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RELICT CRYOPLANATION TERRACES OF CENTRAL KOPAONIK (SERBIA)

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Abstract: The paper deals with cryoplanation terraces on Kopaonik Mountain (2017m) which had been formed for the first time as a relict relief probably during the last glacial maximum (LGM) of Late Pleistocene. Four sites on the slopes of the southern and eastern exposure of the central part of the mountain range at the altitude between 1390 and 1910 m have been studied. Qualitative geomorphological research has dominated. Quantitative research has not been possible due to the properties of the relict formations and genetic inactivity of this relief, which is also typical for modern periglacial environments. Distinction of cryoplanation terraces on Kopaonik is important for understanding the distribution of this relict morphology both in Serbia and South East Europe. The research presents a contribution to one of the primary goals of the concept of cryoplanation in terms of regional distribution of cryoplanation relief.

Key words: relict relief, cryoplanation terraces, qualitative geomorphology, Kopaonik Mountain, Serbia

1. INTRODUCTION

Periglacial geomorphology has developed for more than a century. During this period, numerous papers have been published on the problem of the evolution of slopes in areas with cold climates. Generally, two concepts of slope development in cold areas have been distinguished. These are cryoplanation and denudation, and both present according to the model of slope development up to the stadium of (cryo) pediplain, an advanced stage of evolution of periglacial relief (French, 2007). In the development of periglacial geomorphology cryoplanation presents an important concept for explaining the development of slopes in conditions of cold climate that is increasingly being questioned due to the absence of relevant quantitative indicators indicators (Thorn & Hall, 2002; Migon, 2003; French, 2007; Mackovčin et al, 2007; Hall & André, 2009, etc.). However, cryoplanation is still a useful model for explaining the formation of mountain terraces as a form of irregularities in the relief of slopes. Therefore, the existence of cryoplanation terraces is usually not disputed, although problems arise in interpreting the morphogenesis of these forms.

The procedure of geomorphological reconnaissance and mapping of the central part of the Kopaonik massif led to the recognition of the landforms that according to their morphology belong to cryoplanation terraces like those described in cold and mountainous regions of North America and Eurasia. In Southeast Europe, cryoplanation terraces are found in the mountains of Bulgaria (Demek, 1969; Reger & Péwé, 1976), on Pohorje in Slovenia (Obu, 2011) and Carpatho-Balkan Mountains of Eastern Serbia (Nešić, 2010; 2013). Contemporary periglacial environment on Kopaonik is within boundaries, and the surveyed cryoplanation terraces are covered with grass vegetation. It is assumed that their relict characteristics date back to the period of Late Pleistocene cooling, which is in accordance with the opinion of French (2007) who argues that most of these forms are relict. The subject of this paper is the relict relief, while the aim is the contribution to the knowledge of the regional distribution of cryoplanation terraces, which is one of the prerequisites for solving the issue of cryoplanation

(Czudek, 1995).

2. REGIONAL SETTING

Kopaonik belongs to a group of the highest (2017 m) and the widest (2,750 km^2) mountains of Serbia. Along with the mountains in the region (Željin – 1785 m, Nerađe – 1350 m, Ravna Planina – 1542 m, Goč – 1123 m and Stolovi – 1375 m) it forms the Kopaonik mountain group i.e. the largest mountain geomorphological structure in Serbia (Milinčić & Pecelj, 2008). Kopaonik stretches in the north-west – south-east direction to a length of 80 km, reaching in its middle part width greater than 40km. It reaches maximum heights in the central region of Kopaonik: Pančićev vrh (2017 m), Suvo Rudište (1976 m), Karaman (1917 m), Vučak (1936 m) and Gobelja (1934 m). These peaks rise from the surface of Ravni Kopaonik (163.5 km^2) at the altitudes from 1500 to 1750 m. Several secondary mountain ranges stretch out from Suvo Rudište in the south-east direction such as Bedirovac with its peak Šiljak (1782 m), Ravniška planina (1793 m), Vojetin (1582 m), Nebeska stolica (1913 m) and Bugarin (1636 m). Four sites have been located on the slopes of these mountain ridges, with series of relict cryoplanation terraces at altitudes from 1390 to 1910 m.

In geotectonic sense, Kopaonik belongs to the transitional Vardar Zone that stretches towards the Dinarides. The mountain range is raised in the form of a granodiorite mass of tertiary age, which performed metamorphism of the contact areal through introduction. This resulted in an intricate lithologic and structural formation of the mountain. The result of the complex geological influences in a small space is evident in a shift of different lithologic units, which is also a characteristic of the south-eastern part of Suvo Rudište.

In this part of the mountain, a metamorphic complex of a series of sericite and sericite-chlorite schists predominates. Phyllites are also present within which packages of calc-schists and marble are inserted (Urošević et al., 1970).

South of this complex, there is a wide distribution of serpentinised harzburgite as a variety of peridotite or ultrabasic deep-level magmatites (Urošević et al., 1970, Urošević et al., 1973). The studied cryoplanation terraces are cut into the schists and metamorphosed harzburgites (serpentinites). Rocks of the granitoid complex of central Kopaonik are not present at locations on cryoplanation terraces (Fig. 2).

Morphostructural relief of central Kopaonik has been altered by exogenous processes. In contemporary conditions, denudation with secondary periglacial processes dominates on higher altitudes, whereas in lower, fluvial denundation processes. Despite indications, credible evidence has not been found for traces of Pleistocene glaciation. On the part of the mountain above the altitude of 1700 m, relict periglacial morphology has been exposed to weak recent processes of borderline periglacial environment.

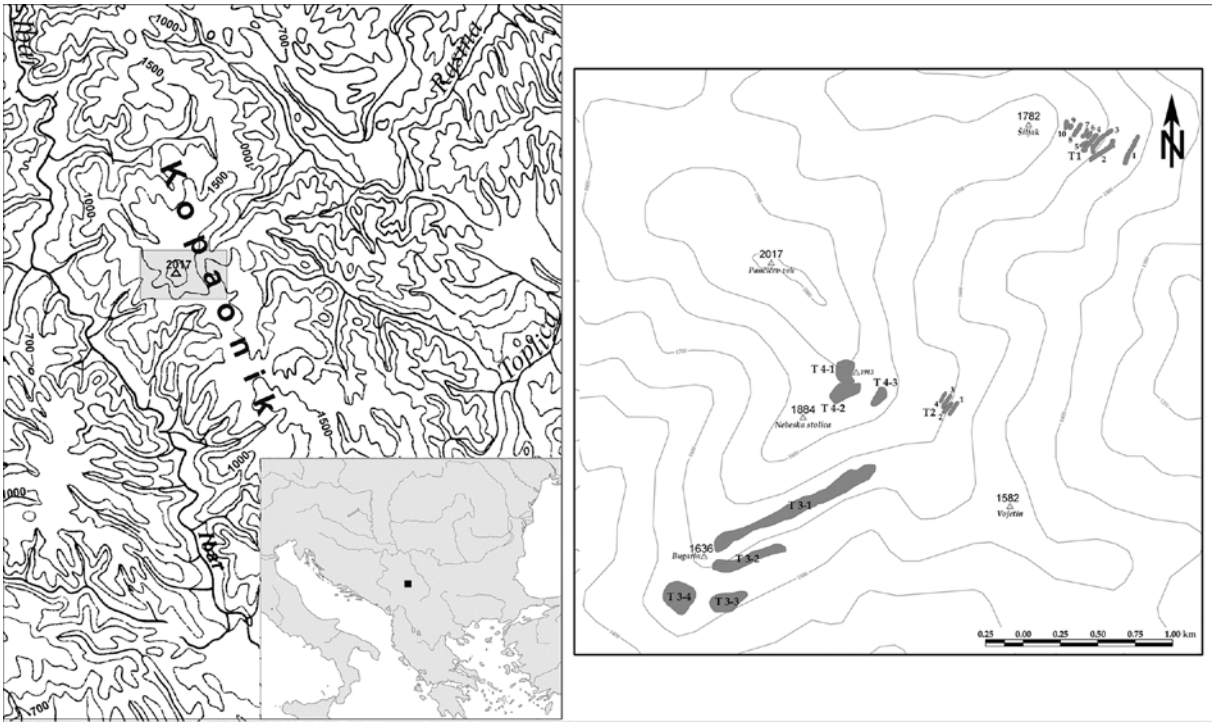

Figure 1. Kopaonik's position in Southeast Europe and the locations of relict cryoplanation terraces.

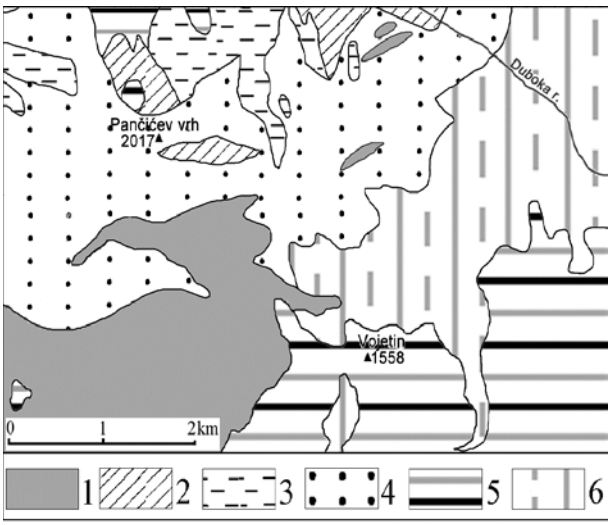

Figure 2. Geological map of the locations of relict cryoplanation terraces (according to Urošević et al., 1970)
Legend: 1 - Serpentinised harzburgite, 2 - Limestone and marbles, 3 - Granodiorite, 4 - Sericite and sericite-chlorite schists, 5 - Quartz latite and latite, 6 - Sandstone

French (2007) indicates that a periglacial environment is typical of areas with a mean annual air temperature of less than + 3°C. Based on meteorological observations for central Kopaonik (station at 1710 m altitude) for the period 1950-1994, mean annual air temperature is +2.9°C. By approximation the temperature has been determined at +1.7 °C for Pančićev vrh (2017 m above the sea) (Nešić et al., 2009). These mean annual air temperatures indicate that the contemporary periglacial environment is represented within borderlines on Kopaonik above the height of 1700 m. Research has confirmed that on the grass areas of the south slopes of Pančićev vrh, above the altitude of 1750 m, periglacial phenomena of coarse-grained rock downslope movement occur. These are caused by the processes of solifluction and frost heaving of coarse-grained rocky ice mass (Nešić et al., 2009). Genetically similar phenomena of thermogenic-solifluctional landslides were investigated at the altitudes from 1770 to 1940 m (Nešić & Milinčić, 2004). Cryoplanation terraces that are the subject of this paper have been discovered at altitudes from 1390 to 1910 m above the sea, partly under the belt of contemporary periglacial environment. It indicates their relict origin probably from the period of the Late Pleistocene cooling.

Natural upper forest boundary is at altitudes above 1900 m. The southeastern part of the central Kopaonik with cryoplanation terraces is without high forest vegetation. Grass slopes (grassland) and groups of prostrate juniper bushes (*Juniperus nana*), blueberries (*Vaccinium myrtilus*) and low sub-alpine spruce (*Piceetum subalpinum*) predominate. Here, the upper forest boundary has been altered by long-term anthropogenic actions (by burning or deforestation) and is found in certain parts at the altitude way below 1500 m in the zone dominated by fluvial processes. This situation has facilitated detection and differentiation of cryoplanation morphology that is more difficult to distinguish in areas covered by forests.

3. RESEARCH METHOD

Cryoplanation terraces were discovered during the survey of the recent periglacial relief of Kopaonik (2003 - 2006). During the period from 2010 to 2013 the study of these forms took place. Cryoplanation terraces were distinguished on the basis of their morphological comparison with similar relief (Demek, 1969; Reger & Péwé, 1976; Czudek, 1995; French, 2007, Obu, 2011) using the method of qualitative geomorphic analysis. The procedure involved the extraction of forms based on morphology, position and mutual relations in relief. Then, there was determination of geomorphological parameters for the expected geomorphic processes of recent or relict origin. A qualitative geomorphologic analysis of relief forms was conducted in the field work: locating, mapping (standard GPS device) and morphometry (length, width and slope). Also, the analysis of the locations and shapes of the relief according to geological and lithological conditions of the surface into which they developed was performed, as well as determination of their exposure and other relevant facts. Lab methods included the application of the procedures of detailed analysis of field results and the existing thematic maps (orographic, topographic and geological), making of sketches and processing of the field results.

4. RESEARCH RESULTS

On the slopes of the southeastern part of the central Kopaonik, i.e. in the zone of overlapping of periglacial and fluvial morphology, four locations have been distinguished with series of cryoplanation terraces. They include the following slopes: Bećirovac (1), Ravniška planina (2), Vrla strana (3) and the local ridge Nebeska stolica (4) (Fig. 1).

Cryoplanation terraces were first observed on the Bećirovac slope (1), between the coordinates 43° 16′ 29.5″ (S), 43° 16′ 39.2″ (N), 20° 51′ 13.1″ (W) и 20° 51′ 31.0″ (E) (coordinates according to the Hermannskogel system). A series of ten terraces with cascading arrangement on a slope at the altitudes from 1520 to 1700 m (Fig. 3, Table 1) have been

studied. Series of 24 – 25 cryoplanation terraces on slopes are mentioned (Czudek, 1995), indicating that the location on Bećirovac with its 10 terraces a representative one.

Table 1. Morphometry of cryoplanation terraces on Bećirovac

Number terraces	Level (m)	Length (m)	Width (m)	Inclination (°)
1-1	1534	200	8-15	0-2
1-2	1580	190	4-14	0-2
1-3	1614	199	5-14	0-2
1-4	1625	129	8-18	0-2
1-5	1630	43	5-9	0-3
1-6	1650	40	6-8	0-3
1-7	1656	55	5-12	0-2
1-8	1671	91	9-12	0-2
1-9	1685	18	10-12	2
1-10	1691	30	3-17	2

In the lower series four terraces are clearly distinguished (1-1, 1-2, 1-3 and 1-4), which correspond to the shelves wide 4 – 18 m and long 129 – 200 m (Table 1), cut into the mountainside composed of schists. The terraces follow overall morphology of the slope and according to their direction they have uneven slopes, while the transverse slopes are 0°-2°. The terraces had developed on the part of the slope with the inclination from 22° to 39° within which individual lairs have been distinguished. On the terraces and the area above them large coarse-grained rocks are observed, while at the edge of the terraces 1-3, a nivation mound 15 m long and 0,9 – 1.2 m high stands out. Occurrences of nivation mounds have been recorded in other cryoplanation terraces and are one of their characteristics (Czudek, 1995; Obu, 2011 and others).

Higher series of terraces (1-5, 1-6, 1-7, 1-8, 1-9 and 1-10) on the slope with inclination from 17° to 23° are of smaller dimensions - width from 3 – 17 m, length from 18 – 91 m (Table 1, Fig. 3). The terraces and the surrounding area are covered with grass vegetation, except for the individual lairs and rare areas where coarse-grained rocks protrude. This indicates that the terraces are primarily genetically inactive and that they correspond to relict morphology.

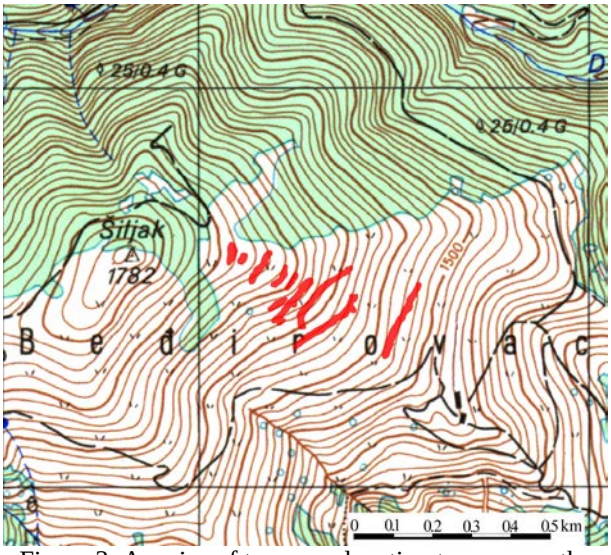

Figure 3. A series of ten cryoplanation terraces on the Bećirovac slope

Within the morphology of a slope on a series of terraces on Bećirovac a steeper part (35°-39°) is clearly distinguished, which is the result of a division of lairs that are mostly destroyed or reduced, where the series of terraces is slightly thicker (terraces 1-3, 1-4, 1-5 and 1-6) (Fig. 3). The destroyed lairs are partly fractions of outside edges of the terraces. The whole series of terraces is on the hillside with eastern – southeastern exposure.

Figure 4. Details from the cryoplanation series of terraces on Bećirovac

A series of four terraces has been observed down the slope of Bećirovac at the altitudes from 1390 to 1410 m. On the slope with inclination of 13°-14°, the terraces are 5 – 10 m wide and 30 – 40 m long. The inclination of the transverse profile of these terraces is 3°-5°, while the division in its hinterland is inclined by 15°-17°. These are morphologically less pronounced terraces in the relief at the lower boundary of their occurrence, probably significantly reduced by denudation.

In addition to these series of terraces on the slope of Bećirovac there are smaller fragments of terraces around nivation depressions, which indicates the importance of cryoplanation in the development of the slopes of this part of Kopaonik. This is confirmed by a series of cryoplanation terraces above Ravniška planina (2), south of Bećirovac. At this site in serpentinites, a series of 4 - 5 terraces (3 – 10 m in width and 20 – 50 m in length) on a slope with the inclination of 34° has been detected. The terraces spread at the altitudes from 1650 to 1750 m in coordinates 43° 15′ 40.2″ (S) and 43° 15′ 42.2″ (N) and 20° 50′ 34.4″ (W) and 20° 50′ 38.8″ (E). A cryoplanation series of terraces above Ravniška planina has a southeastern exposure.

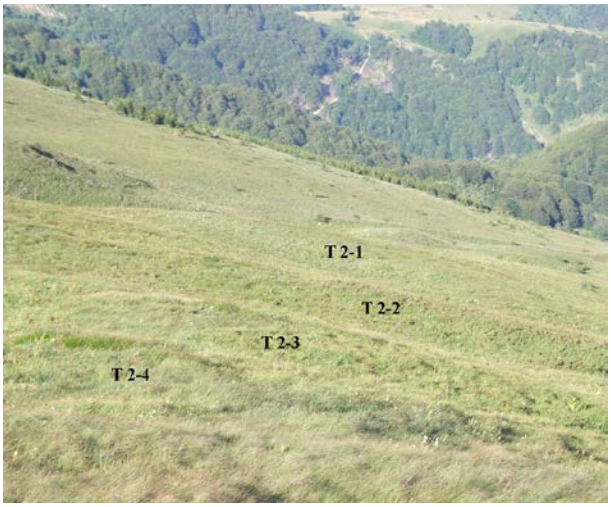

Figure 5. A series of cryoplanation teracces above Ravniška planina (2-1, 2-2, 2-3, 2-4)

On the site Vrla strana (3), southeast slope of Nebeska stolica, cryoplanation relief of complex morphological and genetic features carved into serpentinites has been investigated. This location is within the coordinates 43° 14′ 59.5″ (S), 43° 15′ 25.7″ (N), 20° 49′ 20.0″ (W) and 20° 50′ 15.1″ (E). Because of its morphometry and its genesis, a terrace (3-1) stands out at the altitude from 1620 to 1640 m, with length of 1.2 km and a maximum width of 90 m (Fig. 6). The terrace consists of three parts. The first (east-west direction) contains a plane 400 m long and 60 to 80 m wide, with the cut in the serpentinites at the height of 60 m. The plane is not unified but intersected by ravines and lower plateaus carved into it. It is separated from the second part of the terrace by colluvial sediments of relative height of 10 m. The location of these deposits on the plateau is a result of a colluvial process that is also indicated by several other landsliding hills in the hinterland of the second part of the terrace. This part of the terrace is morphologically well distinguished in the form of an inclined (7°-9°) continuous surface of the length of 330 m and the width of 35 to 90 m (Fig. 6). On the edge of this part of the terrace a nivation rampart has been detected (0.5 – 1.5 m high and 40 m long), covered with grass cover. It should be noted that above the sliding zone in the green rocks, a series of three cryoplanation terraces has been distinguished with respective lengths of 126 m, 36 m and 117 m and respective widths of 5 – 17 m, 6 - 17 m and 4 – 29 m (3-5, 3-6 and 3-7).

Figure 6. Cryoplanation teracce (3-1) cut into serpentinites with a nivation rampart on the outer edge

The third part of the terrace 3-1 in the west below the Bugarin ridge (1636 m) ends in a semicircular extension, like a hanging cirque with a width of 70 m and a length of 160 - 170 m. Lower on the slope, there is a terrace (3-2), with the inclination of -12°, a length of 440 – 450 m and a width of 60 – 65 m (Fig.7) of which the western part, under the Bugarin ridge, consists of a large nivation depression. The third terrace (3-3) is below the nivation depression, but has not been investigated thoroughly.

On the site Vrla strana (3) there is a series of three terraces (3-1, 3-2, 3-3), which end in the direction of the Bugarin ridge in “circular” parts and one nivation depression. The terraced series is carved in serpentinites, which are subject to decay due to frost, what explains the large size of these terraces. On the morphologically complex terrace (3-1) in the west-

ern part, a sub-recent colluvial process on the thermogenic landslide is distinguished. The eastern part of the terrace is exposed to linear fluvial erosion and denudation, especially at the edge of the terrace. This is the only example of significant activities of slope processes on the studied relict morphology.

Figure 7. A series of cryoplanation terraces (3-1, 3-2, 3-3, 3-4) on Vrla strana next to the Bugarin ridge

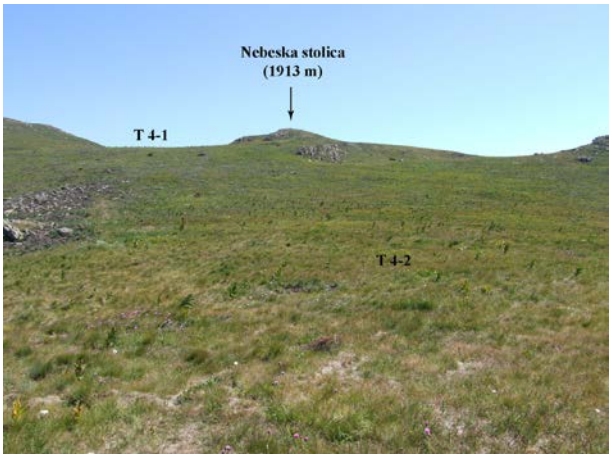

Figure 8. Cryoplanation terraces (4-1 and 4-2) on the wide watershed of Nebeska stolica

On the ridge, more precisely on the watershed below the Bugarin peak there is a cryoplanation terrace (34) inclined 3 – 5°, 100 m long and 60 m wide. Similar cryoplanation terraces on the watershed have been detected on Nebeska stolica (4) between the lairs on the parts of the ridge that had been extended by cryoplanation process. A series of three terraces at the altitudes between 1827 - 1910 m and the coordinates 43° 15′ 38.2″ (S), 43° 15′ 47.0″ (N), 20° 50′ 2.6″ (W) and 20° 50′ 16.0″ (E) has been distinguished. Cryoplanation terraces on Nebeska stolica are morphologically different from the terraces described on the slopes.

The highest terrace (4-1) in a series cuts the lair at the peak of Nebeska stolica (1913 m) on its west side. At the point of separation of the secondary ridge of Nebeska stolica in direction to Vojetin, the second cryoplanation terrace emerged (4 - 2), 125 m long and 70 - 100 m wide. The terrace is tilted toward the south at an angle of -22°. The lower terrace (4-2) in the north cuts the terrace (4-1) at the height of 4-5 m.

On the southeast slope towards Vojetin, the lowest terrace had been cut (4-3), with the inclination of 10°, 70 m long and 35 m wide. The terraced series on Nebeska stolica had been carved in the schists, of which the first two (4-1 and 4-2) have indeterminate exposure on the wide watershed south of Pančićev vrh (2017 m), while the third (4-3) on the slope has a southeast exposure.

5. DISCUSSION

The analysis indicates that relict cryoplanation terraces had been developed on slopes (sites 1, 2, 3) and wide watersheds (terraces: 3-4, 4-1 and 4-2) on Kopaonik, which has been known in the literature (Czudek, 1995; Hall & André, 2009). The fact that terraces are covered with pastures indicates their relict features. Regardless of this, the relief may be studied in paleogenetic and recent context.

It is most often cited in the literature that geological structure and climate are significant for the emergence of cryoplanation terraces (Czudek, 1995). In the example on Kopaonik the influence of geological structure has been observed, in the sense that large and spacious terraces with recent slope processes had emerged in the serpentinites. On these terraces the processes of ravining (linear erosion), denudation at ridges and gelifluction on the ridge of the large terrace (3-1) have been distinguished. Apart from the occurrence of thermogenic landslides, other processes are beyond the domain of periglacial and as such are secondary to the genesis of cryoplanation terraces.

All terraces (sites: 1, 2, 3 and 4) are covered with grass vegetation, which makes them to be inactive cryoplanation forms. On the highest terrace (4-1) on the wide ridge of Nebeska stolica, the probe was opened in a pedological horizon at a depth of 67 cm, all the way to parent material with homogeneous loose mountain chernozem, which is the indicator of seasonal freezing of land at an altitude of 1900 m.

Climatic and chronological framework of emergence of cryoplanation terraces on Kopaonik should be sought in the domain of the last glacial maximum (LGM), when the investigated area had been above the upper forest boundary under the influence of cold periglacial climate. According to

Reger & Péwé (1976) cryoplanation terraces form when the mean annual air temperature is -12 °C, while the mean summer temperatures range from 2 to 6 °C. Such conditions could have been on Kopaonik only during the last glacial maximum (LGM). Most recent research on the Balkan Peninsula in the mountains south of Kopaonik show that the snow line during the LGM had been at 1750 m above the sea, on the Prokletije Mountains (Milivojević et al., 2008), i.e. glacial equilibrium-line altitude (ELA) at Šar planina had been in the range from 1950 to 2150 m (Kuhlemann et al., 2009). On the basis of the theoretical concept of the height of alpine periglacial environment of at least 1000 m above the sea (in recent relations between the atmospheric circulation, air temperature and precipitation), and on the basis of the height from 1750 - 2150 m of the snow line and ELA, the upper forest boundary on Kopaonik could have been at the altitudes from 750 to 1150 m. Therefore, far below the height of the identified relict cryoplanation terraces. In conditions of cold and dry climate, for which there are indications from palynological profile of high-mountain lakes in Bulgaria (Wright et al., 2003), the lower forest boundary could have been even lower. Due to the application of a qualitative geomorphological procedure, a more detailed chronological frame of the Last Pleistocene (Dryas stages) and Holocene cooling stages (Little Ice Age) and their influence in the development of the studied terraces has not been possible so far.

6. CONCLUSION

On Kopaonik, a mountain of the central part of the Balkan Peninsula, cryoplanation terraces have been first isolated as the relict relief of the last glacial maximum (LGM) of the Late Pleistocene. Featured terraces were formed in metamorphic rocks, with noticeably larger dimensions in serpetinites than terraces carved in the schisms. Exposure of terraces is subject to local orographic characteristics of the slopes into which they are cut and is mostly southeast and south, and is generally with sunny-slope exposure, which differs from the result of central Alaska, but is consistent with the results of the Alexander Island in Antarctica (Hall & André, 2009).

Dependance of terraces' exposure on orography of slopes is also present on Pohorje (1543 m) in Slovenia. There, on southern, sunny-slope exposures, terraces of larger dimensions than the northern terraces with shady-slope exposure (Obu, 2011) are observed.

Distinction of relict cryoplanation terraces on Kopaonik does not provide answers to the problem of cryoplanation as one of the basic concepts of periglacial geomorphology. Relict cryoplanation terraces on Kopaonik, in a region where they have not been known so far, are significant for a broader determination of areas where these genetically problematic periglacial forms are present. This helps in solving the problem of cryoplanation within basic studies of regionalization, which has been identified as one of the primary goals of the research of this problem (Czudek, 1995). The discovery of relict cryoplanation terraces on Kopaonik is important because it opens up the possibility of broader regional research in the Balkan Peninsula, which will successfully solve the problem of concept of cryoplanation, but also as a basis for paleoclimatic reconstructions and other research.

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