MORPHOLOGY AND GIS-ANALYSIS OF CLOSED DEPRESSIONS IN SINJAJEVINA MTS (MONTENEGRO)

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

Abstract: *Sinjajevina Mts are found in Montenegro SE of Durmitor Mts. This large plateau surface is covered with glacio-karst features of several order of magnitude. The largest closed depressions of 0.2-7 km^2 area are locally called poljes although these are different from classical poljes. Cirque valleys are another group of (semi-)closed depressions and at present these glacial forms are reshaped by karst processes. Dolines cover most part of the area and their density is calculated 21.7 km^{-2} in a smaller sample area from topographic maps. Dolines are usually closely scattered and in many cases without clearly defined borders. Interdoline ridges are well-rounded probably due to glacial erosion. Furthermore, the plateau surface is dotted by numerous small swallow holes (with depth and diameter of some meters) in a very high density (136 km^{-2} according to our GPS-measurements in a smaller sample area). On the central, higher, smoothed ridges, a „young stage" polygonal karst type is also observed. These types of closed depressions were analyzed in a GIS-framework including digital elevation models and doline morphometry using topographic maps and GPS-survey.*

Introduction

Sinjajevina is a large karst plateau SE of Durmitor Mts with characteristic elevation range between 1300 and 1800 m a.s.l. and higher alpine type ridges exceeding 2200 m (highest peak: Babin Zub, 2277 m). General geomorphological description of the mountains is found in *LIPOVAC* (1987) and an overview of glacio-karst features is given by *TELBISZ* (2009 *submitted*).

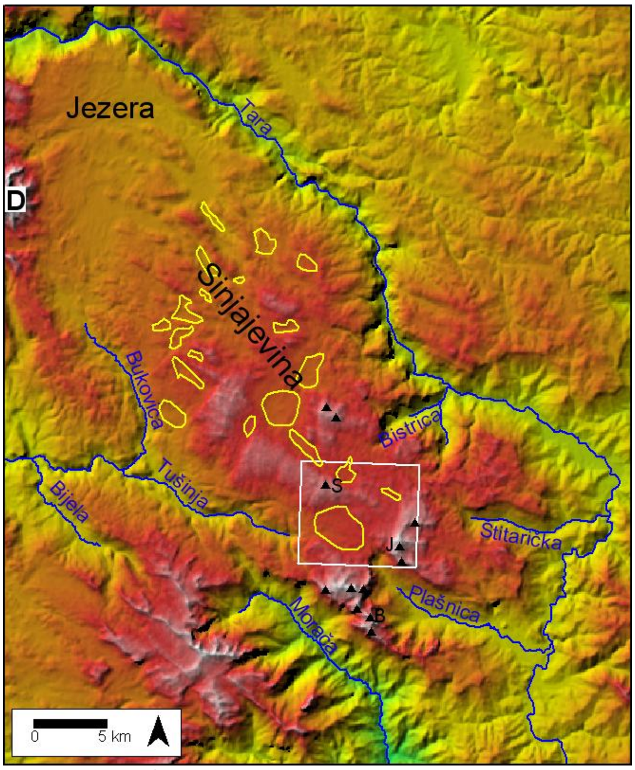

Fig.1: Shaded relief map of Sinjajevina Mts (data from SRTM). White rectangle: sample area; yellow „circles": „poljes"; black triangles: peaks over 2000 m a.s.l.; D: Durmitor Mts; S: V.Starac; J: Jablonov vrh; B: Babin zub.

In the present paper, closed depression morphology is examined using field survey and GIS-analysis in a smaller sample area (see *Fig.1*). At present, doline morphometry is a resurgent field of karst geomorphology since GIS-methods provide several new tools for the analysis (e.g. overlay of different kind map data; easy calculations; variable visualizations) that is proved by the large number of recent publications using these methods (e.g. *ANGEL et* *al, 2004; DENIZMAN*, 2003; *FAIVRE, PAHERNIK*, 2007; *ORNDORFF et al, 2000; TELBISZ, 2001; TELBISZ et al, 2007*).

Methods

Field investigations took place in the SE parts of the Sinjajevina Mts. Beside the observation of landforms, swallow-hole locations and doline borders have been mapped by handheld GPS-instruments in some sample areas.

For the digital terrain analysis several digital elevation models (DEM) have been used. First, the SRTM database (*RABUS* et al, 2003) with horizontal grid resolution of 90 m. A more detailed DEM of the 7 km x 8 km sample area was created using the 1:25000 scale topographic maps by the digitization of contour lines and Kriging interpolation. The horizontal resolution of this detailed DEM was set to 20 m.

GIS-analysis was performed with the help of ArcView GIS 3.2 software. Dolines were digitized from the 1:25000 scale topographic maps. Doline density maps were created using Kernel algorithm, doline axis azimuths and lengths were calculated by *JENNESS'* (2003) algorithm. Larger, closed depressions were determined using standard hydrologic modelling tools (for the theoretical background see *MARTZ, GARBRECHT*, 1998).

Results and discussion

There are closed depressions of several magnitude in the Sinjajevina Mts. The largest type is of 0.2-7 km^2 areal extent. These are locally called as „polje" (*Fig.1*) however, these are not „classical" poljes: their size is smaller, their bottom is neither so flat, nor is there any alluvial fill in them and polje bottoms are not in the level of the karst water table although after snow melt these large depressions may be partly filled with water. Their origin is not yet fully explained but beside karst processes, tectonics could also play a role since it is demonstrated that in several cases structural lines border them (*TELBISZ*, 2009 *submitted*).

In the SE parts of Sinjajevina Mts, cirque valleys of glacial origin form (semi)-closed depressions (two of them can be seen in the SE part of *Fig.2* as well) and the interplay of glacial and karst processes is obvious in the present surface (as it is discussed in general by e.g. *FORD, WILLIAMS*, 2007).

In most part of the plateau (and the sample area) dolines cover the surface. However, in many cases, doline borders are difficult to precisely define since dolines are not isolated from each other but form large complexes (uvalas) or strips. Moreover, interdoline ridges are strongly rounded due to glacial erosion (*Photo 1, TELBISZ, 2009*).

Photo 1: Rounded interdoline ridges

Fig.2 presents the dolines and the larger, closed depressions (~uvalas) of the 56 km^2 sample area. Based on the topographic maps, 1215 dolines were found in the sample area resulting in a density of 21.7 km^{-2}. It is noted that both the number and the size of dolines are underestimated using the topographic maps but it is difficult to quantify the ratio of underestimation. The spatial distribution of dolines visually does not show any clear pattern or regularity. Its nearest neighbour index (*CLARK, EVANS*, 1954) is 0.92 supporting also a random pattern. It is not surprising that dolines are formed at lower slope categories (for this analysis the „generalized" SRTM DDM was used): 84% of them are found on slopes less than 10° and 95% on slopes less then 14°. Linear arrangement of dolines is observed at many locations, however, it can not be stated as a general rule.

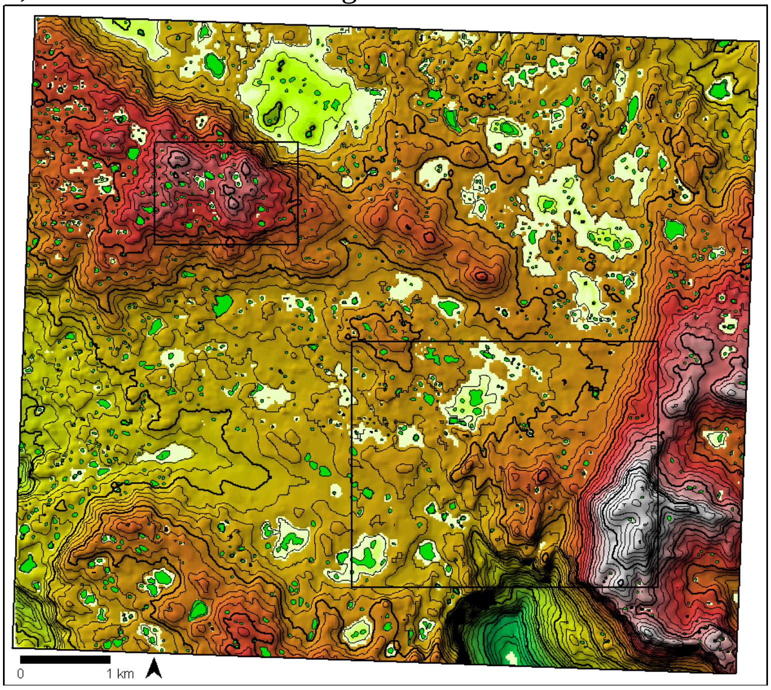

Fig.2: Dolines and larger, closed depressions in the sample area. Green polygon: doline marked in the topographic map. Pale green patch: large, closed depression delineated by the hydrologic „fill" command. Black boxes: NW: map frame of Fig.5; SE: map frame of Fig.4. Contour interval is 20 m.

The number and mean area of dolines decrease with height (*Fig.9a*). Frequency distribution of doline area (*Fig.9b*) is somewhat different from the general lognormal distribution (cf. *TELBISZ* et al, 2007 and references therein), namely, the small-sized dolines are present in a larger proportion than expected from the lognormal distribution. This result means that doline evolution is still in an „immature" state, i.e. there was not enough time for the dolines to grow and coalesce. Doline long axis directions (*Fig.9c*) clearly show a NW-SE and a SW-NE trend. These maxima are in good accordance with structural and relief orientations of the whole mountain.

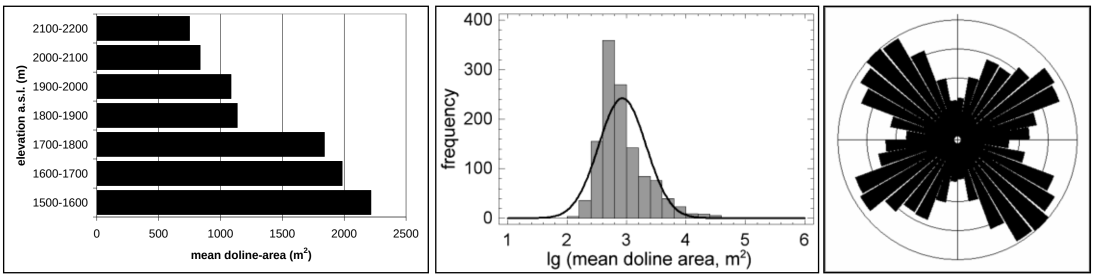

Fig.3: Some important morphometrical parameters of dolines (in the sample area)
a) Mean doline area vs elevation a.s.l.
b) Doline area frequency distribution (in a semilog plot)
c) Rose diagram of doline long axes

On the plateau surface, the most frequent closed depressions are the smallest features: swallow-holes with diameter and depth of only few meters (that is much smaller than dolines, *Photo 2-3*). Nivation seems to play an important role in their formation (*Photo 3*). These small depressions were mapped by GPS in a small segment (2.36 km^2) of the sample area. These swallow-holes are found in groups at the bottom of dolines but in many cases these forms sink into ridges and hillslopes as well. Their density is 136 km^{-2} in the mapped area (*Fig.4*).

The evolution of the numerous small-sized swallow-holes seems to be a recent, ongoing process. It is highly possible, that the rate of this process has been increased as a response to XIXth century deforestation.

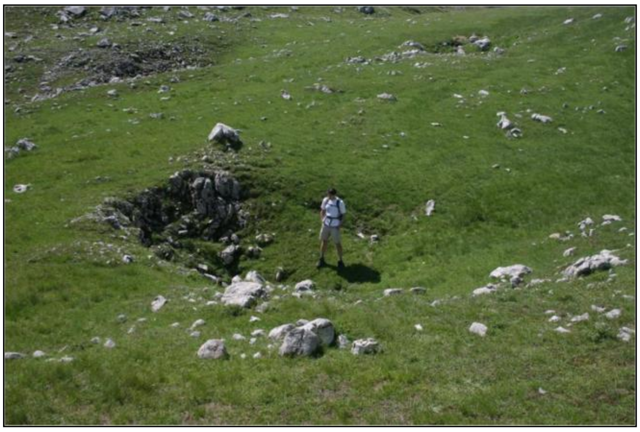

Photo 2: Small-sized swallow-hole W of Jablonov vrh

Photo 3: Snow-filled swallow-holes SE of Jablonov vrh

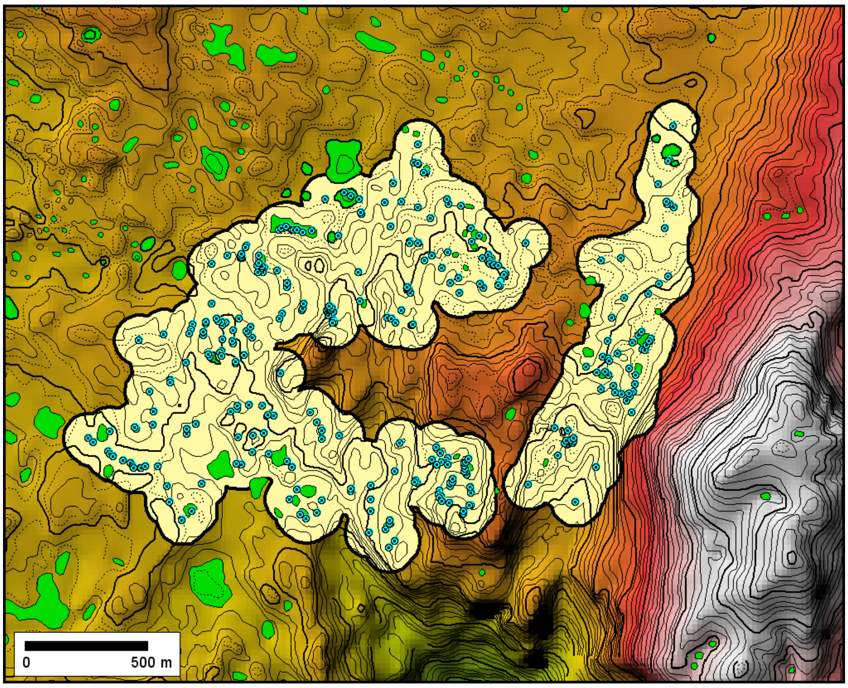

Fig.4: Spatial distribution of swallow-holes mapped by GPS. Green polygon: doline. Small, pointed circle: swallow-hole. Yellow patch: areal extent of GPS mapping. Contour interval is 10m.

In the top region of V.Starac ridge (in the southern, central part of Sinjajevina) doline features are different (*Photo 4*). Large vertical ratio (depth/diameter) and narrow interdoline ridges are typical at this locality, therefore this area can be identified as a polygonal karst (*FORD, WILLIAMS*, 2007) although not fully developped. The polygonal ridge-network and the swallow-holes have been mapped here by GPS (*Fig.5*). Doline density is calculated 50.5 km^{-2} after the map, 77.1 km^{-2} after the GPS-measurements and swallow-hole density is 188.8 km^{-2} again from the GPS-data. Furthermore, it is concluded that the ridge network can be relatively well derived from the topographic map using hydrologic modelling (although results are not presented here for the lack of clarity of *Fig.5*).

Photo 4: Dolines with large depth/diameter ratio near V.Starac peak.

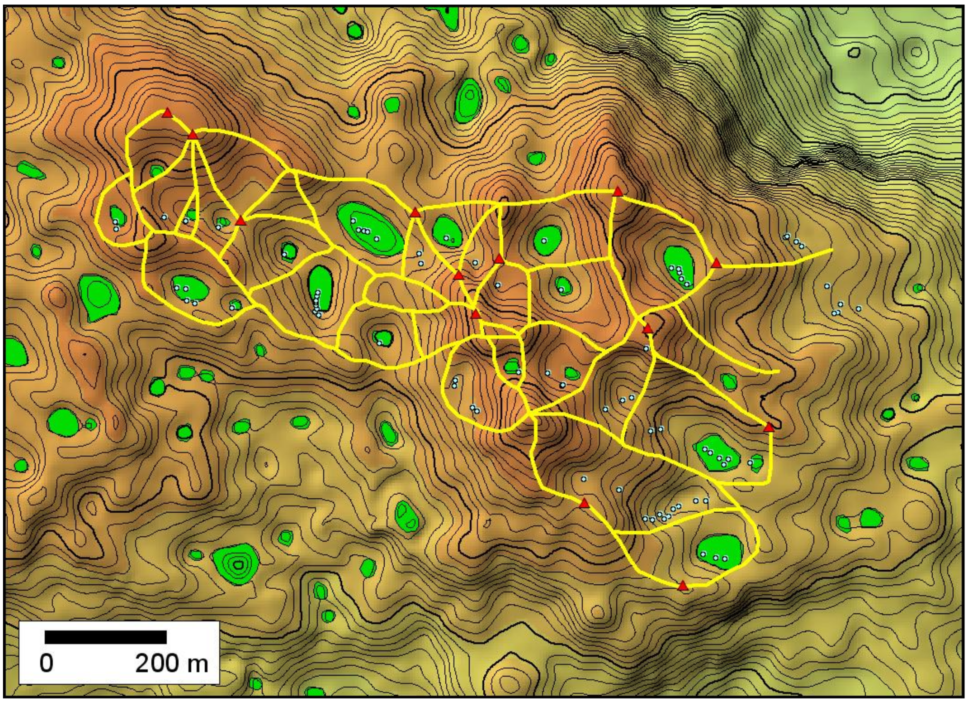

Fig.5: The polygonal karst of V.Starac. Green polygon: doline (after the topographic map); small circle: swallow-hole (by GPS); yellow line: interdoline ridge (by GPS). Contour interval is 5m.

Conclusions

Closed depressions of Sinjajevina Mts can be classified into four types.
1) Large depressions (0.2-7km^2 area) of karstic-structural origin are found in the plateau.
2) In the SE part, an alpine type glacio-karst terrain is formed with cirque valleys.
3) On the central, relatively high, rounded ridges a „young stage" polygonal karst is observed.
4) On the lower, vast plateau surfaces, the formation of dolines and swallow-holes takes place on a terrain strongly eroded by glacial processes.

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