appearance and a like development as those in the Hrubý Jeseník Mts., though — as mentioned above — they are owing to the local conditions substantially smaller in size. Frost riven cliffs are in the Nízký Jeseník Mts. usually developed in the bed fronts. Fine examples of block-streams and block-fields were recently described from the valley of the river Bystřice (J. Fencl, A. Svatoš 1962).

Variously pronounced talus can often be found at the foot of steep valley- and marginal slopes of the Nízký Jeseník Mts. Their size depends on the local geomorphic conditions. The most conspicuous talus occur at the foot of the marginal slopes of the Nízký Jeseník Mts. in the larger surroundings of the town Šternberk, the village Samotíšky, farther in the stretch between the villages Střítež n. Ludinou and Kletné, south of the town Opava and in the valley of the river Odra, from the village Klokočůvek up to Emauzy.

The Pleistocene age of the talus is proved not only by their character in the vertical profile, but also by the fact, that at the foot of the SW marginal slope of the Nízký Jeseník Mts. there is a talus which is certainly younger than the Pliocene deposits of the Hornomoravský úval (the Upper Moravian Graben) and the talus in the area south of the town Opava is overlapping over a narrow strip in the margin of the Nízký Jeseník Mts. with the deposits of the Middle-Polish glaciation (see J. Macoun 1958). They are partly composed of material supplied directly from the slopes and partly of material from the valleys. In some places the thickness of the talus reaches more than 30 m which shows that the slope underwent intensive modelling in the time of their formation. The Pleistocene deposits composing the talus display all the characteristics of bedded slope deposits, which constitute a conclusive evidence of the dynamic nature of the slope processes of the Pleistocene.

The talus were investigated in detail especially at the foot of the SW marginal slope of the Nízký Jeseník Mts. in the village Paseka, in the town Šternberk and in the village Samotíšky (T. Czudek, *et al.* 1963). In the surroundings of these localities the marginal slope consists of two parts — a higher and the lower one. The higher slope part grades more than 20° and exhibits outcrops of solid rocks (Devonian, Culm). The lower slope part formed by a talus, has a maximum angle of some 10°. The talus consists of slope deposits, in which beds of coarser and finer material are clearly alternating. Two types were distinguished here: slope debris deposits with thicker beds and deposits of *grèzes litées* type.

The first consists of beds (varying in thickness from 0,1 m up to more than 2 m) of clayey loams, sandy loams and loamy sand with a greater or smaller content of local rock fragments (from 10% up to more than 60%) and buried soil horizons, containing generally up to 95% of brown-coloured loamy material. In the upper part of the 17,4 m thick profile in the town Šternberk are 26 different beds, and 24 beds in the upper part of the 9,75 m thick profile in the village Samotíšky. The rock fragments in these deposits are angular and subangular. Their size varies from 1 to 10 cm, in some places even more. Most fragments lie with their major axis according to the line of slope (K. P. Unger 1958). The structure of the loamy beds with local rock fragments shows that these sediments were deposited chiefly by solifluction and sheet-wash. According to the present state of research it may be said, that these sediments originated particularly in the warmer phases of periglacial climate (mainly during the periods of transition between glacial and interglacial periods and between stadial and interstadial periods). But their uppermost layers are Holocene in age.

The best developed slope deposits, that may be compared with those of the *grèzes liteés* type, which were described for the first time by French workers, were found in the lower part of the profile in the town Šternberk (2,95 m) and in the upper part of the same profile at the depths of 9,40—11,00 m and 11,40—15,50 m, beneath the surface (T. Czudek, *et al.* 1963). They consist of thin beds of angular and subangular fragments of graywackes and schists averaging from 0,5 up to about 3 cm in size, separated by thin beds of sandy loam and loamy sand. The inclination of the individual beds downslope varies from some degrees to 15°. The beds are contorted and often wedging. Their thickness averages from 1 to 10 cm. The origin of these finely rhythmically bedded slope deposits was caused by sheet-wash, solifluction, gravity, eolian and supranival processes under the periglacial conditions of the Pleistocene. It may be said that on the whole in the above-mentioned locality the chief agents of their formation were solifluction and sheet-wash (J. Dylik 1960 and others).

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Pl. 1. Frost riven cliff overlain by angular quartzite blocks near the altitude 1250 m, NE of the Ztracené kameny, E of the village Klepáčov in the Hrubý Jeseník Mts.

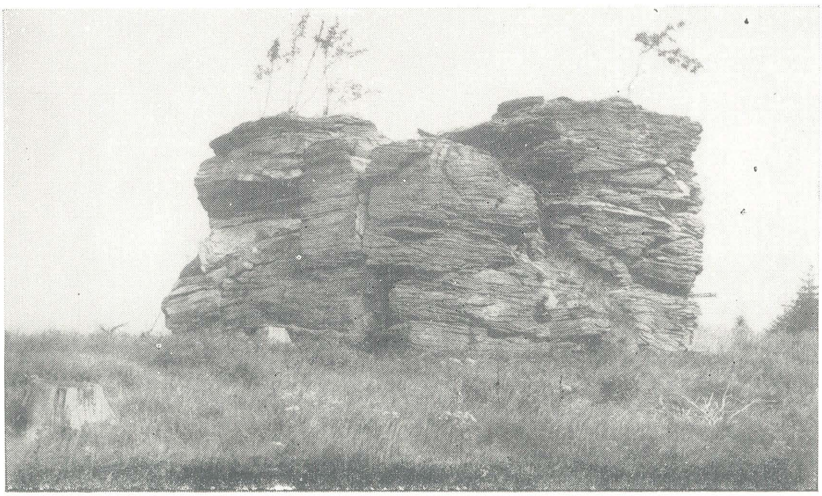

Photo by T. Czudek

Pl. 2. Tor and altiplanation terrace on the top (1015 m), W of the town Vrbno p. Pradědem in the Hrubý Jeseník Mts.

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Pl. 3. Tor and altiplanation terrace on the top NE of the altitude 1019 m, W of the village Ludvíkov in the Hrubý Jeseník Mts.

Photo by T. Czudek

Pl. 4. Tor and altiplanation terraces in the surroundings of the altitude 1015 m W of the town Vrbno p. Pradědem in the Hrubý Jeseník Mts.

Photo by T. Czudek

Pl. 5. Tor with angular boulders called Ztracené kameny, composed of quartzites, E of village Klepáčov in the Hrubý Jeseník Mts.

Photo by T. Czudek

Pl. 6. Fissure cave in the lower part of the tor NE of the altitude 1094 m (Žárový vrch Hill) WSW of the town Vrbno p. Pradědem in the Hrubý Jeseník Mts.

Photo by T. Czudek

Pl. 7. Block-field formed by angular quartzite boulders on the slope grading some 30° NE of the altitude Bílé kameny WNW of the village Rejvíz in the Hrubý Jeseník Mts,

Photo by T. Czudek

Pl. 8. Cryoturbation in debris composed of fragments of Culm graywackes and schists mixed with sandy loam on the gentle slope S of the village Tísek in the Nízký Jeseník Mts

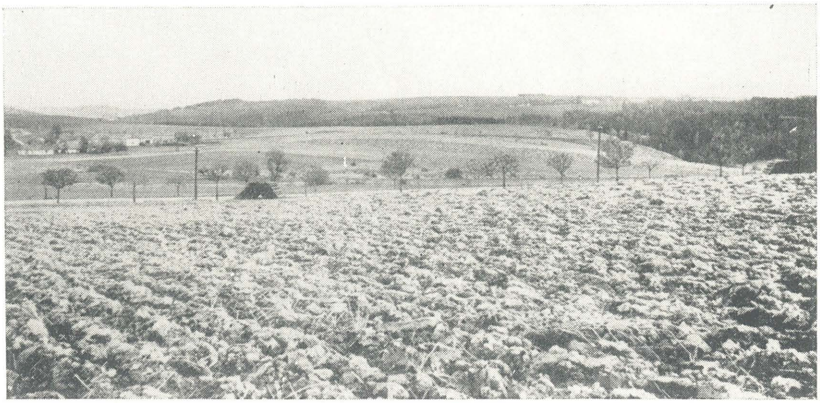

Photo by O. Bárta

Pl. 9. General view of the Nízký Jeseník Mts. in the surroundings of the village Staré Těchanovice and the flat pass S of this village

Photo by T. Czudek

Pl. 10. Slope asymmetry of the valley heads at the W outskirts of the village Velká Polom in the Nízký Jeseník Mts.