PEAKS OF THE KRKONOŠE TUNDRA

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Podpořeno grantem z Islandu, Lichtenštejnska a Norska. Supported by grant from Iceland, Liechtenstein and Norway.

Peaks of the Krkonoše Tundra

Krkonoše are the highest mountain range in our republic, but this is not the most important feature – what is more important is how high they are. Further mountain ranges – Šumava, Beskydy are only a little lower (by around 200 m), and yet they cannot boast of tundra conditions on their summits. The deciding factor is, by how much in our climatic conditions they rise above the montane zone, or in other words, the alpine upper tree line. This is where the Krkonoše Mountains excel, as the great majority of the area of tundra above the tree line can be found in Krkonoše, to a limited extent also in the Hrubý Jeseník Mountains and a tiny area on the summit of Mt. Králický Sněžník.

Krkonoše have one great advantage over all of the other mountain ranges: their specific geological conditions allowed for extensive areas of levelled surfaces to be preserved in two of their summit areas (eastern Krkonoše, western Krkonoše) to that, which forms the basic prerequisite for the development of tundra relief and the tundra phenomenon in general. These specific features include two belts of very hard rocks, which, during the long-term geological development of the mountains, slowed the headward stream erosion so much that it has not yet reached the springs of the main rivers, meaning that a very old type of relief, called a levelled surface (experts call it by the international term etchplain), has been preserved here. For this is how the whole surface of Krkonoše looked until the late Tertiary period – for clarity, let us imagine that

The four highest mountains in Krkonoše (Mt. Sněžka, Studniční hora, Luční hora, Smogornia)

The highest massif of western Krkonoše (Mt. Vysoké Kolo)

they appeared very similar to what we know today in the Českomoravská vrchovina Highlands.

The eastern Krkonoše levelled surface lies around 100 m higher than the western one. There could be two reasons for this: – either eastern Krkonoše was uplifted slightly higher during the Tertiary tectonic inversion, which gave the mountain range its current appearance, or with regard to the lesser role played by the hard rock belt in the western section, the headward erosion advanced more slowly. Or both of these factors could have come into play. In addition to the lower elevation, this could also be the result of the smaller area of the western Krkonoše summit etchplain.

A very important, and along with the tectonic uplift of the Krkonoše Mountains, the decisive factor for the current appearance of the tundra on the summits of Krkonoše was the contact aureole: a cause which formed much earlier, in the Upper Carboniferous, during the Palaeozoic Era, around 300 million years ago. At that time the granite pluton was formed, a massive, molten magma body, rising up from the Earth's interior. However, it did not manage to emerge on the surface, halting and solidifying at depth below the older rocks of the Krkonoše Crystalline Complex, nevertheless it formed the contact aureole as a "by-product". The effect of the high temperatures and pressure emanating from the molten granite magma metamorphosed the near-contact rocks of the crystalline complex in a belt around 1 km wide. One of the most important results of this metamorphism was that the rocks became harder and more resistant, partly because abundant beds of quartzite, one of the hardest minerals, originated here. As a result of the later, long-term denudation (removal)

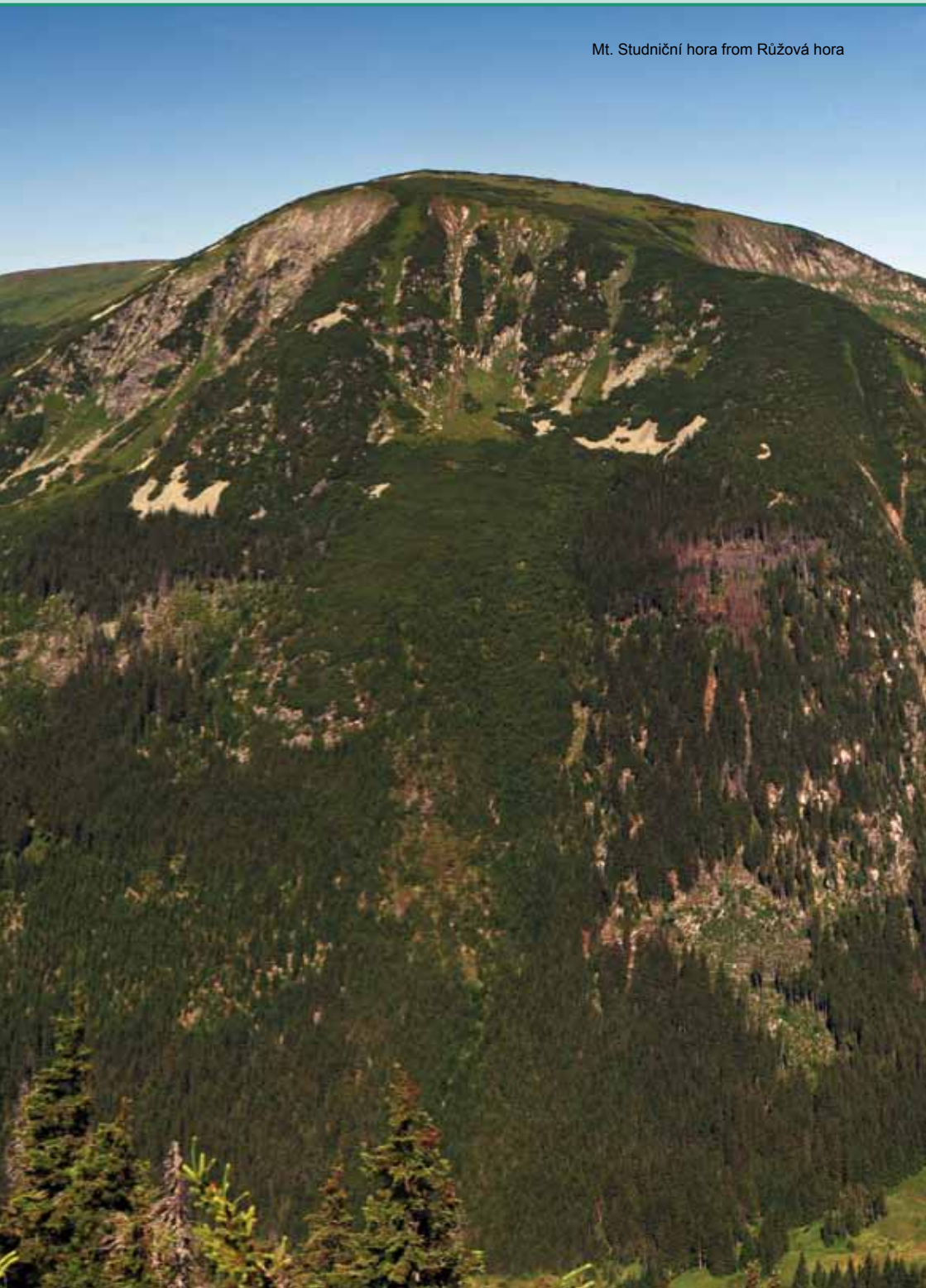
Mt. Sněžka from the Žlab Úpičky Gully

Mt. Studniční hora

the overlying rocks of the crystalline complex were carried away, meaning that the granite pluton and its contact aureole emerged on the surface. After the tectonic uplift of Krkonoše, when erosive forces increased rapidly, the hard rocks of the contact aureole resisted erosion much more than the surrounding mica schists and phyllites. This was the main factor which slowed the process of headward erosion towards the main Krkonoše mountain ridges, and allowed the preservation of extensive remnants of the levelled surfaces. It is just this paradox, in which the flattest parts of their relief are found on the summits of the mountains, which allowed for such perfect development of the montane tundra. In the majority of mountain ranges, especially those of younger, of fold origin, this is just the opposite – the higher you go, the steeper are their slopes and the sharper their peaks. This is, however, the very reason why mountains much higher than our Krkonoše, such as the Carpathians and Alps, show a lesser perfection in certain relief forms connected with the tundra climate.

In the eastern half of the mountain range, in addition to the contact aureole, there was one more cause, leading to the same result: a belt of hard orthogneiss, which had a similar retarding effect on the erosion. These orthogneisses most influenced the development of the relief in the Úpa river catchment.

In nature there is no such thing as "what if...?" but we cannot rule out that without the effects of these two factors, no montane tundra as we know it today could have formed on the current summit levelled areas. There could be much sharper ridges with steep slopes, which would greatly restrict the area of the tundra and prevent the development of many component parts and phenomena completely. This does not only concern the tundra itself, but also the mountain summits, especially the highest ones – Mt. Sněžka, Mt. Luční hora, Mt. Studniční hora and Mt. Vysoké Kolo, which could be much lower, but also have completely different shapes from the profiles we know today.



Mt. Studniční hora from Růžová hora

Mt. Sněžka (Śnieżka, 1,603 m)

Mt. Sněžka is not only the highest mountain in Krkonoše and in the Czech Republic, but in the continental part of Europe to the north of the younger folded mountains of the Alps and Carpathians. It is not only exceptional for its height, but also for its shape, modelling, and its diverse internal geological structure. For these reasons it is one of the most interesting and most valuable mountains in our country as a whole. Even its height has passed through changes – since 2014 the previously stated height of 1,602 m has been officially refined to 1,603 m. Looking back into history we can find German sources which give figures of 1,605 m, but also 1,603 m (when the peak was part of the Austro-Hungarian Empire, which measured height from the different surface level of the Adriatic Sea, but the difference is several decimetres), not to speak of the unrealistic data from earlier centuries (5,880 m according to Kryštof Schilling from the years 1563–1566, or 2,035 m according to Jiřík of Řásné from the year 1569).

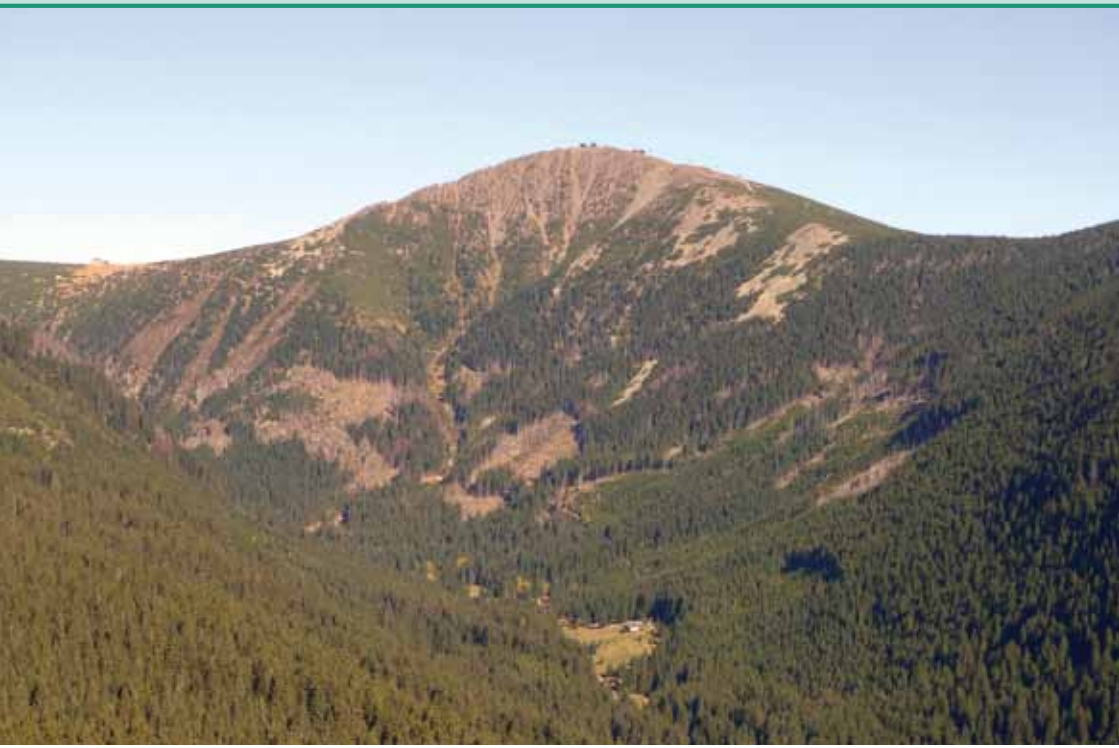
The fact that Mt. Sněžka stands so dominantly above its surroundings is due to its position directly in the area of the contact aureole, where the granite pluton meets the Krkonoše Crystalline Complex. The surroundings were lowered more rapidly by water and glacial erosion, but Mt. Sněžka itself has remained increasingly “protruding” above it.

Within the whole Bohemian Massif, Mt. Sněžka with its three-sided pyramidal shape, rising high above its

surroundings is also an exceptional landform. It is a carling type of peak, which is typical for high-mountain regions, but is the only mountain of this shape in the Czech Republic. The name carling is derived from the cirques or corries (glacial cirques), because it was modelled into its pointed shape by headward erosion by glaciers from more directions. Mt. Sněžka was only shaped by glaciers from two sides (not from three sides, as previously stated), the glacier in the Obří důl Valley from the west and the Łomniczki glacier from the north, making it an imperfect carling. Considering the lower elevation of the Krkonoše Mountains it is also not as rocky as peaks we know from the high mountains (such as the Alps). It rises high above the upper tree line and it is also clearly visible that each of the three slopes is absolutely exceptional. Even this feature is something that is not often seen in our republic. The northern slope running into Poland is covered by a monolithic boulder field, one of the largest in Krkonoše, the formation of which was facilitated by its "cold" north-facing orientation. This boulder field was formed by frost-induced disintegration of the bedrock. On the slope falling into the Obří důl Valley the frost weathering is less advanced due to its south- and south-east facing orientation. Narrow strips of rocks of contrasting hardness run parallel to each other down the slope, and therefore downslope ridges developed on harder rocks alternate with extensive talus fields developed on less resistant rock. As these lines spread out in a fan shape as they run downhill, this place is aptly known as the "giant Krakonoš's Glove". Lower down, this slope passes into the Rudná rokle Ravine, which is one of the most steep-sided valley forms in

all of Krkonoše; in its upper section it has the character of a rock incision with numerous waterfalls and rapids, while the lower slopes are covered by an extensive alluvial cone. Even this is a unique shape in the whole republic and is very similar to the ravines we know from the high mountains. Therefore, we call these "alpine-type" landforms – The Rudná rokle Ravine is the most typical valley form of this kind in the republic. The eastern slope of Mt. Sněžka is also covered in talus, but because it has the most gentle slope gradient and was not glaciated – at least in the last ice age – the sorting ability of frost processes took priority due to the lesser effect of gravitational forces. These processes led to the formation of a system of several cryoplanation terraces above each other. The slopes of Mt. Sněžka towards the Obří důl Valley and especially towards the Úpské jámy Cirques are one of the most important localities for the formation of mudflows (debris avalanches, also called muras), which belong to the largest (in length, width and volume) in the Czech Republic. The greatest number of mudflows took place during the floods in 1882 and especially in 1897, when it even wiped out two mountain chalets and killed 7 people. Despite their age, the avalanche runs are clearly visible and are a textbook example of how slowly the montane nature renews itself after various catastrophic episodes.

In addition to its exceptional diversity of surface landforms and processes, Mt. Sněžka also has a great "internal" wealth. In the space below its slope ridge called Rudník the emplacement



of granitic magma was accompanied by the formation of an ore body of the skarn type. At first the hot solutions from the molten magma dissolved the beds of carbonate rocks and then the ores of various metals were deposited in their place. Arsenic, copper, iron, and most recently tungsten, were extracted here over several centuries. The mining lasted for several centuries (with breaks) until the mid-20th century. The mining left behind a number of small old mine workings which are visible on the surface, as well as an extensive underground labyrinth on 5 levels with a total length of more than 7 km. The mine workings represent a very important mineralogical locality, which is famous for its scheelite, rose quartz and crystal quartz; although in previous decades it was plundered by collectors for commercial purposes.

The dominance of Mt. Sněžka has attracted people since time immemorial, with all of man's negative impacts on the nature. Land ownership disputes on the border led to the construction of a chapel on the summit, which was consecrated in 1681, making it the first larger structure to be built on the summit areas of Krkonoše. Other structures which were built later are the chalets of Česká bouda and Slezská bouda, a meteorological station, as well as access roads and paths. Logically, this was all at the expense of nature; the summit plateau was most affected, as it was transformed into a trampled and bare rocky plain without vegetation. The highly endangered speedwell *Veronica bellidioides*, which currently has its only locality in the Czech Republic here, suffered the most from these developments.

Mt. Luční hora (1,455 m)

Mt. Luční hora is the second highest in our republic (although the neighbouring Mt. Studniční hora was long considered to be higher), but the same is true here as on Mt. Sněžka; its value is much more than just its absolute height, but is in the wealth, diversity and uniqueness of its nature. Both of these mountains are among the most valuable and most exceptional features in the whole of our republic and we should not compare them in an imposed order. This would be like the proverbial comparison of an apple and a pear; each of them is different and is more valuable and exceptional in different ways.

In a similar way to Mt. Sněžka each slope of the mountain is different. As the mountain is triangular in plan view, there are only three slopes. The long, south-western flank, falling into the Dlouhý důl Valley, is of erosional origin and is by far the highest one. It is divided by three short slope valleys (Hrazený důl, Lovecký důl and Pramenný důl), typically with steep gradients, which is the reason why they contain numerous waterfalls and cascades, but also suffer from mudflows (debris avalanches) and contain some of the longest avalanche runs in Krkonoše. The less steep south-eastern slope, being the leeward slope in terms of anemo-orographic systems, is typified by its deep snowbeds, which often remain long into the springtime. The northern slopes falling to the Bílá louka Meadow are the lowest and have the smallest gradient, but are extremely interesting from a geomorphological perspective.

The mountain is part of the contact aureole, so it is built of schists with quartzite intercalations. In contrast to the pointed Mt. Sněžka it has a relatively extensive, flat crown. This flat summit, together with the gentle nature of the slopes, particularly the eastern and northern ones, allowed the optimal frost-induced sorting processes to take place here. Frost can rip rocks apart, but can also transport and sort the rocky weathering products by the effect of ice in the soil. The long-term effects of frost lead to the formation of cryoplanation terraces, dividing the slopes along horizontal lines, which

resemble step pyramids. These terraces have steep frontal slopes (called frost scarps) and flat upper parts (cryoplanation plateaus). On the slopes of Mt. Luční hora they have formed a complete multi-level system, which represents the best example of this phenomenon, not only in the Czech Republic, but also in all of Europe, with the exceptions of Scandinavia and the Northern Urals.

Larger fragments of weathering products are more exposed to the effects of ice lenses in the soil, and are more exposed to greater pressure from the ice, due to the long-term and repeated freeze and thaw cycles. This causes the various fragments of weathering products to gather together, the larger pieces are transported away, while the smaller fragments remain where they are. In this way, polygonal structures form in the surface layers of skeletal soils with soil and small rock fragments in the centre and a “fringe” of coarser fragments around the edges. They often form whole groups of polygons and where the rocky edges of neighbouring polygons meet, the surface is often raised. Experts call these polygonal soils (or soil polygons) and in their most perfect form they resemble a bee hive. They develop on flat surfaces and on Mt. Luční hora we can find them on the summit plateau and on the top plateaus of the cryoplanation terraces. In the current climatic conditions they are often partially or fully overgrown by vegetation (especially grasses), making them less distinctive. However, on gentle slopes gravitation is starting to play a role during the phase of melting of the soil ice,

meaning that the polygons are stretching out on the downhill side. This is how the stone stripes (or striped ground) are formed, and on Mt. Luční hora they are the most developed in our entire republic. On the steeper northern slopes of the mountains, where solifluction (flow of thawed slushy soils over the frozen bedrock) is the strongest, we can also find solifluction mounds and tongues of the weathered material; the largest of them was misidentified in the past as a rock glacier.

All of the forms described above generally belong to the most typical forms for the tundra (sub-polar) climate. However, the question which has not been clearly answered yet is, whether the stone polygons and strips in Krkonoše only contain fossil evidence from the end of the ice ages, or whether their development continues, at a lesser intensity, to the present day.

Josef Sekyra, our greatest expert on cryogenic geology and geomorphology described the northern slopes of Mt. Luční hora and the adjacent Bílá louka Meadow as previously covered by a small summit (fjeld) glacier, the only one in this country. However, other researchers believe that it was unlikely, and the whole issue requires further studies. In any case, the complex of all of these forms and processes makes Mt. Luční hora unique, not only in our republic, and we can consider it to be our “most tundra-like” mountain. The local combination of the climatic and soil conditions is also significant for the vegetation conditions. Mt. Luční hora can also boast a number of hawkweed species, some of which are endemic.

Mt. Studniční hora (1,544 m)

Mt. Studniční hora was long considered to be the second highest mountain in Krkonoše, but after detailed remeasuring in 1995 it changed positions with Mt. Luční hora. It was very close as their heights only differ by one metre. Both mountains, especially their summit areas, have much in common, but they also differ in several respects. The geological conditions are identical as both summits are formed by rocks of the contact aureole, i.e. schist hardened by temperature and pressure metamorphism, and primarily by the beds of quartzite. From a geomorphological perspective what is important is their contrasting position within the anemo-orographic system. The slopes of the more easterly Studniční hora fall towards the Obří důl Valley, the deepest glacial valley in Krkonoše. Therefore, behind its massif there are strong downdrafts and wind turbulence, depositing massive amounts of snow, which gradually changes into firn and ice. Thus there are three kinds of cirques to be seen on this mountain: the main Úpská jáma Cirque and the pair of hanging cirques Velká Studniční jáma and Malá Studniční jáma. They are divided by the rocky Čertův hřebínek (Devil's Comb), built of the hardest rocks in the contact aureole. It runs from Mt. Studniční hora and is one of the several most perfect alpine-type landforms in the whole of Krkonoše. In the upper part of the Lavinový žlab Gully in the Úpská jáma Cirque we can find a curved bank of rocks, which experts call a protalus rampart. This bank of rocks formed at the head of a snow bed from rocky material which fell from the higher-lying rocky slopes. In this country these can only be found in Krkonoše and even here there are only a few of them, meaning that this is the largest one.

The actual summit elevation of the mountain is modelled in a very similar way to Mt. Luční hora. Several levels of cryoplanation terraces can be seen (the most perfectly formed are on the western slope towards the Modrý sedlo Saddle) and polygonal soils are developed on flat areas, especially on the actual summit area. However, furrowed soils are not found here. Mt. Studniční hora also has one disadvantage. It has much more extensive growths of dwarf pine scrub than Mt. Luční hora and its cryogenic forms are more often lost in the pine scrub. If we consider the possible recent development of these landforms, we cannot rule out, that the root systems of the pine scrub effectively block them.

The southern slopes of the summit area are covered by an extensive boulder field. On these slopes we can admire the largest and most important snow bed in the whole of Krkonoše, known as the "Map of the Republic", where the depth of the snow can be up to 15 metres in some years. Therefore, the snow very often remains here until summertime, in optimal cases until August. At the same time, the paradox is that it lies on a south-facing slope; most snowbeds form on north-facing slopes, or in places which are sheltered as a result of local conditions. This is one of the consequences of the anemo-orographic system. The most frequent winter winds blow from the north-west across the lower section of the ridge at the Modré sedlo Saddle and deposit exceptional amounts of snow on the leeward side in the area called the Map of the Republic. In the spring the snow transforms into firn and subsides down the slope under its own weight, which has such an erosive effect on the bedrock that shallow nivation depressions have gradually formed here. After the snow melts every year we can observe small movements of the weathering products on the floor of the depressions. These movements are facilitated by the fact that, on the areas where the snow lays the longest, the vegetative season is very short, meaning there is only sporadic vegetation, or that the vegetation is missing. This is the best example of recent snow erosion in the Czech Republic. The name of the snowbed comes from the fact that at certain phases of melting, the snow bed has the shape of former Czechoslovakia. Thanks to its unique character, this locality is the subject of regular monitoring by staff from the KRNAP Administration.

On the north-western slope of Mt. Studniční hora is the spring of the Růžencový potok Stream, which largely flows as a series of oval-shaped pools with soil and vegetation dams. The beaded stream form was described for science and terminologically determined for the first time in our republic here. Beaded streams are one of the typical phenomena for montane and subpolar tundra. Around the near springs of the Bílé Labe and Úpa rivers we can also find subterranean streams in the peat – sections of underground flow, accompanied by depressions, "ponors" and "resurgences". These are also characteristic forms on a tundra raised peatbog.

The southern and eastern slopes of Mt. Studniční hora are among the most active avalanche runs and the avalanches falling here are among the largest in Krkonoše. The well-known avalanche running down from the Map of the Republic into the Modrý důl Valley can be so large that it can run up the opposite slope.

Stříbrný hřbet (Smogórnia, Srebrny Uplaz, 1,490 m) a **Čertovo návrší** (1,471 m)

Due to its huge summit area the peak of Stříbrný hřbet (Smogornia) is perhaps the least pronounced and conspicuous among the Krkonoše peaks, but still represents the fifth highest elevation of the entire mountain range. Most visitors do not even regard it as a separate mountain. It represents a very extensive (the summit "plateau" has a diameter of over 1 kilometre), but extremely flat elevation with gentle slopes capped by the north peak on the etchplain of eastern Krkonoše along the line of the state border. The slightly lower elevation of Čertovo návrší extends to the southwest and has the same character.

In contrast to Mt. Luční hora and Mt. Studniční hora, which delimit this plateau in the south, it is made of granitic bedrock. This is clearly the reason why no complex of cryogenic forms has developed here, unlike on the other summits. On the other hand, some of these forms may exist, but are hidden under quite extensive areas of dwarf

pine scrub. On the southern slopes on the Čertova louka there is a shallow nivation depression, which some experts think could have been part of a summit glacier. On the slopes of both elevations, especially on the east-facing slope of Čertovo návrší we can find the greatest locality for wandering boulders in Krkonoše. These are isolated boulders, which were moved down the slopes due to solifluction, and are still moving today. They represent one of the most striking of the recent frost processes on the ridges of Krkonoše. On peatbogs and peaty soil on slopes and at the foot of slopes, the tiny streams form many subterranean sections, with imperfect beaded streams in places. In the area of the spring peatbog called Stříbrná bystřina (Mlaki) we can find flat hummock forms, reminding us of palsas in the Arctic, which form due to the uneven freezing of the peat. On the southern slopes of Čertovo návrší towards the Důl Bílého Labe Valley there is a boulder field and small boulder flows.

Mt. Malý Šišák (Mały Szyszak, 1,439 m)

The rather isolated Mt. Malý Šišák is the westernmost extremity of the Eastern Krkonoše summit tundra. Among the levelled surfaces (etchplain) areas, its distinctively pointed shape is quite unusual, but is due to the bedrock of harder fine-grained granite. As a result of frost weathering processes the original rocky outcrops have completely broken up, so that the whole of the summit is covered by an extensive boulder field. Neither the pointed shape of the mountain, nor the large blocks and boulders without soil are favourable for the creation of frost-induced soil forms, which are absent here. Only the actual summit elevation could be considered to represent an imperfectly developed cryoplanation terrace, which has also contributed to the asymmetrical form of the mountain, and after which it is named the "Little Cone". The eastern slopes, with the nivation depression called Čertova jáma, are the steepest.

Kozí hřbety Ridge (1,318–1,422 m)

It represents the most striking ridges in Krkonoše, but given the absence of a flat summit area, it is not a direct example of the tundra relief, but is the most extensive alpine-type landform in the entire mountain range climatically comparable with the tundra.

Along the three-kilometre length of the summit section and the relative height of the slopes of up to 500 m, the ridge is characterised by its rugged summit area and, along with the Čertův hřebínek Ridge, it is the only one in Krkonoše with a roof-like shape, which is usual in younger, folded mountain ranges, such as the Carpathians and the Alps. The reason for the formation of such an unusual montane landform is the peculiar development of the hydrological network in their surroundings. The most common type of streams in the mountains are those which flow from both sides of mountain ridges straight down into the valleys (experts say they flow consequently). However, under the influence of certain tectonic factors, or as a result of the differing hardness of the rock types, it can happen that the streams and rivers flow parallel to the mountain ridge (experts say they flow subsequently). Such cases are much less frequent. A Krkonoše "speciality", which we cannot find in other mountain ranges in the Czech Republic, is that four of the large valleys within the summit area, the Mumlava Valley, Labský důl and Dlouhý důl Valleys and the Důl Bílého Labe Valley, are subsequent. The flows in the latter two (Bílé Labe and Dolský potok),

which flow all the way along either side of the Kozí hřbety Ridge, have contributed to its exceptional shape. This is because both streams flow across bedrock of less resistant rocks, allowing them to deepen more rapidly. In contrast, the Kozí hřbety Ridge, which follows the aforementioned contact aureole of hard rocks for their entire length, has only suffered from minimal erosion, meaning that it has gained in prominence between the two valleys and continues to "stick up" higher into the sky. The rugged profile of the summit line of the Kozí hřbety Ridge is further complemented by numerous, but small, rocky outcrops.

The Kozí hřbety Ridge runs out from Mt. Luční hora, and thus in accordance with the direction of erosion, its height decreases towards the west. Thus, the high-mountain characteristics, which are closely connected with the tundra phenomenon, can be found on its higher eastern half, especially between the Lavinova jáma Cirque and the Hrazený důl Cirque. The effects of frost weathering can be seen in the breakdown of the rocky outcrops and the formation of extensive boulder fields, which mainly cover their southern slopes, especially around the Tetřeví žlab Gully. Both of these slopes are also known for their snow avalanches and mudflows (debris avalanches). In 1994, the Lavinova jáma Cirque on the northern side of the ridge witnessed one of the last landslides to fall on the Czech side of the mountain range, which even destroyed the hiking trail through the Důl Bílého Labe Valley.

Mt. Kopa *(1,377 m)*

The only summit on the Eastern Krkonoše etchplain which lies entirely on Polish territory. Despite its low prominence, it is characterised by its exceptional asymmetry. To the west it follows on from the etchplain, above which it only rises a little, but to the east it falls via high and very steep slopes into the Dolina Łomniczki, the largest glacial valley in the Polish part of the Krkonoše Mountains. This slope is the most significant locality for the formation of mudflows on the Polish side of the mountains, which have formed here in the past and still do.

Mt. Svorová hora *(1,411 m) a* ***Obří hřeben Ridge*** *(Czarna Kopa, Czarny Grzbiet)*

To the east of Mt. Sněžka the Slezský hřbet Ridge starts to fall and tundra conditions can only be found as far as the Obří hřeben Ridge, culminating at Mt. Svorová hora. Their summit areas are covered by stone-dominated weathering products, which pass onto the slopes too. Especially on the northern side towards Poland they form extensive boulder fields, which are a continuation of the even more extensive scree slopes on the northern side of Mt. Sněžka. In some areas, especially on the Czech side, they have a higher soil content, which allows them to become more intensively overgrown by dwarf pine scrub.

The most valuable landforms on the Obří hřeben Ridge are the structured, frost-sorted soils on the flat crown areas, which have a different form here. The polygons have a minimal soil content and thus here the angular blocks are radially oriented and mostly standing with their long axes upright, so that the view from above reminds us of the flowers of a rose. This modification of the soil structure in Krkonoše can only be found here. Which makes it a greater shame is that during the years at the turn of the 21st century, when vandals started to build large numbers of “stone men” for no

particular reason, they often dismantled these unique forms and irretrievably damaged, and even destroyed, some of them.

In the climatic sense there are conditions very similar to the tundra on the highest summits of some of the Krkonoše spurs (side ridges).

On the Černohorská rozsocha Spur this concerns Mt. Zadní Planina (1,423 m) and Mt. Liščí hora (1,363 m) and on the Růžohorská rozsocha Spur this is Mt. Růžová hora (1,398 m). However, the spatial isolation from the main summit etchplain with typical tundra and the slightly lower elevations means that the summit areas of these spurs are mostly, or almost completely, covered by dwarf pine scrub. The boulder fields and cryoplanation terraces are now hidden under this pine scrub, which provides clear evidence that tundra conditions also prevailed here during some periods in the past.

Further evidence is provided by the cirque-like and nivation depressions on their leeward slopes (Liščí jáma Cirque and Vlčí jáma Cirque by Mt. Liščí hora, Vasova jáma Cirque by Mt. Růžová hora).

Mt. Vysoké Kolo *(Wielki Szyszak, 1,509 m)*

Although Mt. Vysoké Kolo is only the fourth highest mountain in Krkonoše, it holds several records and is characterised by certain specific features. The three highest peaks are all in the eastern section of the mountain range, which makes Mt. Vysoké Kolo the highest peak in western Krkonoše. It is also first among the summits located beyond the contact aureole of hard rocks. Nevertheless, its height is related to the hardness of rocks, as it is built of fine-grained granites, which are harder and more resistant than the surrounding medium-grained granites.

It is also very interesting from a geomorphological perspective. The ice ages made a great contribution to the current appearance of the mountain. Then, extensive boulder fields were formed by frost-induced rock disintegration. They cover the majority of the mountain slopes and belong to the largest in Krkonoše. These differ in appearance from other boulder fields on schists. Due to its blocky disintegration, granite breaks down into much larger fragments, of boulder size, meaning that the surface of the talus is wavier and appears more chaotic than boulder fields on schists.

The most striking relief form, which was created in the ice ages, is certainly the Wielki Śnieżny Kocioł (Velká Sněžná jáma) Cirque on the north-western slopes of the mountain. This represents the most perfect glacial cirque in the whole Krkonoše range, with the rockiest cliffs of more than 200 metres in height. At their foot the cliffs pass into

extensive rocky talus piles, which, under larger grooves in the rocks, are sometimes modelled by stream erosion in a similar way to mudflows. The Wielki Śnieżny Kocioł is separated by the narrow Grzęda rocky ridge from the second cirque Mały Śnieżny Kocioł (Malá Sněžná jáma), which stands outside of the massif of Mt. Vysoké Kolo, but cannot be excluded as they are closely related. The slope glaciers which formed in both cirques joined together further down the slope and deposited massive moraines on the slopes, most of which are now hidden in the forests. If we look from the upper rim of the cirque down to the floor of the Wielki Śnieżny Kocioł we can see the last recessional moraine, which has a "text-book" shape in the form of a curved bread roll and represents the most perfectly preserved Krkonoše moraine. There is a specific reason why it is so perfectly preserved. Due to the deep accumulation of boulders on the floor of the cirque all of the surface water disappears underground and there are no surface flows which could disturb and erode the moraines during the postglacial period. This is the case with nearly all of the Krkonoše moraines, which are more or less disturbed and carried away by later erosion, as unconsolidated glacial till is very easily disturbed and also carried away. The surfaces of the main moraines on the slopes are chaotically wavy and the floors of certain depressions are sealed by fine-grained weathering products, or by organic materials, which means they are flooded by precipitation runoff. Several small pools, known as Śnieżne Stawky and Młaki, were formed in this way. They are mostly shallow, so that the same vegetation which participated in

their formation also brings about their gradual demise, because they gradually become overgrown and change into small mires and peatbogs.

The neighbouring Mały Śnieżny Kocioł (Malá Sněžná jáma) is not as rocky, but can still boast of another unique feature, which is a basalt dyke. This young igneous rock was emplaced in relatively near past in the Late Tertiary, during the tectonic movements which uplifted the whole of Krkonoše. This dyke holds another Krkonoše record, as it is the highest volcanic body in central Europe. This dyke is famous as a botanical locality, because it represents an island of basic bedrock, which is much more favourable for plants than the surrounding acidic granites (and also the schists). In addition to the species diversity (here we can find the largest number of plant species in Krkonoše), it also plays host to some completely unique species (endemic sub-species basalt musky saxifrage, or the glacial relict alpine saxifrage – at its only locality, not only in Krkonoše, but in all of central Europe, or the alpine woodsia, also growing at a single site in Krkonoše and also very rare). This basalt dyke is also of importance from a geomorphological perspective. Basalt is a resistant rock type, but as it breaks up into tiny fragments, it submits to erosion much faster than the surrounding blocky-disintegrated granite. Therefore, along the line of the basalt dyke a downslope-elongated ravine (Żleb Bazaltowy) was formed with an alluvial cone at its lower end. The cone is built mainly of basaltic material and, as such, it also poses a site of high plant diversity. The face of the basaltic ravine also shows columnar jointing, which is typical for this rock type.

The Czech side of Mt. Vysoké Kolo was not as suitable for the creation of a glacier as the shaded and cold north side. Nevertheless a glacier did form in the Martinova jáma Cirque on the leeward, south-eastern slope. It left behind a shallow amphitheatre-shaped form, which is more reminiscent of a nivation depression than a true cirque.

During the ice ages, most of the summit of Mt. Vysoké Kolo was a deflation surface, from which snow was blown away, meaning that it was exposed to intensive freezing processes. At that time the spaces between the boulders were filled with ice, and therefore the boulders were moved and transported according to size. This led to the

formation of a several-storey system of cryoplanation terraces, which, together with those on Mt. Luční hora and Mt. Studniční hora, are the most perfect in Krkonoše. They are best visible on the eastern side of the mountain, when viewing from the Mužské kameny Tor or Ptačí kámen Tor. In the boulder fields we can even find several rock basins, which are relatively rare in free standing boulders. On the boulders on Mt. Vysoké Kolo we can also observe examples of how freezing processes are currently taking place, of course at a much lower intensity than in the ice ages. Witnesses to this freeze-thaw process are the "freshly" split boulders (most often along joints) which have sharp edges, unlike the boulders in other boulder fields with more or less rounded edges. The highest cryoplanation terrace, forming the summit "hump" of the mountain has its upper plateau covered with a network of radially spreading frost-sorted soils.

On the Polish, northern slopes of Mt. Vysoké Kola above the green hiking trail we can observe a massive, rather unusually emerging pile of granite boulders. Polish geomorphologists consider this to be a slope rock glacier. This is a landform, which developed in the ice ages, in places where not enough snow was deposited to create a real glacier. The proportion of rock and ice content was about 50:50, but it was sufficient for the glacier to move down the slope under the influence of gravity. After the last ice age ended the ice melted and only the rocky elevation remained, meaning that these are only fossil landforms in our mountains.

On the summit, which is not open to the public, there is a partially collapsed stone monument. It was built in honour of the German Emperor Wilhelm I in the second half of the 19th century, at a time when the German (Prussian) border ran over the summit here.

Mužské kameny Tor *(Czeskie Kamienie, 1,417 m)*

Mužské kameny refer to two different objects: it is the name of one of the peaks on the Slezský hřbet Ridge as a whole, but it is also a particular rocky outcrop on its summit. It does not belong to the eye-catching and prominent peaks, but the rocky outcrop makes this a famous mountain too. Typologically, a castle koppie is a rocky cliff or barrier, genetically of the same origin as the popular tors, but due to the robustness and compactness of the rocky outcrop this landform was given a specific term. Together with Violík it belongs to the most perfect tors of this type on the main Slezský hřeben Ridge in Krkonoše. The castle koppie is elongated in downhill direction, but in comparison with Violík, it is at an earlier stage of disintegration. This means that it has a less extensive pile of weathered boulders at its foot; larger ones are only found on the western side. The head of the castle koppie is even more "spiky" thanks to the fracture system of granite with a great dominance of horizontal cracks in two directions. The whole landform also includes a small cliff next to the hiking trail, which on the other hand, is a low tor.

Dívčí kameny Tor *(Śląskie Kamienie, 1,413 m)*

Less than half a kilometre from the head of the Slezský hřbet Ridge we can find Dívčí kameny. The situation is similar in that this is the name for a separate mountain peak, and also for the rock formation on its summit. Despite the short distance it is of a different type than Mužské kameny. Dívčí kameny are a combination of an elongated castle koppie and typical narrow, pillar-like tors. Dívčí kameny also differs from Mužské kameny in the joint system in the rocks, in which the horizontal, "bedding-parallel" joints predominate, and tabular disintegration plays the main role. These rocks form two groups, of which the group to the west is larger, taller and more rugged than the eastern group. Approximately half way between them and near the hiking trail is the so-called "Krakonošova hrobka – giant Krakonoš's Grave". This is a very flat rocky outcrop, which is markedly dissected by vertical and especially sub-horizontal joints, with straight joints surrounding a hollow, reminding us

of a grave. This feature has its origins towards the end of the ice age as a result of ice in the fissures which opened and widened the horizontal joints, while on the other hand the tabular blocks were transported along the sub-horizontal joints. Dívčí kameny is one of the few summit tors in Krkonoše, which can boast that it has rock basins: round, bowl-shaped depressions, which are of natural origin. At the beginnings of scientific study, these landforms, with their regular shapes and sometimes also drainage grooves, were considered to be artificial creations, used for pagan sacrifice ceremonies. This term was even adopted by the German language, which uses the name Opferkessel (sacrifice bowl).

The northern slopes of Dívčí kameny are covered by extensive boulder fields, which are overgrown by patches of dwarf pine scrub. Lower down the slope on the Polish side of the border there is another smaller castle koppie called Małe Śląskie Kamienie.

Mt. Violík (Labski Szczyt, 1,472 m)

This small but distinctive rocky knob on the Slezský hřbet Ridge on the line of the state border is, together with Mužské kameny, the most typical example of a castle koppie in the tundra section of Krkonoše. The summit consists of a solitary jagged rocky outcrop with distinctive jointing of granite. However, it is in a relatively advanced state of disintegration to destruction. The fundamental role was played by the dense network of vertical or sub-vertical joints, which allowed water to penetrate deep inside and accelerate the disintegration of the rocks by frost wedging. The large number of boulders created in this way constitute a ring of slope-base piles of angular boulders around the foot of the tor on the summit. The most extensive piles are on the west and north sides, thereby documenting the influence of directional exposure on the intensity of the frost weathering processes. On the western side we may observe signs of further frost-induced sorting in the form of imperfect cryoplanation terraces. The boulders in these accumulations are also broken down by continuing frost weathering processes. These progress along the joints, and are confirmed by the sharp edges of some of the boulders. This peak stands next to the Cesta Česko-polského přátelství (Czech-Polish Friendship Trail), from which these forms may be seen in detail. A so-called stone glacier – a slope accumulation formed in the ice ages by a mass of weathering products and ice in approximately equal proportions – has been described from the nivation depression of Łabski Kocioł in the slopes on the north side of Mt. Violík. However, this genesis is disputable and requires further study.

Mt. Szrenica (1,362 m)

This peak, together with the less prominent Mt. Śmielec, is the only summit on the western half of the Slezský hřbet Ridge, which stands completely on Polish territory. It is also the terminus of the tundra zone on the western Krkonoše etchplain along the line of the Slezský hřbet Ridge. Probably it originally had the appearance of an extensive castle koppie, most of which has disintegrated due to frost weathering. This is why the majority of the summit area is now covered by a boulder field, but on the upper slopes there are only small rocky outcrops (in addition to the Szrenicka Skała on the summit, they are mostly found on the eastern and south-eastern slopes), although further down the slopes we can find isolated castle koppies and tors on the Polish border (Svinské kameny), but also on the northern side (Końskie Łby). However, in the ice ages the summit of Mt. Szrenica represented a deflation surface, thanks to which the westernmost of the great nivation depressions on the Slezský hřbet Ridge – Szrenicki Kocioł – was created on the eastern side. The view from the Polish side offers us the chance to see one of the most striking and dominant peaks in Krkonoše. Directly on the summit there is a tourist chalet, which also serves as the meteorological observatory of University of Wrocław.

Mt. Kotel *(1,435 m)*

Most of the summits on the western Krkonoše tundra stand on the Slezský hřbet Ridge, but three of them can be also found on the Český hřbet Ridge. In this sense the two main tundra areas are back-to-front – the eastern Krkonoše tundra has all of its main summits, except Mt. Sněžka, on the Český hřbet Ridge, whereas the western Krkonoše summits stand on the Slezský hřbet Ridge. The highest of the three summits is Mt. Kotel. Its name is apt as its regular summit area really reminds us of an upside down cauldron. As with most of the main Krkonoše peaks, its slopes are not equal, even though the slopes on two sides are mostly gentle, passing down to the surrounding levelled surface (etchplain). Given the height of this mountain it is surprising that a more perfect system of cryoplanation terraces did not develop here. They can only be found on the northern slopes and in comparison with other described peaks they are of an imperfect nature.

On the contrary, the eastern slope is formed by the steep and partly rocky slopes of the Velká Kotelní jáma Cirque and Malá Kotelní jáma Cirque, which are the highest glacial erosion landforms to originate mostly from schists. They are separated by the Kotelský hřebínek Ridge which is a structural landform conditioned by the presence of a belt of hard rocks. The fact that this also represents a geological anomaly, is confirmed by the existence of an old mine in its upper section. These are the highest mine workings in the Czech Republic, and consist of a surface pit and two short galleries. Mining only took place here for a short time due to the climatic and relief difficulties. Both cirques are also important botanical localities, showing some of the highest species diversity in Krkonoše.

Mt. Krkonoš (1,413 m)

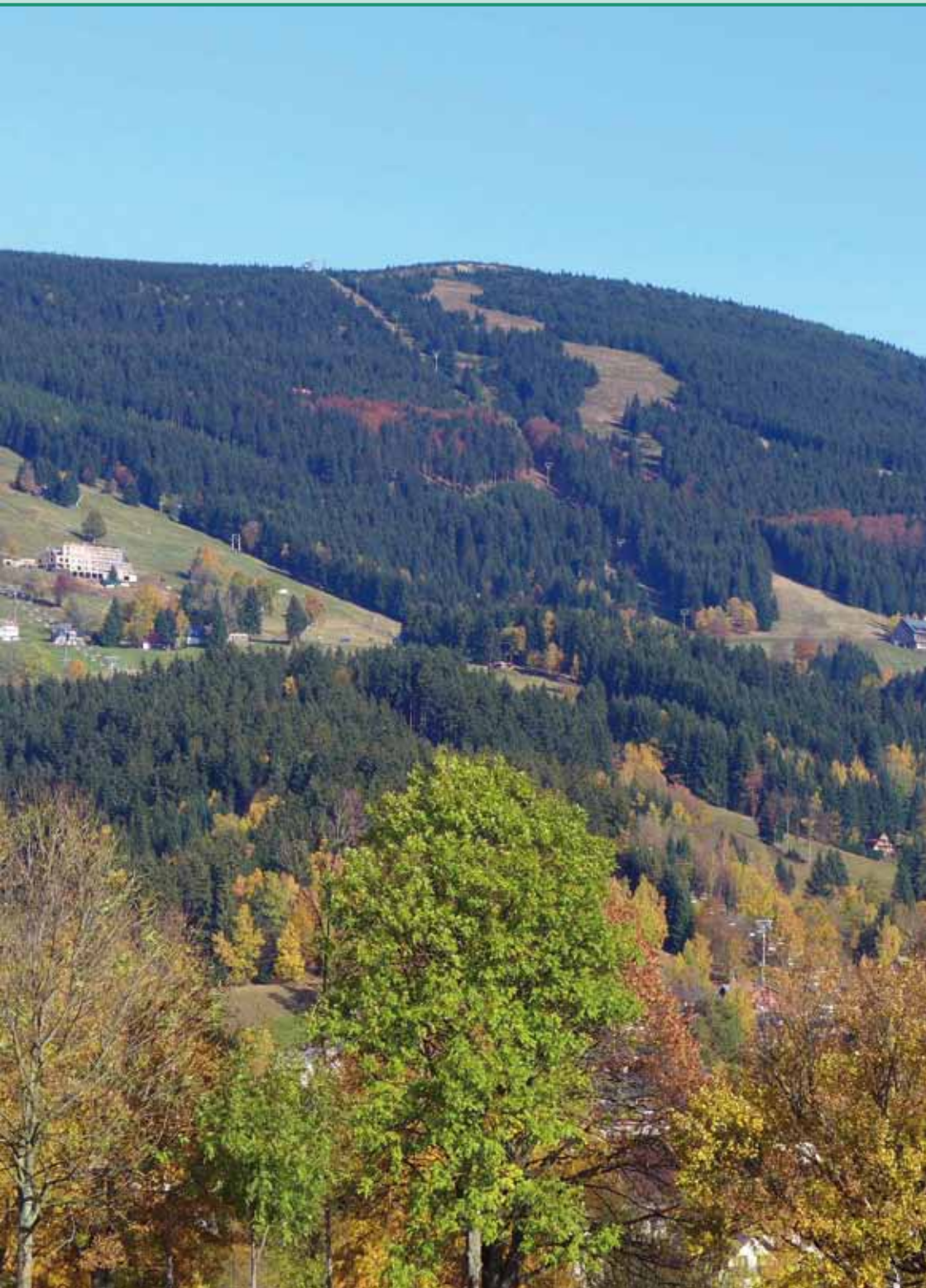
The south-eastern terminus of the western Krkonoše tundra runs along the narrow ridge of Mt. Krkonoš, which is a part of the Český hřbet Ridge along the line of the contact aureole. Thus, the hard rocks, primarily quartzites, also contributed to the creation and shape of this mountain. Mt. Krkonoš effectively has two summits: Vrbatovo návrší (1,413 m) and Zlaté návrší (1,411 m), before falling to the montane level at Medvědín. The landforms typical for tundra conditions which can be found here are the boulder fields, clearly visible above the access road. The conditions for the development of further frost-induced landforms were not very suitable, because the ridge is too narrow. The hanging cirque called Harrachova jáma, which is one of the rockiest cirques on the Czech side of the mountains, is incised into the northern slopes. At the foot of the cliffs we can find raised rocky mounds, known by experts as protalus ramparts. We could also call them snowbank mounds, as they form at the foot of snowfields as accumulations of rock fragments fallen from higher up the cliffs.

The summit area of Mt. Krkonoš is among the most affected by human activity, including the construction of the strategic road to supply the construction of the border fortifications built before the Second World War. The site of the car park was then mechanically graded. The summit was also damaged during the construction of the Jestřábí Boudy Chalets and Vrbatova bouda Chalet, as well as the stone cairn to commemorate Hanč and Vrbata on the summit.

Mt. Lysá hora (1,344 m)

Mt. Lysá hora is the last and westernmost spur of tundra on the opposite side of Mt. Kotel. It is only separated from Mt. Kotel by the very shallow Kotelské sedlo Saddle, above which it only rises less than 20 m, making it one of the least prominent summits on the main Krkonoše ridges. From a geomorphological perspective it has few distinctive signs indicating the influence of a tundra climate. Even the large amount and variety of talus, which accompanies most of the high summits in Krkonoše, is only found here in small amounts. Most of the area is covered by dwarf pine scrub, especially on the north side. The only cryoplanation terrace is also on the north side, but is hidden deep in the pine scrub.

The summit is accessible via the controversial chairlift from Rokytnice nad Jizerou, with two connected downhill ski runs, which are in conflict with the interests of nature protection. The chairlift is also subject to the long-running disputes concerning its use in the summertime, and potentially endangers the whole western Krkonoše tundra ecosystem.



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Peaks of the Krkonoše Tundra

Published by the Krkonoše National Park Administration in 2016
Text: Vlastimil Pilous
Photography: Kamila Antošová, Radek Drahný, Jiří Dvořák, Simona Macháčková, Vlastimil Pilous, Lubomír Sklenár

Printed on recycled paper.

ISBN: 978-80-7535-040-4

PILOUS, Vlastimil. *Vrcholy krkonošské tundry*.
Vrchlabí: Správa KRNAP, 2016. ISBN 978-80-7535-040-4.