PERIGLACIAL LANDFORMS IN THE POHORJE MOUNTAINS

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Abstract
Contrary to the well-studied Pleistocene glaciation, periglacial phenomena in Slovenia have been given less scientific attention because they are not particularly evident in high mountains due to prevailing carbonate rocks. This, however, is not the case in the Pohorje Mountains: built of igneous and metamorphic rocks, it was not glaciated due to its insufficient elevation, but was subject to periglacial processes. In the article, some of the periglacial landforms of the Pohorje Mountains are presented for the first time, especially nivation hollows in the uppermost zone, and the Jezerc cirque where a smaller glacier, unknown until recently, existed at the peak of the glaciation.

Key words: geomorphology, periglacial landforms, glaciation, nivation hollows, cirques, Pohorje Mountains, Slovenia.

PERIGLACIALNE OBLIKE NA POHORJU

Izvleček
Za razliko od dobro raziskane pleistocenske poledenitve so periglacialni pojavi v Sloveniji slabo preučeni, saj zaradi prevlade karbonatnih kamnin v visokogorju niso posebno opazni. Drugače je na Pohorju, zgrajenem iz magmatskih in metamorfnih kamnin, ki zaradi premajhne višine ni bilo poledenelo, pač pa so bili aktivni periglacialni procesi. V članku so prvič predstavljene nekatere periglacialne oblike na Pohorju, predvsem nivacijske kotanje v vršnih delih, in krnica Jezerc, v kateri je ob višku poledenitve obstajal doslej nepoznan manjši ledenik.

Ključne besede: geomorfologija, periglacialne oblike, poledenitev, nivacijske kotanje, krnice, Pohorje, Slovenija.

1. INTRODUCTION

Until today, the Pohorje Mountains remain geomorphologically poorly studied, leaving many hidden phenomena in its vast forest expanse. Despite of the size of the area (about 60 km long and up to 20 km wide), its elevation (the highest peak Črni vrh, 1543 m) during ice ages was several hundred meters too low for the development of glaciers. Furthermore, the traces of ice-age geomorphic processes are well concealed by dense forests and thick regolith. At least during the last ice age, the vast majority of the Pohorje Mountains was within the zone of intensive periglacial processes above the upper forest-line which intensely transformed the former fluvio-denudational relief, leaving behind numerous periglacial landforms we are only beginning to recognize.

The term 'periglacial' was introduced in 1909 by the Polish geomorphologist W. Łoziński when he studied frost weathering of sandstones in the Polish part of the Carpathian Mountains. He used it for the areas in the immediate proximity of the Pleistocene continental glaciation and climate conditions in such an environment (Embleton, King 1975, 1). Later, a series of other special geomorphic processes (solifluction, cryoplanation, nivation, etc.) were discovered by other researchers in these areas, resulting in a gradual establishment of the term 'periglacial' for a not precisely defined "area at the edge of recent or Pleistocene glaciers" (Embleton, King 1975, 2).

Research carried out in the eastern Alps in the neighbouring Austria has revealed that intensive periglacial processes are taking place above the upper tree-line even today, creating a wide array of micro-relief forms largely depending on microclimatic conditions as well as the thickness and duration of snow cover (Höllermann 1967; Stingl 1969; Fritz 1976). Similar conditions as today in these areas can be presumed for upper parts of the Pohorje Mountains during the Würm ice age. Later on, during the Holocene, denudation and other processes have largely blurred smaller periglacial landforms (patterned ground, stone stripes, gelifluction terracettes), while some larger landforms have been preserved until today, especially numerous nivation hollows and the Jezerc cirque with traces of glacial activity.

So far, no explanation has been offered for non-existence of small tors and genetically related rock piles and individual boulders typical of, e.g., upper areas of the Koralpe in the neighbouring Austria (Natek 2006) or Kranjska reber in the Kamnik-Savinja Alps. A possible cause could be the bedrock composition since upper areas of the Pohorje Mountains are almost entirely built of granodiorite (tonalite) which breaks down into a coarse-grained regolith. Numerous large rounded boulders, by origin ploughing rocks from the Pleistocene, which in many places protrude from the thick regolith cover or are entirely buried within it, speak against this hypothesis. The answer to this question could only be given after an in-depth comparison analysis with similar areas in the neighbouring Austria and elsewhere in central Europe.

2. AN OVERVIEW OF RESEARCH

For more than a century, Alpine glaciers that – especially during the peak of the Würm glaciation –were gathering in central parts of high mountainous areas and flowing outward in all directions down the valleys, have been subject to numerous geomorphological and geological studies also in Slovenia. These studies were spurred by the fundamental scientific work of E. Brückner and A. Penck (1909) because their findings were relatively generalized for Slovenian Alps and local authors completed the picture of the Slovenian Alps during that time with detailed studies (Melik 1930, 1932, 1935, 1954, 1955b; Kunaver 1975, 1980, 1983, 1999; Meze 1966, 1974; Šifrer 1952, 1955, 1959, 1961; Winkler 1931). At first, the research was not so much focused on the conditions in non-glaciated areas, especially between the upper tree-line of that time (at about 600 m a.s.l., but at 700–800 m in north-eastern Slovenia according to Melik (1935,222)) and the snow-line (at about 1300–1400 m; Melik, 1935, 188; Šifrer 1983, 147). It was partially dealt with only by individual researchers, e.g., Melik in poljes of Dinaric Mountains (1955a), Habič on Trnovski gozd plateau (1968, 1997), Gams in eastern Carynthia (1970) and later Šifrer in his flood-prone areas research (1974, 1983).

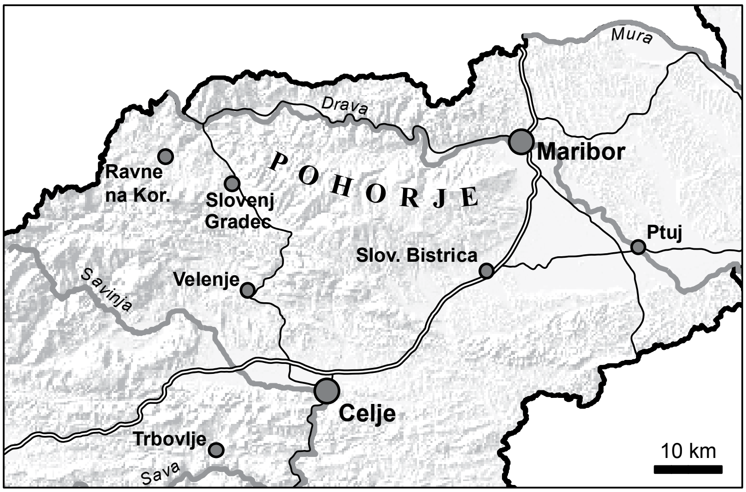
Melik (1935, 222) discovered early that frost weathering had been very effective geomorphic process in non-glaciated areas of Slovenian Alps during the Pleistocene. However, in relation with mass movement processes, he only mentioned increased transport of scree down the slopes because the term 'periglacial' was not well-known at that time. The new term 'periglacial' was used by Melik in the second edition of the general part of his Slovenia monograph (Melik, 1963, 180) where he also described prevailing geomorphic processes on the slopes in more detail. In such areas, frost weathering was very intensive in cold periods due to lower temperatures and frequent transition of temperatures below the freezing point, resulting in a very intensive fluvial accumulation also in the valleys that had no direct or indirect contact with glaciated mountains (Melik, 1955a, 121).

Later, Šifrer (1983) studied thoroughly the fluvio-periglacial accumulation, especially in the upper Dravinja River basin in south-eastern parts of the Pohorje Mountains (1974) and in Škofja Loka Mountains. He also explained large quantities of periglacial debris in the upper reaches of valleys and extensive fluvio-periglacial alluvial fans deposited by the Pohorje streams (at the exits of narrow valleys into the Dravsko polje plain and the Konjice Basin) as a result of intensive frost weathering and fluvial transport during annual spring thawing. Since his research was focused on fluvial activity in relation to climate change during the Pleistocene, he did not devote any special attention to periglacial processes in the upper areas of the Pohorje Mountains where a substantial share of this periglacial material originated.

3. THE POHORJE MOUNTAINS DURING THE PLEISTOCENE

Although very little has been written about the Pohorje Mountains during the Pleistocene, findings from similar, slightly higher areas in the neighbouring Austria, where periglacial conditions still prevail above the upper tree-line, can be adequately applied. The belt of periglacial processes in mountainous areas is relatively narrow and local conditions – especially bedrock composition, regolith thickness, soil moisture and the number of frost events – have a large impact (Fritz 1976, 241). Terrain configuration is a very important factor here because it largely affects the action of winter winds that blow the snow from exposed areas and open the ground to deeper freezing, while at the same time they blow larger quantities of snow into wind-sheltered areas or various hollows. Sun exposure also plays and important role because due to the warming of the exposed ground on sunny slopes, especially in autumns and springs, there are more transitions over the freezing point than on shady slopes which remain frozen for a longer period of time. In the Pohorje Mountains, the subsequent denudation and other processes during the Holocene largely blure smaller periglacial landforms (patterned ground, stone stripes, gelifluction terracettes), while some larger landforms have been preserved until the present and are described below, especially numerous nivation hollows and the Jezerc cirque with traces of glacial activity.

Figure 1: Geographical location of the Pohorje Mountains.



According to Gams (1959, 29), the "snow-line during the peak of the ice age was at about 1300 m on eastern Pohorje plateaus … and raised towards the west similarly as today the altitude of agrarian settlement raises" (e.g., to 1450 m on the northern side of Olševa; Gams 1970, 33). His research revealed that glaciation in this part of the Pre-Alpine region was not such a "showcase" as in high Alps because periglacial processes were more efficient here (Gams 1959, 29–30). He based his conclusion on thick layers of periglacial debris on the slopes and the extensive fluvio-periglacial accumulation at the base of the Pohorje Mountains. Later, he actually found traces of smaller glaciers on the northern side of Olševa and Uršlja gora and even in the Topla valley on the southern side of Peca (Gams 1970), however he hasn't found similar traces of former glaciers in the Pohorje Mountains even though more possibilities for local accumulation of snow could be expected in more massive mountains, especially on the central Pohorje plateau between the peaks of Rogla and Žigartov vrh (1200–1300 m a.s.l.).

Melik (1935; 1963) believed that small slope glaciers might have developed in the uppermost areas of the Pohorje Mountains during the Pleistocene and formed shallow hollows in which peat bogs developed later, "and periglacial processes also contributed considerably to the transformation of this terrain". Gams later established (1962, 249) that peat bogs in the uppermost areas of the Pohorje Mountains developed after the Pleistocene which was also confirmed by palinological research: Ribnica and Lovrenc peat bogs are believed to have been formed not sooner than in the early phase of the Atlantic period (8000–5000 years ago; Budnar-Tregubov 1958, 216; Culiberg 1986, 8), while peat bogs in nivation hollows on the central Pohorje plateau are much more recent, from the Subboreal or the Subatlantic period (800–500 B.C.; Budnar-Tregubov 1958, 216; Culiberg 1986, 216). Based on their circular shape, shallowness and peat bottoms, rounded lakes in these peat bogs can be palsas and are of Holocene age as opposed to larger hollows where peat accumulated during the Holocene (Embleton, King 1975).

Figure 2: The central Pohorje plateau from the west (from the observation tower on Rogla, 1517 m) (photo: K. Natek).

In the past, gently sloped uppermost areas of the Pohorje Mountains were interpreted as remnants of older erosional surface (Gams 1959) or as a result of lower intensity of denudational processes in the upper parts of the slopes (Gams 1976). The latter explanation is most probably adequate for the broad main ridge of the Pohorje Mountains, while the formation of the central Pohorje plateau cannot be explained in this way (Fig. 2). After all, well preserved periglacial landforms from the Pleistocene also prove that it could not have been formed by recent processes. Similar broad ridges as in the Pohorje Mountains can also be found in other lower parts of the Central Alps, e.g., in the Koralpe, the Saualpe and the Niedere Tauern in neighbouring Austria – however, they are of pre-Quaternary age according to a generally established opinion.

4. NIVATION HOLLOWS

While studying aerial photos during the preparation of detailed geomorphological map, sheet Celje, in the scale 1 : 100.000 (Natek 1993), a large number of shallow hollows with flat bottoms in the uppermost areas of the Pohorje Mountains attracted my attention where only thin and meager spruce forest could often be seen. These hollows were indented in the surrounding terrain from a few meters to several tens of meters deep. During the field research, the following common characteristics were discovered:

- several tens of meters wide flat bottom slightly inclined away from the slope
- more or less distinctive concave flexure between the valley bottom and the surrounding slope
- in the bottom of a hollow mostly bogs with thick layers of peat from which a small stream with a minimal gradient flows out.

I eliminated the possibility of fluvio-denudational formation of the hollows immediately because neither in the hollows nor in the immediate surroundings there are no visible signs of recent denudation and fluvial activity, the source springs have exceptionally low gradients with channels predominantly formed in peat moss (Sphagnum sp.) or only slightly carved into the sand-loam regolith. Very weak recent morphodynamics as well as the shape and position of hollows indicated their formation in different climatic and geomorphic conditions – during the last ice age when the uppermost areas of the Pohorje Mountains were within the belt of intensive periglacial processes between the upper tree-line and the snow-line. Nivation hollows, a result of different intensity in weathering and erosional processes due to variations in the thickness of snow cover, are a very characteristic landform in such an environment (Fig. 3).

The term 'nivation' was introduced by F. E. Matthes in 1900 in his study on the Bighorn Mountains in Wyoming (USA) for the transformation of the relief related to more permanent snow patches. Main geomorphic factor is frost weathering or differences in the intensity of this weathering between the ground beneath the snow cover and barren ground at the edge of the snow patch. Later studies in mountainous polar regions revealed that even a thin snow cover has an important insulation effect because it considerably reduces the number of freeze-thaw cycles in the ground beneath the snow. At the same time, frost weathering is the most effective along the edges of snow patches where the ground is not protected by snow. This action is taking place in a wider belt due to changing size of snow-covered area during the year in the immediate proximity of the snow edge (Embleton, King 1975, 131).

Research carried out in subpolar and mountainous areas revealed the existence of the following three types of nivation hollows (Embleton, King 1975, 135–137).

- transverse nivation hollows with the longer axis parallel to contour lines of the slope, they can be over one kilometer wide and up to several hundred meters long, with almost completely flat bottom. On the inner side, they are encircled by a steeper slope (over 30°) which is receding backwards due to nivation, its height increasing. They are often related to variations in petrographic composition (interchanging of different rock layers) and, according to some researchers, proper cirques frequently develop from these hollows.
- longitudinal nivation hollows have a longer axes parallel to slope inclination and are

distinctly elongated. They are formed by nivation processes in the uppermost parts of previously created valleys or dells where larger quantities of snow accumulate.

- circular nivation hollows are distinctly rounded to slightly elongated in shape and are completely independent of geological composition and former fluvio-denudational landforms. They are formed on gentler slopes with homogenous bedrock.

Figure 3: A typical nivation hollow (from Embleton, King 1975, 139).

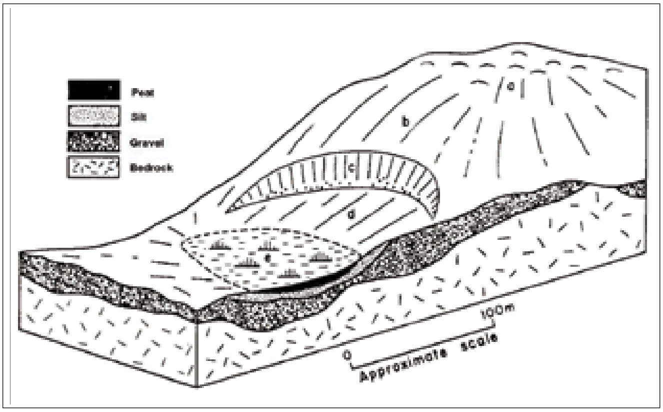


Figure 4: Periglacial material exposed in a road cut northeast of Koča na Pesku mountain hut (photo: K. Natek).

In the process of transport of the weathered material down the slope, which is a necessary precondition for the formation of a hollow, gelifluction is the most efficient in more arid areas, additionally accelerated by the mere mass of the snow field and the meltwater during thawing, while in more humid areas denudation, related to non-concentrated outflow of meltwater, also plays an important role (Embleton, King 1975, 133). Sometimes, slow creeping of the entire snow patch mass down the slope has also been stated as a factor of relief transformation, however, erosional effect of these movements is considerably weaker than in other two processes, especially in the hollows with small bottom inclination.

The study included 59 nivation hollows from the central part of the Pohorje Mountains between the peaks of Jezerski vrh (1537 m) in the west and Žigartov vrh (1346 m) in the east. All nivation hollows on the central Pohorje plateau were studied, as well as nivation hollows in source areas of the streams flowing outward from this plateau in all directions. Within detailed geomorphological mapping at the scale of 1 : 25.000, I identified nivation hollows by using aerial photos at the scale of 1 : 17.500 and during additional field mapping (Natek 1993), while morphometric data was acquired from the basic topographic map at the scale of 1 : 10.000 and partly corrected in the field.

According to the average inclination of their bottoms, nivation hollows can be divided into for groups: there are 27 hollows with bottoms inclined less than 6°, 16 hollows 6–12°, 12 hollows 12–20°, while in four hollows the inclination was over 20°. Especially the bottoms of nivation hollows on the central Pohorje plateau have very small inclination (average 3.7°), resulting in hindered outflow of precipitation water, therefore peat bogs are located in most of them with small streams flowing out. All studied hollows with bottom inclination over 20° are today source hollows of smaller streams which deepen into narrow gullies just slightly downstream. However, when all their other characteristics are considered, they are nivation hollows by origin, subsequently transformed due to denudation and fluvial processes (Fig. 5).

Upper edges of nivation hollows are usually located very close to the gently sloped ridge area, in some cases the transition from the bottom of hollows into the surrounding slope, especially on the back side, is rather unclear and is therefore difficult to identify. Lower edge of the hollows, at the supposed limit of the former snow patch, is often a distinct convex flexure where the almost flat hollow's bottom very distinctly bends down the slope. In several cases, the stream gradient quickly increases at this transition point, and the nivation hollow changes down slope into a shallow gully which becomes steeper farther down the slope. The average elevation of hollows' lower edges was established at 1201 m; their lowest elevation was recorded in the Bistrica source area where there is plenty of flat terrain at the altitude of 900–1150 m, and in the middle of slopes above the deeply incised Lobnica valley. Only in five hollows, middle sections of bottoms are below 1000 m, while by far the largest number of bottoms is at the elevation between 1200–1300 m, especially due to a considerable number of hollows on the central Pohorje plateau.

Among the studied nivation hollows, 27 are of the third type (circular to slightly elongated), longitudinal nivation hollows are as numerous as the third type (more or less distinctly elongated), while there are only five transverse hollows (the width exceeding their length). Circular hollows were presumably formed in sheltered areas where winter winds deposited larger quantities of snow. This type of hollows appears on sunny as well as on shady slopes, while on the central Pohorje plateau longitudinal hollows appear along with them. These findings speak for pre-Quaternary age and fluvio-denudational formation of this plateau. It is evident that during the ice ages some more snow accumulated in the pre-existing shallow hollows of fluvio-denudational origin, while subsequent nivation processes only slightly transformed the already existing uppermost parts of the valleys and dells.

Figure 5: Nivation hollow of Tiho jezero in the headwaters of the Lobnica brook (photo: K. Natek)

A somewhat surprising orientation of nivation hollows could be explained by the prevailing west-east direction of the main Pohorje ridge and related climatic conditions. As much as a half of all hollows (30) are open towards the north-east, east or south-east (azimuth 22.5°–157.5°), while only 14 are open towards the north-west and north (azimuth 292.5–22.5°) and 15 towards the south and west (azimuth 157.5°–292.5°); the hollows are open in various directions also on the central Pohorje plateau. More frequent orientation towards the north-east cannot be adequately explained by prevailing south-westerly winds because abundant snowfall is frequently brought to the area by easterly winds even today when a low pressure area is located over the Balkan peninsula or the eastern Mediterranean. Even the Jezerc cirque is oriented towards north-east, but its formation also cannot be adequately explained as a result of its leeward position from south-westerly winds.

5. THE JEZERC CIRQUE

The studied depression is situated on the eastern slope of Planinka ridge (on its top there is Lovrenc peat bog at 1515–1529 m). It has a flat bottom at 1220 m a.s.l. (largely filled by a smaller artificial lake) which is about 30 m above the recent channel of the Radoljna stream. The depression is closed on three sides by steeper slopes, while on the lower side it is closed by a five meters high semicircular terminal moraine. Bedrock is composed entirely of granodiorite (tonalite), the slopes are predominantly overgrown by spruce forest. The size of the depression is 780 m in the west-east direction and 500 m in the north-south direction (Fig. 6, 7).

Research carried out in non-carbonate parts of Austrian Alps (Höllermann 1967, 161) clearly revealed that hollows on mountain slopes, regardless of their origin, are more convenient for the formation of periglacial landforms than flatter ridge areas and steep slopes. Main reasons for this are larger quantities of finer unconsolidated material and larger quantities of available water, partly due to the influx of water from adjacent slopes through the regolith and partly due to large quantities of snow that accumulates in such hollows during winters. This is clearly evident also in the Jezerc cirque where in the middle and upper parts of the slopes, up to several meters thick layer of unconsolidated material can be found. Mostly it is a mixture of fine particles (clay and sand – direct result of the granodiorite weathering) containing many larger boulders, while in the lower part of the south-western slope of the cirque there is an accumulation of boulders turning into a blockmeer (Fig. 8).

Figure 6: Geomorphological map of the Jezerc cirque.

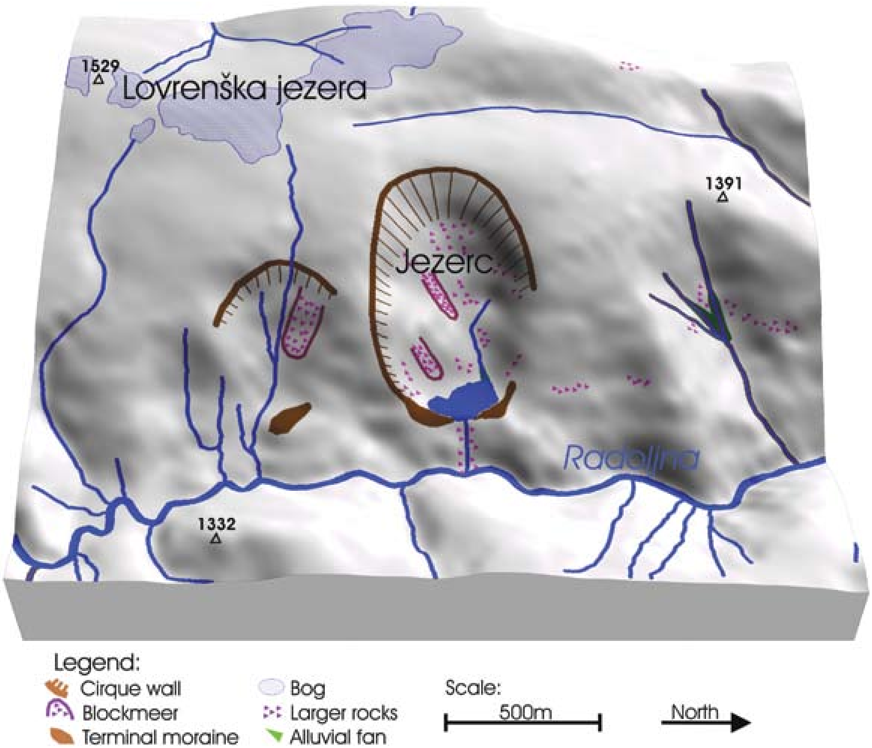


Figure 7: The Jezerc cirque from the terminal moraine to the west (photo: K. Natek).

Figure 8: Small blockmeer at the south-western slope of the Jezerc cirque (photo: K. Natek).

At the northern end of the terminal moraine, foresters' hut is located. A skid trail leads diagonally upwards past the hut. All the way up to the elevation of 1310 m, bedrock is unexposed but large rounded boulders (up to one meter of diameter) can be seen, inserted in a mixture of finer particles. A small stream, created from several sources at 1300 m, runs through the lowest part of the cirque; in its lower section it flows in a 2–5 m deep channel where similar material is exposed. At its outlet into the artificial lake, the stream deposited a small alluvial fan. The slope angle in this lower part of the cirque is 12–18°, followed upwards by an inconspicuous convex flexure at 1260 m, running transverse to the hollow. Above it, there is a 50 m wide stripe of flatter land with average inclination of 9°. Both flexure and this stripe are filled with boulders.

The bedrock appears on the surface at 1310 m where a prominent rock hummock outcrops from the cirque slope, some 20 m high at its lower side. Below the hummock, the aforementioned gentle-sloped surface is located, covered with randomly scattered boulders, their longer axes exceeding two meters in some cases. This material is of periglacial origin and probably originates from the Later Würm when only the lower part of the cirque was filled with ice. Several smaller blockmeers in the cirque are also of similar origin and age, e.g., an approximately 20 m wide and 3 m high blockmeer to the south of the rocky hummock at 1290–1350 m and two smaller blockmeers on the southern slope of the cirque (1240–1300 m).

On the western side of the cirque a prominent concave flexure at 1400 m marks the upper edge of the cirque. The slope angle above the flexure is between 35° and over 40°. The bedrock is covered only with a thin layer of regolith, while at the base of the steepest slope there is again an accumulation of boulders (scree), but here they are smaller than in the blockmeers below. On its upper side, the steep cirque edge reaches up to 1470 m and gradually changes into a more gently-sloped broad Planinka ridge which runs in the south-north direction.

Some 300 m to the south of the Jezerc cirque, there is a similar but smaller and less distinctive depression on the western slopes of the Radoljna valley which also contained a more permanent snow field or even a smaller glacier during the Würm, however, its glacial origin is not so clearly visible. The hollow was also subsequently transformed by a stream running from the Lovrenc peat bog, depositing a small alluvial fan on the lower edge of the hollow (at 1260–1265 m). A similar situation can also be seen in the inconspicuous hollow of the Radel gully to the north from the Jezerc cirque, where an alluvial fan, containing a similar mixture of fine regolith and large boulders can also be found on the lower edge of the hollow. Subsequently, the recent stream cut its channel 20 m deep into this alluvial fan. At its upper side, this hollow ends with about 10-m high steeper section (slope angle 25°) just below the Planinka top ridge (1382 m). Similarly non-prominent, subsequently transformed by fluvio-denudational processes, are the hollows in the headwaters of Radoljna stream below Rogla and also on eastern slopes of the Radoljna valley, which however, have not been studied so far.

6. CONCLUSION

In the past, the Pohorje Mountains were not in the focus of geomorphological research, and, therefore, we do not know as much about the situation during the last ice age as we know for the high-alpine areas in Northwestern Slovenia. Few hundred meters to low, the was no possibility for larger valley glaciers to develop, similar to those in Julian or Kamnik-Savinja Alps, but, the upper parts of the mountains were above the upper forest-line and exposed to strong periglacial processes. Previous researches have already linked their activity with extensive fluvial accumulation as large alluvial fans at the foot of the mountains but, the periglacial landforms of the highest parts of the mountains themselves are presented for the first time in this paper. The ensuing geomorphic processes during the Holocene and dense forest cover have obliterated smaller periglacial forms, so only larger forms are preserved, especially a number of nivation hollows where permanent snowfields or even small glaciers existed during the last ice age. Such hollows are best preserved on the central Pohorje plateau (1200–1300 m a.s.l.), which is of fluvio-denudational origin and Pre-Quaternary age. Similar hollows on the fringes of this plateau and elsewhere in the Pohorje Mountains are more or less degraded by later fluvio-denudational processes but still clearly visible, representing an important part of recent landform inventory of the mountains.

Detailed study of the Jezerc cirque on the western slope of the Radoljna stream valley has revealed for the first time the clear evidence of a small glacier from the last ice age in the Pohorje Mountains and, also, in the whole Pre-Alpine mountains of Slovenia. The main indicators of the former cirque glacier are up to five meters high semicircular terminal moraine with large boulders embedded in small-size detritus and the occurrence of unconsolidated material, consecutively transformed by periglacial processes. It is quite possible that further geomorphological research in the Pohorje Mountains and elsewhere in the Pre-Alpine mountains will disclose new locations of small ice age glaciers but the Jezerc cirque shall be considered as locus classicus in Slovenia and, therefore, needs to be protected against further human impact.

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PERIGLACIALNE OBLIKE NA POHORJU

Povzetek

Pohorje je bilo v ledenih dobah nekaj sto metrov prenizko, da bi se na njem razvili ledeniki, je bila pa velika večina hribovja vsaj v zadnji ledeni dobi v pasu intenzivnih periglacialnih procesov nad zgornjo gozdno mejo, ki so nam zapustili številne periglacialne oblike. Preučevanja v Vzhodnih Alpah v sosednji Avstriji kažejo, da potekajo nad zgornjo gozdno mejo še danes intenzivni periglacialni procesi (soliflukcija, krioplanacija, nivacija idr.) in ustvarjajo pisan nabor drobnih reliefnih oblik, ki je v veliki meri odvisen od mikroklimatskih razmer ter od debeline in trajanja snežne odeje. Tem podobne razmere so bile v obdobju würma tudi v vršnih delih Pohorja, le da so poznejši denudacijski in drugi procesi v holocenu v veliki meri zabrisali drobne periglacialne oblike (deflacijske kotanje, geliflukcijske terasice, potujoče skale), nekatere večje oblike pa so se ohranile do današnjih dni, predvsem številne nivacijske kotanje in krnica Jezerc s sledovi ledeniškega delovanja.

Pas intenzivnih periglacialnih procesov je v gorskem svetu razmeroma ozek, hrati pa imajo močan vpliv lokalne razmere, predvsem kamninska zgradba, debelina preperelìne, vlaga v tleh in število zmrzalnih dogodkov. Zelo pomembna je tudi predhodna izoblikovanost površja, saj v veliki meri pogojuje delovanje zimskih vetrov, ki z izpostavljenih mest odpihajo sneg in s tem omogočijo globlje zamrzovanje, hkrati pa napihajo večje količine snega v zavetrne lege in različne kotanje. Pomembno vlogo ima tudi ekspozicija, saj je na prisojnih pobočjih zlasti jeseni

in spomladi zaradi vsakodnevnega ogrevanja razgaljenih tal več prehodov prek ledišča kot na dlje časa zamrznjenih osojnih pobočjih. Na osnovi debelih plasti periglacialnega drobirja na pobočjih in obsežnih fluvioperiglacialnih nanosov ob vznožju Pohorja so starejši raziskovalci sicer ugotavljali močno periglacialno delovanje v vršnih delih Pohorja (meja večnega snega in ledu je bila na ok. 1300 m), vendar se s konkretnimi periglacialnimi reliefnimi oblikami niso ukvarjali. Tudi sledovi nekdanjih ledenikov na Pohorju doslej niso bili poznani, čeprav bi mogli na tako obsežnem hribovju pričakovati ugodne možnosti za lokalno kopičenje snega, zlasti na osrednjepohorski uravnavi med Roglo in Žigartovim vrhom.

Geomorfološko kartiranje vršnih delov Pohorja je razkrilo veliko število plitvih kotanj, za nekaj metrov do nekaj deset metrov globoko zajedenih v okoliško površje in z ravnim dnom, na njem pa visoko barje z debelimi plastmi šote, iz katerega izteka manjši potok z neznatnim strmcem. Po izoblikovanosti, nastanku in legi so to nivacijske kotanje iz zadnje ledene dobe, rezultat različne intenzivnosti procesov preperevanja in odnašanja zaradi razlik v debelini snežne odeje. Podrobnejše preučevanje je zajelo 59 nivacijskih kotanj v osrednjem delu Pohorja, med Jezerskim vrhom (1537 m) na zahodu in Žigartovim vrhom (1346 m) na vzhodu. Zajete so bile vse nivacijske kotanje na osrednjepohorski uravnavi, poleg njih pa še kotanje v povirju potokov, ki se od te uravnave raztekajo na vse štiri strani neba.

Glede na povprečni naklon dna jih lahko razdelimo v štiri skupine: dna z naklonom do 6o ima 27 kotanj, 6–12o 16 kotanj, 12–20o 12 kotanj, 4 kotanje pa so imele naklon dna več kot 20o. Zlasti dna nivacijskih kotanj na osrednjepohorski uravnavi imajo zelo majhen naklon (povprečno 3,7o) in s tem otežen odtok padavinske vode, zato so skoraj v vseh visoka barja. Vse preučevane kotanje z naklonom dna nad 20o so danes povirne kotanje manjših potokov, ki le nekaj niže preidejo v ozke grape, vendar pa so glede na vse ostale značilnosti po nastanku nivacijske kotanje, naknadno preoblikovane zaradi denudacijskih in fluvialnih procesov.

Zgornji robovi nivacijskih kotanj ležijo praviloma zelo blizu položnega ovršja, v nekaterih primerih je prehod iz dna kotanje v okoliško pobočje zlasti na zatrepni strani precej neizrazit, tako da ga je razmeroma težko natančneje določiti. Spodnji rob kotanj, do kamor naj bi praviloma segalo nekdanje snežišče, je pri mnogih kotanjah izrazit konveksni pregib, kjer se položno dno kotanje prevesi po pobočju navzdol. Povprečna ugotovljena nadmorska višina spodnjih robov kotanj znaša 1201 m; najnižje so spodnji robovi kotanj v povirju Bistrice, kjer je v n.v. 900–1150 m precej uravnanega sveta, in pa sredi pobočij nad globoko zajedeno dolino Lobnice. Največ kotanj ima dno v n.v. od 1200 do 1300 m, predvsem na osrednjepohorski uravnavi. Ker v nižjih nadmorskih višinah takšnih kotanj ni, te res ne morejo biti fluvio-denudacijskega nastanka.

Usmerjenost nivacijskih kotanj lahko le deloma pojasnimo s prevladujočo usmerjenostjo pohorskega glavnega slemena v smeri Z–V in s tem povezanimi mikroklimatskimi razmerami. Kar polovica vseh kotanj (30) se odpira proti severovzhodu, vzhodu in jugovzhodu (azimut od 22,5o do 157,5o), proti severozahodu in severu komaj 14 (azimut 292,5–22,5o), proti jugu in zahodu pa 15 kotanj (azimut 157,5–292,5o); tudi na osrednjepohorski uravnavi se kotanje odpirajo v različne smeri neba. Pogostejšo usmerjenost proti severovzhodu bi morda lahko pojasnili s precejšnjo pogostnostjo močnih jugozahodnih vetrov (tudi krnica Jezerc se odpira proti severovzhodu), ostalega pa ne, kar ponovno kaže na fluviodenudacijski izvor velike večine kotanj.

Na vzhodnem pobočju Planinke (v njenem ovršju je v n.v. 1515–1529 m Lovrenško barje) leži obsežnejša kotanja z izrazito uravnjenim dnom v n.v. 1220 m (večinoma ga zapolnjuje manjše umetno jezero), ok. 30 m nad današnjo strugo potoka Radoljna. Kotanjo na treh straneh zapirajo strmejša pobočja, na spodnji strani pa do 5 m visok polkrožni čelnomorenski nasip. Kamninska podlaga je granodiorit (tonalit), pobočja so v celoti zaraščena s pretežno smrekovim gozdom. V smeri zahod–vzhod meri kotanja 780 m, v smeri sever–jug 500 m in je po nastanku krnica, v kateri se je ob višku zadnje ledene dobe zadrževal manjši ledenik. To dokazujejo zelo lepo ohranjena polkrožna čelna morena, zgrajena iz velikih skalnatih blokov, vsajenih v finejši peščeno-gruščnati drobir, ter strma živoskalna pobočja kotanje, le mestoma prekrita z debelejšo plastjo nesprijetega drobirja. Večinoma gre za mešanico drobnih delcev (glina in pesek – neposredni rezultat preperevanja granodiorita), v kateri je polno skalnatih blokov, mestoma pa najdemo tudi nakopičenja večjih skalnatih blokov, ki v spodnjem delu južnega pobočja krnice preidejo v pravi blockmeer.

Podobna, a manjša in slabše razvita kotanja je tudi kakšnih 300 m južneje od krnice Jezerc, v kateri se je v würmu verjetno prav tako zadrževalo trajnejše snežišče ali celo manjši ledenik, vendar v njej ni tako izrazitih oblik. Kotanjo je naknadno preoblikoval tudi potok iz Lovrenškega barja in na njenem spodnjem robu (n.v. 1260–65 m) nasul manjši vršaj. Podobna situacija je tudi v neizraziti kotanji Radelske grape severno od krnice Jezerc, kjer je ravno tako v spodnjem delu kotanje vršaj iz mešanice drobne prepereline in večjih skal, v katerega se je sedanji potok naknadno vrezal za skoraj 20 m. Podobne, naknadno fluviodenudacijsko preoblikovane kotanje so tudi v povirnem delu Radoljne pod Roglo in na njenih vzhodnih pobočjih, morda pa jih bo podrobno geomorfološko preučevanje razkrilo tudi še drugod po Pohorju v povirnih delih današnjih dolin.