GLACIO-KARST FEATURES OF THE SINJAJEVINA MTS (MONTENEGRO): AN OVERVIEW AND DEM-ANALYSIS

TELBISZ TAMÁS
ELTE Természetföldrajzi Tanszék, 1117 Budapest, Pázmány Péter sétány 1/C.,
telbisztom@ludens.elte.hu

Abstract: *Sinjajevina Mountain with Jezerska Povrs form a large karst plateau of 928 km^2 area, SE of Durmitor Mt in Montenegro. Plateau elevation gradually rises from 1300 m to 1800 m along a NW-SE trend. The plateau relief is generally flat but towards SE smoothed ridges dissect the landscape, whereas the highest peaks (above 2200 m) are found on the southeasternmost, glacially sharpened ridges. During the Pleistocene glacial periods the planina could be covered by a several 100 m thick ice sheet and valley glaciers were connectedly formed in the deep southern and eastern valleys. The scouring effect of this ice sheet can be detected in the rolling landscape of the plateau. At present, the surface is mostly covered with dolines. Karren forms are relatively rare and most part of the plateau is covered by pastures as a consequence of XIXth century deforestation. Geomorphological features were analyzed using digital terrain analysis.*

Introduction

East and southeast of Durmitor Mts (Montenegro) a 928 km^2 large karst plateau stretches with NW-SE orientation (*Fig.1*). Its northwestern, flat part called Jezerska Povrs (or Jezera) accounts for about one sixth of the total territory. Jezera is often thought of as the foreground of Durmitor Mts (*LIPOVAC*, 1987; *MAROVIC, MARKOVIC*, 1972). The highest peak of Sinjajevina, the 2277 m high Babin zub is found at the southern part of the mountain. The boundaries of the mountain are morphologically well-defined due to the deep valleys (canyons) around it. The only problematic boundary is to the NW where the river valleys are absent. The boundary towards Jezera can be defined by the decrease in the relative relief and by the change in the surface material: the Jezera is predominated by glacial and glacio-fluvial sediments (according to the geological maps and *MAROVIC, MARKOVIC,* 1972; *Fig.2*). The Jezera-Durmitor boundary can be defined similarly.

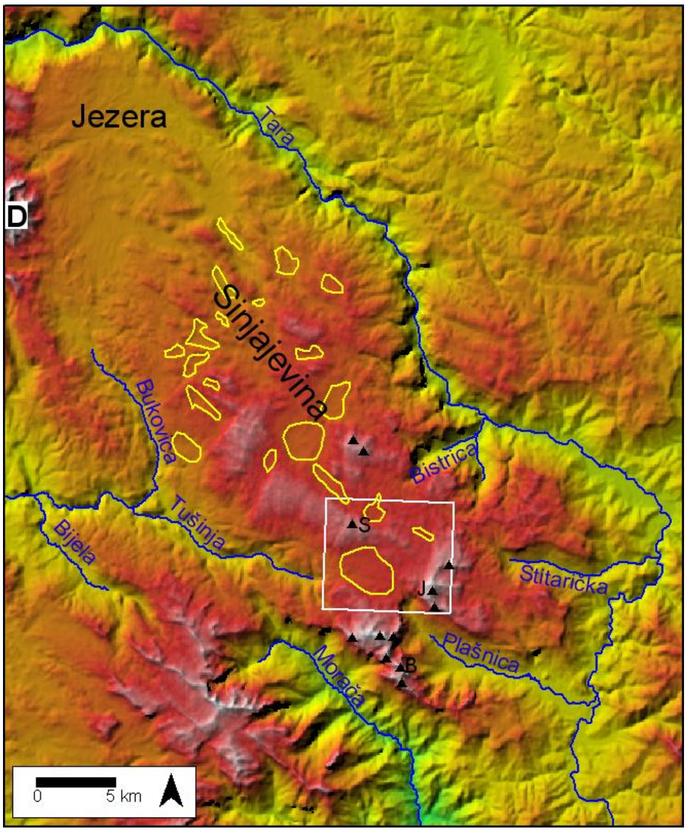

Fig.1: Shaded relief map of Sinjajevina Mts (data from SRTM). „Circle”: so-called polje; black triangles: peaks over 2000 m a.s.l.; D: Durmitor Mts; S: V.Starac; J: Jablonov vrh; B: Babin zub.

According to the geological maps (*KALEZIĆ, MIRKOVIĆ,*1966; *MIRKOVIĆ, VUJISIĆ*, 1989; *ŽIVALJEVIĆ* et al, 1981) the plateau is built up of more than 1000 m thick Triassic and Jurassic limestones. The Plašnica and Štitarička valleys were formed along the axes of eroded anticlines, thus older Permian metamorphic rocks are exposed in the lower hillslopes of these valleys.

The uplift of the Sinjajevina occurred in several phases since the Cretaceous. The tectonically inactive periods resulted denudation surfaces (peneplains). In the Sinjajevina, the most characteristic of them is the level around 1600 m a.s.l., which could be formed in the early Pliocene as an abrasion surface. Deep valleys around the plateau were incised due to the increasing uplift since the end of Pliocene (*LIPOVAC*, 1987). During the Pleistocene cold periods, glacial processes effectively formed the landscape. According to the map of *MAROVIC*, *MARKOVIC* (1972) the valley glaciers expanding from Durmitor Mts reached the Jezera plateau in the foreground (1300 m a.s.l.) where a large ice sheet was formed and some smaller glaciers branched off this ice sheet towards the Bukovica, Tara valleys and the Sinjajevina embayments (*Fig.2*).

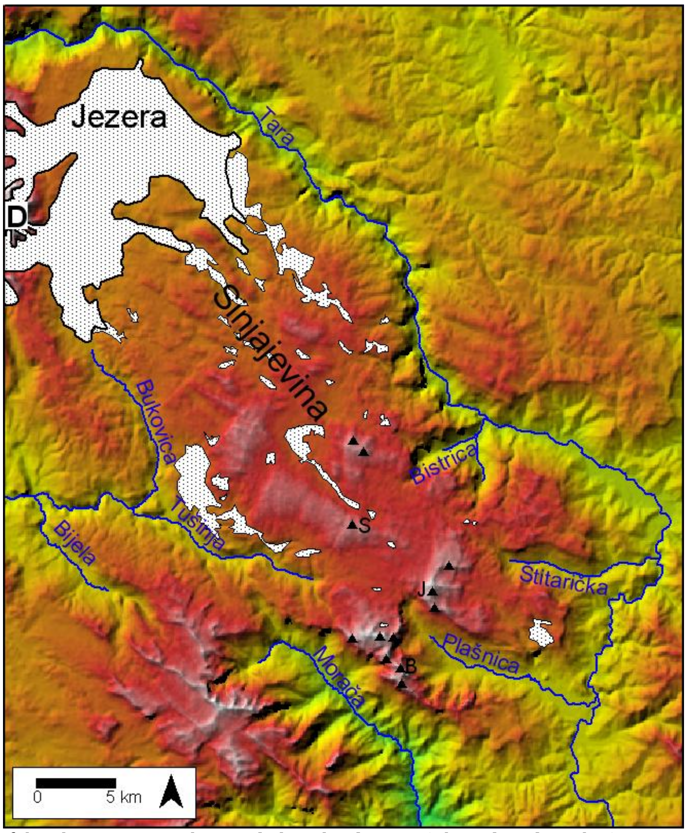

Fig.2: The extent of the pleistocene ice sheet and glacial sediments (white, dotted patches) in Sinjajevina and Jezera (source: MAROVIC, MARKOVIC, 1972; geological maps)

According to *LIPOVAC* (1987) the relief of Sinjajevina is relatively slightly moderated by glacial erosion and the amount of moraine material is also less than in the surrounding mountains (especially Durmitor Mts) therefore there could be no larger ice sheet in the Sinjajevina. Exceptions are the southern, higher ridges and the valleys dissecting the plateau rim (Plašnica, Štitarička), where lateral and terminal moraines are both found as remnants of the former valley glaciers even at 900 m a.s.l near the mouth of the Plašnica valley. This low position is quite surprising at first sight, but there are several publications about glacial material at such low or even lower elevation in the Balkan. (*HUGHES* et al, 2006; *MILIVOJEVIĆ* et al, 2008 and references therein).

Since the end of glaciation (and during the interglacials) karst processes have been predominant. At present, the plateau surface is covered with a vast number of dolines, in many cases arranged as doline rows or as uvalas (*LIPOVAC*, 1987). Some larger, closed depressions, locally called as „polje" are also observed on the plateau (*Fig.1*), however these are not „classical" poljes: their bottom is neither so flat, nor is there any alluvial fill in them and their bottoms are not in the level of the karst water table although after snow melt these poljes may be partly filled with water.

Bare karren forms are relatively rare since most of the terrain is grazing land due to the XIXth century deforestations.

Mean annual temperature is 4-5°C, the annual sum of precipitation is high, 1500-2000 mm, and due to the Mediterranean mountain climate the proportion of winter snow precipitation is also high (*LIPOVAC*, 1987).

Methods

In the present paper, the relief characteristics of the Sinjajevina Mts are examined by digital terrain analysis. Doline morphometry of the area is addressed in another study (*TELBISZ, 2009, submitted*)

Digital terrain analysis of the mountain was carried out using the SRTM database (*RABUS* et al, 2003) with horizontal grid resolution of 90 m. The 1:50000 scale topographic maps, the 1:100000 scale geologic maps and GoogleEarth images were also used in the analysis. All these data were georeferenced into UTM coordinate system and integrated into a geodatabase.

GIS-analysis was performed with the help of ArcView GIS 3.2 software.

Results and discussion

The elevation histogram created from the DEM (*Fig.3*) may help in determining the characteristic level of Jezera and Sinjajevina. It shows that 66% of the whole terrain is situated between 1300 m and 1800 m a.s.l. The lower section of this elevation range (below 1450 m) is typical for the Jezera, whereas the higher section of this pronounced level makes up the Sinjajevina plateau surface (*Fig.4*). Higher ridges rise from this surface in the central and southern parts where these exceed 2000 m a.s.l. These ridges are usually rounded except the ones along Plašnica valley, where the only real alpine type sharp, rocky landforms of Sinjajevina are present (including the highest peaks). Cirques are situated at the eastern and northern sides of the main peak's ridge and at the eastern side of the third highest peak (Jablonov vrh, 2203 m). These aspects imply that westerly winds were likely to dominate during the glacial periods, too.

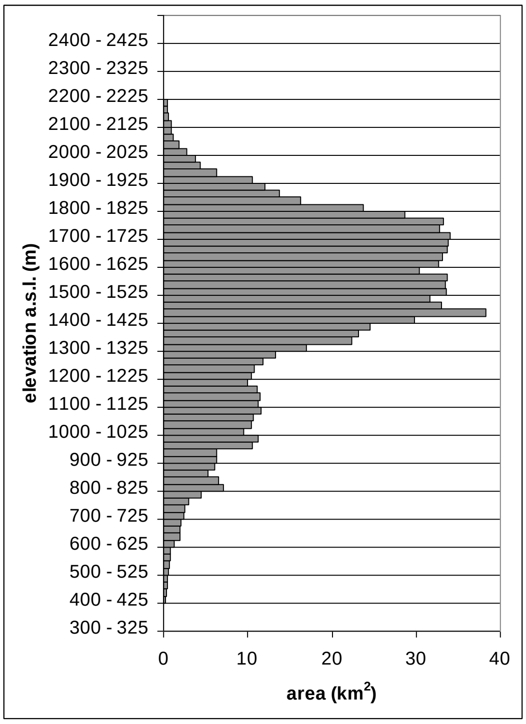

Fig.3: Elevation histogram of Sinjajevina and Jezera

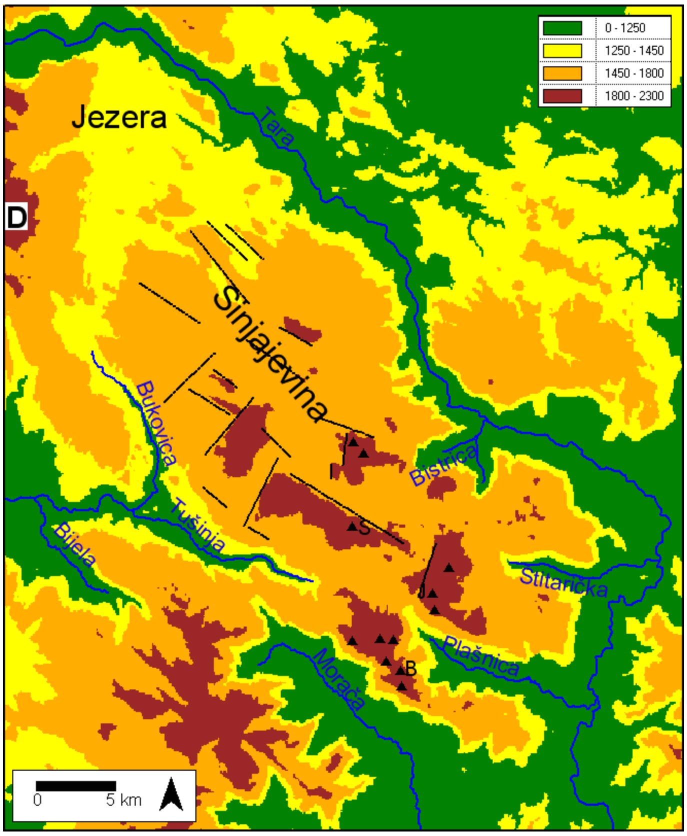

Fig.4: Pronounced elevation levels in Sinjajevina and Jezera with structural lines

Regarding the slope map (*Fig.5*) it is clear that most part of the Jezera is characterized by slope angles less than 5°, whereas in the Sinjajevina this low slope category is mainly limited to the territory of the so-called poljes. Taking into consideration the steep, rectilinear hillslopes, several lineaments can be observed with NW-SE and SW-NE orientations. Some of them coincide with structural lines drawn in the geologic maps, but not all. NW-SE lineaments are usually parallel with fold axes and rectangular to the dip direction so these steep slopes can be interpreted at some locations as bassets of cuesta-like ridges. The NW and NE sides of ridges rising above 1800 m a.s.l. are typically bordered with these lineaments (*Fig.4*) therefore it is possible that these slopes denote vertical displacements along fault lines.

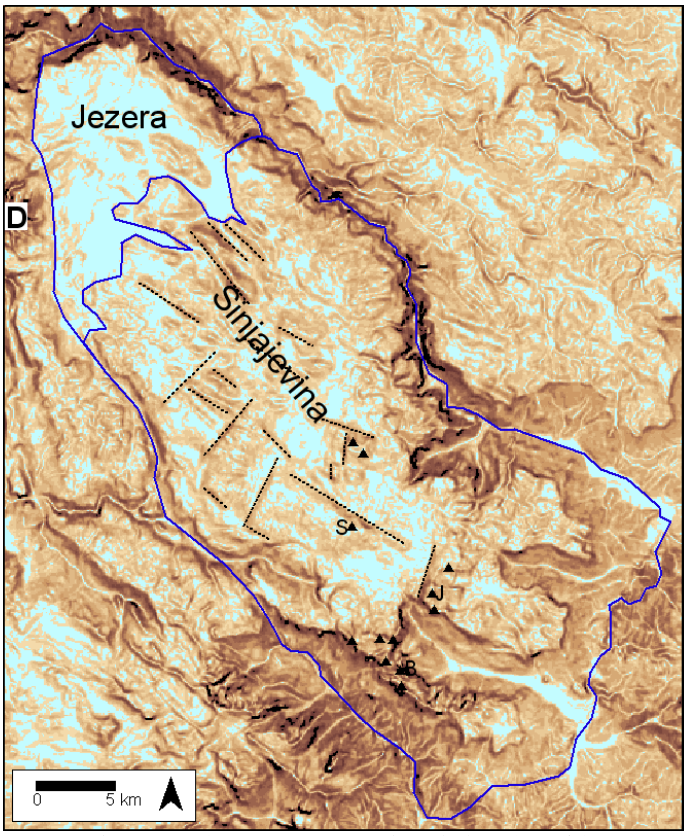

Fig.5: Slope map with lineaments. White areas: slope<5°. Continuous line: the boundary of the mountains. Dotted line: lineament.

Based on the satellite image (GoogleEarth) the present-day small proportion of forests to bare, grassy land is well detected. Furthermore, a remarkable radial pattern is observed next to the Bistrica valley head, at the plateau rim (*Fig.6*). This pattern consists of small (only few meters deep) „channels" (presently forming connected dolines). The pattern itself is hardly recognizable from the surface. This pattern is most probably the result of glacial scouring.

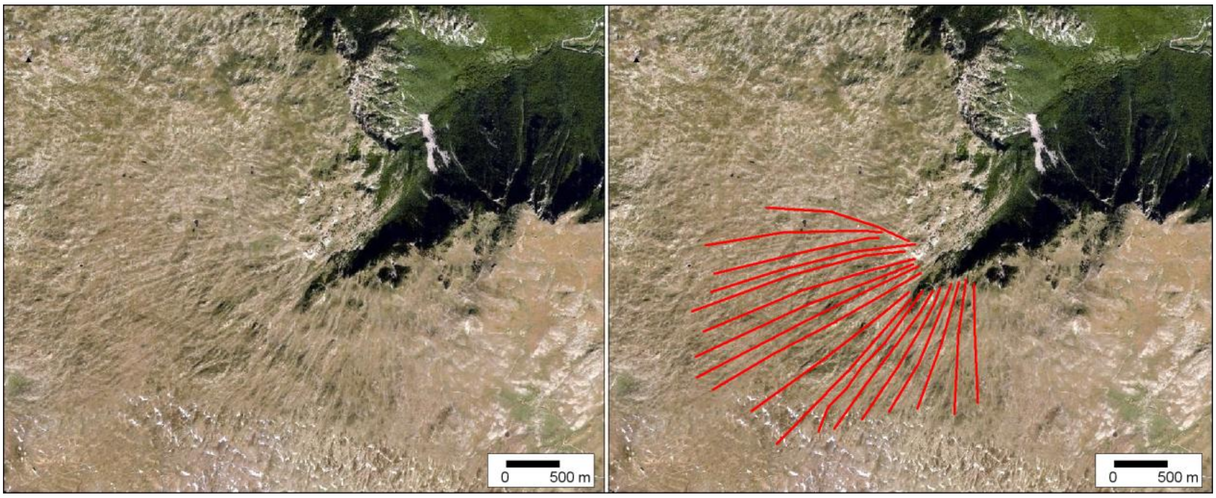

Fig.6: Glacially scoured radial pattern next to the Bistrica valley head
(Left: GoogleEarth image; Right: the radial pattern outlined with black lines)

The Plašnica valley is admittedly a glacial valley as it is proved by moraines. Other glacial features of it are the rocky shoulders, the flat (though not too wide) valley bottom and the steep, rocky upper hillslopes (*Photo 1*). However the presently forest-covered debris slopes are well-developed along the valley and the typical U-shape of glacial troughs is not so obvious in the elevation profiles (*Fig.7*).

Photo 1: The Plašnica valley viewing from the plateau rim towards SE

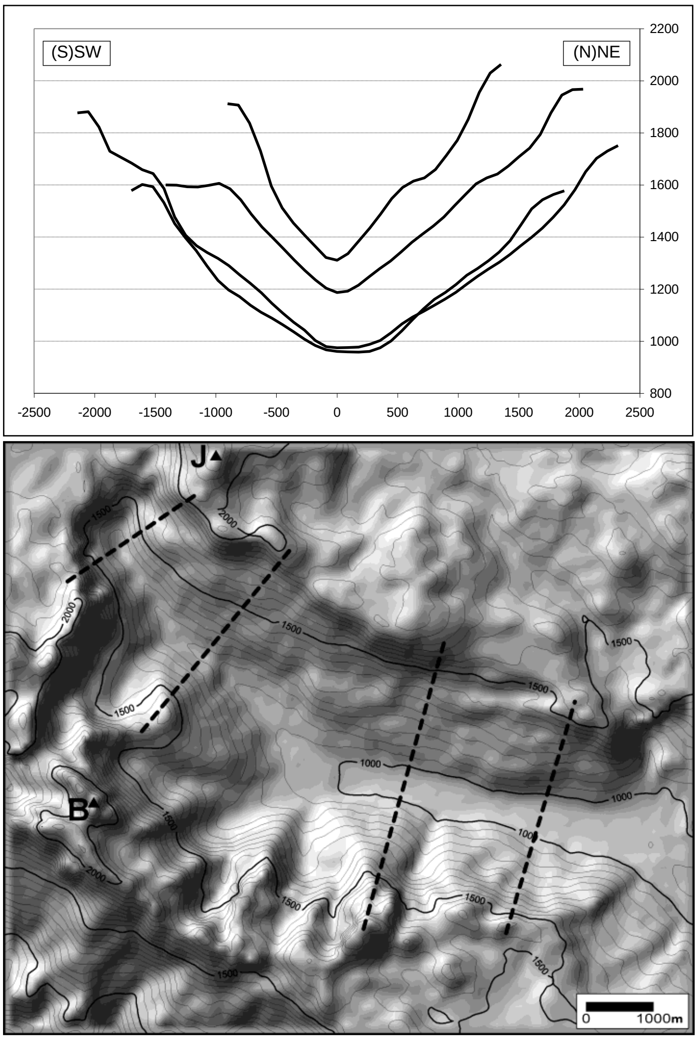

Fig.7: Above: Elevation profiles across the Plašnica valley (distance and elevation in meters); bottom: profile locations

On the relatively flat surfaces of the plateau the interdoline ridges are strongly rounded and in many cases arranged into strips (*Photo 2*). These landforms also suggest strong glacial erosion of the area.

Photo 2: In the foreground: eroded, undulating plateau surface; background: N side of the high ridge at the southern rim of Sinjajevina

Conclusions

Considering the morphological evidences of glacial processes, it is supposed that the mountains were covered with a thick plateau glacier. The formation of the ice sheet could start with the accumulation of snow/firn within the so-called poljes at the onset of Pleistocene glaciations. This snow accumulation could be supported by high winter precipitation. The relatively small amount of moraine material found within the mountains can be explained assuming that the central ridges were almost entirely covered with ice, therefore the production of rock debris was hindered. This assumption implies 2-300 m thick ice. The ice sheet moved slowly towards the deep valleys around the plateau rim and could feed valley glaciers (analogous to the present-day Jostedalsbreen in Norway). It explains the low elevation of glacier termini as well.

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