GEOMORPHOLOGICAL PROPERTIES OF THE KRASNO POLJE, NORTHERN VELEBIT, CROATIA

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Abstract
The Krasno polje is located within the Northern Velebit Mountain in the Dinaric Alps, Croatia. It is completely filled with gravel and is inactive in a hydrological sense. We established that slopes above the polje were intensively modified by glacial action during the colder periods of the Pleistocene. Therefore, proglacial fans filled the karst depression, forming a piedmont polje. We assume that the polje was filled by proglacial material over at least two separate glacial events.

Key words: Dinaric Alps, Velebit Mountain, polje, glaciations, Croatia

GEOMORFOLOŠKE ZNAČILNOSTI KRASNEGA POLJA, SEVERNI VELEBIT, HRVAŠKA

Izvleček
Krasno polje se nahaja v severnem Velebitu v Dinarskem gorstvu na Hrvaškem. Kraško polje je popolnoma zapolnjeno s prodom in v hidrološkem pogledu neaktivno. Ugotovili smo, da so bila pobočja nad poljem v hladnejših obdobjih pleistocena izrazito preoblikovana z ledeniškim delovanjem. Tako so predledeniški vršaji zapolnili kraško kotanjo pod njimi in oblikovali piedmontski tip kraškega polja. Domnevamo, da je bilo kraško polje zapolnjeno s predledeniškim materialom vsaj v dveh različnih poledenitvenih fazah.

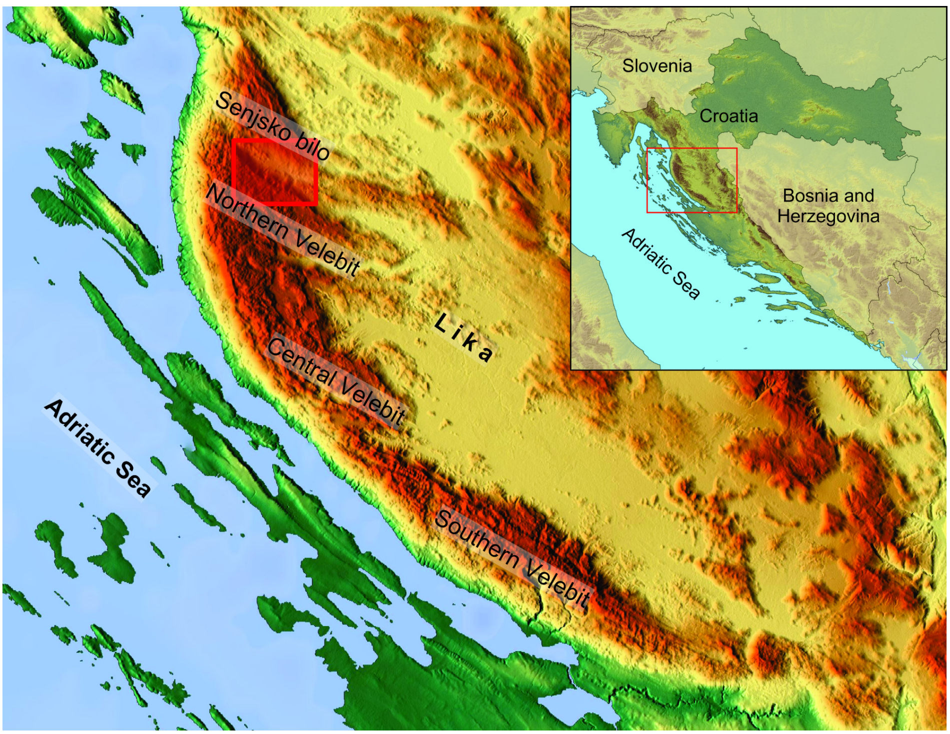
Ključne besede: Dinarsko gorstvo, Velebit, kraško polje, poledenitev, Hrvaška

1. INTRODUCTION

The Dinaric Alps are one of the largest contiguous mountain belts of the European part of the Eurasian orogen, with a total length of 645 km and a width of approximately 150 km. They are positioned between the Pannonian Basin in the northeast and the Adriatic Sea in the southwest. The Dinaric Alps are separated into different natural belts in which morphology is strongly influenced by differences in lithology. Inland, non-carbonate rocks hosting fluvial relief prevail, while the central and outer belts are formed mostly of limestone and dolomite – therefore karst landscape prevails. Characteristic forms associated with the karst area of the Dinaric Alps are extensive mountains, large levelled corrosion plains and intramontane basins which host poljes (Mihevc, 2010). Whole surface is dissected by smaller karst features such as uvalas, dolines, canyons, dry valleys and collapse dolines.

Poljes are the largest enclosed depressions in karst. Their size distinguishes them from other depressions, as do their large flat floors. There are about 130 poljes in the Dinaric karst region (Gams, 1978). Most of them are elongated along the strike of the Dinaric Alps which runs in a northwest–southeast direction, as most of them developed along regional fault lines, graben structures or overthrusts.

Figure 1: Location of the study area
Slika 1: Lega preučevanega območja



The most extensive topographic massif within the Dinaric Alps is Velebit Mountain which is situated within the northwestern part of the Dinaric Alps in Croatia. It rises sharply from the Adriatic coast between 44.2–44.85° N and 14.9–16.05° E, and covers an area of about 2274 km^2. It extends to a length of 145 km, with an average width of about 15 km. East of Velebit Mountain is the Lika region; to its south and southeast it borders Zrmanja and Krupa canyons, and to the west it steeply descends towards the Adriatic Sea. It is dissected by areas of lower terrain where two poljes are also situated: Baške Oštarije polje (Perica, Bognar, Lozić, 2002) and the Krasno polje.

The main purpose of this article is to present morphographic and morphometric data relating to the area of the Krasno polje, to determine the morphogenesis of the polje, hydrological function and to present morphochronological assumptions about its formation.

2. REGIONAL SETTINGS

The northern section of Velebit Mountain is dissected by an area of lowered terrain, the Oltari pass, which also hosts the Krasno polje. The basin of Krasno polje is enclosed between the highest part of the Northern Velebit Mountain to the south and its lower northern extension, the Senjsko bilo. The lowered relief in between is distinctly elongated in a northwest–southeast direction. The highest elevation of the polje is about 850 m, from where it gently lowers to an elevation of 660 m on the southeastern side. The width

Figure 2: Aerial photograph of Veliko polje (in the foreground) and Jerkuše area (photo: V. Glavaš)
Slika 2: Zračni posnetek območja Velikega polja (v ospredju) in Jerkuš (foto: V. Glavaš)

of the polje is not uniform, as the floor consists of three enlargements. The northwestern enlargement, Jerkuše, is 800 m wide and about 1700 m long; the central enlargement Veliko polje is 600 m wide and 1700 m long, and the lowest enlargement, Malo polje, is 300 m wide and 600 m long. Northern and eastern slopes above the polje floor are well karstified, covered with karren and dolines. Southern slopes are much steeper, karstified and covered with karren; dolines are almost absent due to the high inclination of the active slopes (Stepišnik, Kosec, 2012).

The Northern Velebit Mountain was intensively modified by glaciation during the Pleistocene (Bognar, Faivre, Pavelić, 1991a; 1991b). The ice cap which supposedly occupied an area of about 115 km^2 was positioned at an altitude above 1300–1400 m. On southern slopes above the Krasno polje, three cirques were identified: Žestikovac, Splitvina and Ripljevica (Bognar, Faivre, Pavelić, 1991a; 1991b). These cirques were supposedly functioning as heads for small-scale cirque glaciers which were between 750 to 1000 m long. They were allegedly connected to the glacial plateau at Jezera only during the peaks of glaciation (Bognar, Faivre, Pavelić, 1991a; 1991b). The only reported site where glacial material was identified was below Ripljevica cirque in the area of Trapolovica (Bognar, Faivre, Pavelić, 1991a; 1991b).

In lithological sense, the Krasno polje area is filled with Quaternary fluvio-glacial material. Its northern escarpments are built of Middle Jurassic grey and dark grey limestone with layers of dolomitized limestone. The southern slopes are composed of Lower Jurassic well-bedded grey limestone and dolomite (Dimitrijević et al., 1970; Velić, Velić, 2009). Tectonically, the Krasno polje is positioned in an area of lowered relief which is oriented along

Figure 3: Dry riverbed in the Veliko polje area (photo: U. Stepišnik)
Slika 3: Suho rečno korito na območju Velikega polja (foto: U. Stepišnik)

the Krasno polje fault. The fault is one of the most prominently expressed structural units running in a perpendicular direction to the main ridge of the Velebit Mountain (Dimitrijević et al., 1970; Bognar, Faivre, Pavelić, 1991a; 1991b; Faivre, 2007).

Steep slopes above the Adriatic Sea make Mount Velebit an effective barrier for orographic precipitation. The average annual rainfall measured in the area of Krasno polje is 2538 mm (Perica, Orešič, 1999) and the average annual temperature is 8.3 °C (Medvedović, Milković, Tomaić, 2009). In the hydrological sense, the polje is positioned completely in a vadose zone, with no recorded flooding of any section of the floor. The thickness of vadose zone in the area of the polje is not known. There is a dry riverbed running along the whole length of the polje. Local legends suggest that it was once occupied by river Krasica, which supposedly drained as a result of the Dubrovnik earthquake in 1667 (Glavičić, 1981). The names of the polje and of the village were allegedly derived from the Krasica River (Glavičić, 1981). Today, there are no periodic or permanent surface streams on any part of the polje.

3. METHODOLOGY

3.1. Theoretic concepts of poljes

The international term *polje* comes from southern Slavic languages. It was presumably first used in the context of describing karst in Bosnia by Mojsisowicz in 1880 (cv: Gams, 2003). The first morphographic and morphometric description of polje was given by Cvijić (1900; cv: Gams, 1978) in which he specified that a polje must be a great depression with a levelled floor generated by Tertiary sedimentation, with their longer axis parallel to local geological structures. He stated that poljes should also have certain hydrological functions, with solely subsurface outflows. Cvijić (1900) suggested that the polje is the final stage of evolution from the doline through uvala to polje. Grund (1903) later defined poljes as being closed basins with an entire rim higher than their floor, thus excluding some types of open depressions from being defined as poljes. All further definitions of the term polje (e.g. Šerko, 1947; Lehmann, 1959; Roglić, 1964; Monroe, 1970; Sweeting, 1972; Gavrilović, 1974) in general followed the statements of Cvijić (1900) and Grund (1903).

The first systematic definition of polje types was proposed by Gams (1974). He divided poljes into five types according to their hydrological function:

- *Border polje* is formed at the contact of permeable and impermeable rocks which drain into the polje.
- *Overflow polje* has either a belt or the whole floor built of impermeable or semipermeable sediments, which act as a barrier for underground water rising to the surface at one side and submerging at another side of the polje floor.
- *Peripheral polje* is of impermeable sediments in the central part from where waters are drained towards the ponors in bordering limestone.
- *Piedmont polje* is situated at the footslope of a mountain and was under Pleistocene glacial or periglacial conditions filled by extensive quantities of alluvium.
- *Polje at the piezometric level* is regularly inundated solely by karst groundwater rise.

More recent scientific literature regarding poljes generally uses these hydrology based classifications (e.g. White, 1988; Ford, Williams, 2004), however, general definitions of the morphometry of poljes are still under debate. Some authors claim that size does not matter (Ford, Williams, 2004) while others suggest that the minimal width of a polje should be 400 m (e.g. Gams, 1978; Jennings, 1985) and others 1–5 km (e.g. White, 1988).

3.2. Research methods

Geomorphological analysis of Krasno polje was conducted by applying analytic geomorphological methods (Pavlopoulos, Evelpidou, Vassilopoulos, 2009). Morphographic analyses included identification and spatial documentation of geomorphological features in the area of Krasno polje and the surrounding slopes through the use of topographic maps (in scales of 1 : 5,000 and 1 : 25,000) and through detailed morphographic mapping in the field. The morphographic field mapping was accompanied by morphometric analysis of landforms such as moraine ridges, moraine boulders, glacial outwash plains, suffosion dolines and riverbeds. Morphometric data regarding landforms were obtained in the field using barometric altimeters and GPS. Furthermore, the morphometric analyses were supported by analysis of topographic maps. Morphostructural analysis of glacial and proglacial sediments were conducted in exposed profiles at road cuttings and construction and gravel excavation sites. The analysis included clast fabric, shape, roundness and identification of the surface clast textures (Evans, Benn, 2004; Coe, 2010). Morphochronological analyses were based on assumed analogy with adjacent areas of the Dinaric Alps.

4. GEOMORPHOLOGICAL ANALYSIS OF THE KRASNO POLJE AREA

In the course of our field research, which included morphographic, morphometric and morphostructural analyses, we encountered evidence of glacial action on the southern and southwestern slopes above the polje, which is essential for the morphogenetic interpretation of the polje and surrounding area.

The most extensive geomorphological traces of glaciation are in the area of Žestikovac. There are two sets of lateral moraine ridges which begin on an elevation of about 1100 m and terminate at the elevation of about 850 m, just above the Jerkuše area. The moraine ridges reach an elevation of up to 80 m and extend in length to approximately 1.1 km. Between the two major lateral moraine ridges, there are some small terminal and lateral recessional moraine ridges. A large gully is entrenched between lateral moraine pairs. These moraine ridges are well preserved and are entirely composed of non-lithified material. We examined glacial deposits in an exposed gravel pit in the lower section of the northern lateral moraine consisting of matrix to clasts supported diamicton with a sandy or silty matrix, supporting cobble- to boulder-sized clasts. The clasts are predominantly subrounded and some are covered by non-distinct striae. The sediments are composed of Lower Jurassic grey, dark grey and spotted limestone and calcarenite.

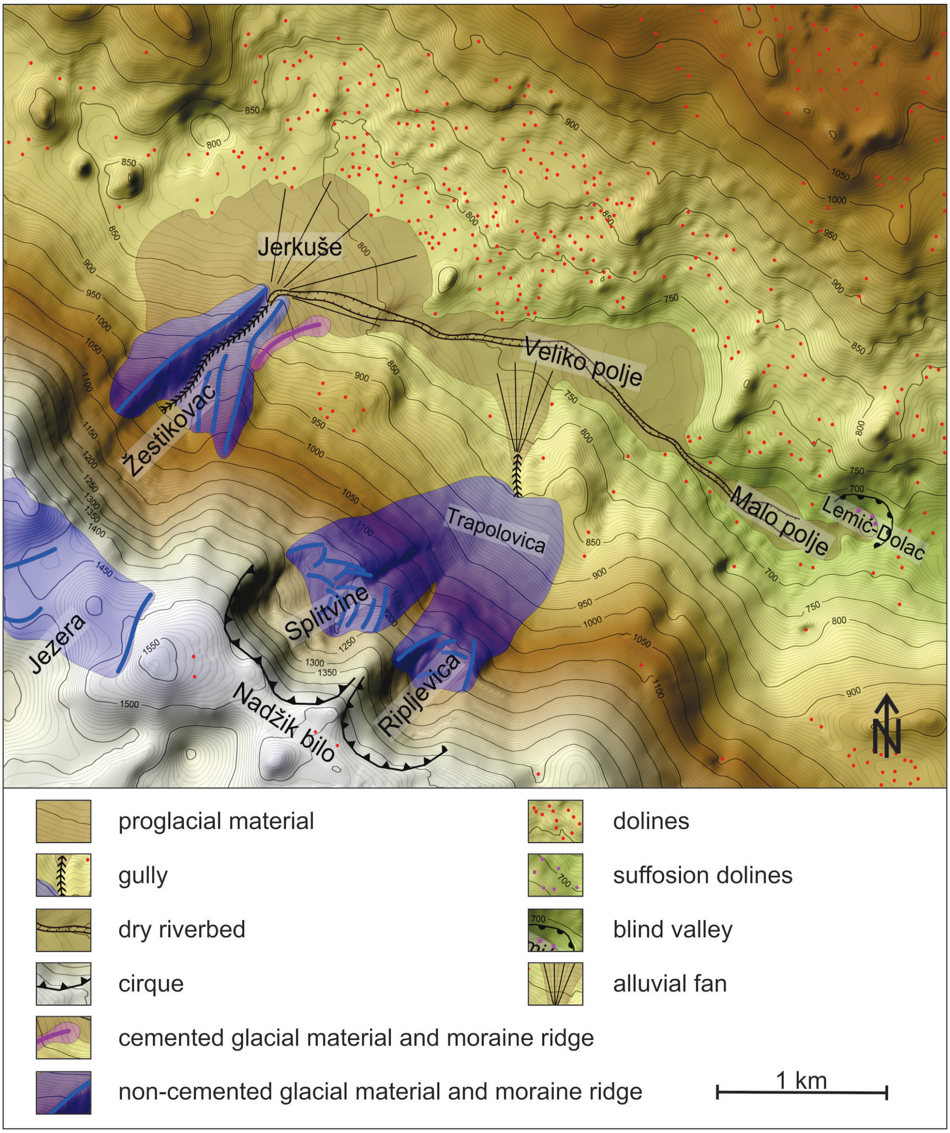
Figure 4: Jerkuše area with outlet glacier valley Žestikovac (photo: U. Stepišnik)
Slika 4: Jerkuše z dolino odtočnega ledenika Žestikovac (foto: U. Stepišnik)

About 200 m to the east of the major lateral moraine ridge there is a non-distinct parallel ridge of well-lithified moraine. It is about 300 m long and up to 7 m high. It is composed of matrix to clasts supported diamict with a sandy or silty matrix, supporting cobble-sized subrounded clasts. The lithological composition of this material corresponds with non-lithified moraines.

Southeast from Žestikovac there are two cirques named Splitvine and Ripljevica. The cirque Splitvine is 600 m wide and 700 m long with its floor at an elevation of 1200 m. The cirque Ripljevica is smaller with a width of about 500 m and length of 600 m. Its floor is at an elevation of 1140 m. The floors of both cirques are covered by slope material, while the lowest rims are covered by several moraine ridges. In road cuttings on the rims of the cirque, well exposed profiles in the glacial material can be found. It is composed of non-lithified matrix to clasts supported material with a sandy or silty matrix, supporting mostly boulder-sized clasts. The material is composed of lower Jurassic grey and dark grey limestone. Uniform slopes below the cirques are evenly covered by glacial material. Moraine ridges are not preserved on the steep slopes, so it is impossible to reconstruct the extent of those two cirque glaciers. Some 100 m above the polje floor, in the area of Trapolovica, is a gentler slope with more extensive cover of glacial or proglacial material, which has been previously identified in the literature (Bognar, Faivre, Pavelić, 1991a; 1991b). Downslope from Trapolovica is a gully entrenched into bedrock, which terminates on the southern slopes above the Veliko polje.

The floor of the polje is divided into three enlargements. The northwesternmost enlargement Jerkuše is situated just below the extensive moraines of Žestikovac valley. The whole area is covered by an extensive proglacial fan which gradually terminates on the northern and eastern sides of the area. Just below the moraines, in the continuation of the gully, is a dry riverbed running in an easterly direction onto Veliko polje. In its upper section, it is up to 15 m deep and 50 m wide. In the lower section of the fan it gradually widens and becomes shallower.

Figure 5: Geomorphological map of the Krasno polje area
Slika 5: Geomorfološka karta območja Krasnega polja



The gap between Jerkuše and Veliko polje is almost 150 m wide, and hosts a dry riverbed (Fig. 3). In this section, proglacial outwash thins as bedrock is exposed in some places. The enlargement of Veliko polje is completely covered by the continuation of the proglacial fan from the Jerkuše area. It is inclined towards the east, hosting a dry riverbed along its whole length. In the middle part of the area, bedrock is exposed in the riverbed. The western side of the polje is partially covered by a smaller proglacial fan which begins just below the gully leading from the Trapolovica area.

The riverbed extends from the Veliko polje towards the southeast through a narrow gap which is partially filled with alluvium and partially entrenched in bedrock. Below this gap, the Malo polje is situated. In its upper section, it is covered by a fan, while the lower section of the polje is flattened and composed by a loamy sediment. A profile at a construction site in the upper part of Malo polje revealed that the material is non-lithified and well stratified, composed of gravel and sandy layers. The lower section of the Malo polje extends into a blind valley named Lemić-Dolac. The blind valley terminates in a 25 m high escarpment. It is entirely filled by fine-grained material in which two suffosion dolines are positioned.

5. DISCUSSION

The Krasno polje is situated within the Northern Velebit Mountain between the elevations of 660 and 850 m a.s.l. It is distinctly elongated in the northwest–southeast direction. It consists of three enlarged areas which are connected by a uniform floor. The floor is completely covered by alluvium and is slightly inclined toward southeast. The maximum width of the polje is 800 m, its total length 1700 m and its floor covers an area of 1.7 km^2. The rim of the polje is higher than the floor, so it fulfils all theoretic morphographic, morphometric and function criteria for being classified as a polje according to literature (Cvijić, 1900; Grund, 1903; Gams, 1978).

The position of the Krasno polje is predetermined by the Krasno polje fault, which is one of the most expressed morphostructural units in the area of Northern Velebit. It is situated in the lowered relief which developed along the fault from the Oltari pass towards the Kosinj polje (Dimitrijević et al., 1970; Bognar, Faivre, Pavelić, 1991a; 1991b; Faivre, 2007).

The slopes south and southeast of the Krasno polje were intensively modified by glacial action during the Pleistocene. In this area we identified two well-expressed cirques and a valley from an outlet glacier. Two cirques in the southeast, Splitvina and Ripljevica, developed just below the ridge of Nadžik bilo. Some distinct moraine ridges are preserved only on the lowest rims of the cirques. Slopes below the cirques are covered by glacial or fluvio-glacial material. The accumulations were intensively modified by slope processes, so it is not possible to determine the exact extent of cirque glaciers. Traces of proglacial streams can be found in material evenly distributed along the slopes below the cirques, which have already been mentioned in previous literature (Bognar, Faivre, Pavelić, 1991a; 1991b). Below the accumulations is a well expressed gully which terminates just above the middle section of Veliko polje. The gully terminates at the apex of the extensive fluvio-glacial fan which covers part of this section of the polje.

The outlet glacier valley, Žestikovac, was misinterpreted by previous literature as a cirque (Bognar, Faivre, Pavelić, 1991a; 1991b). The extensive plateau glacier which occupied most of the high plateau Jezera was partially draining along this valley. In the highest part of the valley, on the edge of the plateau Jezera, extensive glacial accumulations with several distinct moraine ridges are preserved. The steep slopes of the upper section of the valley are of bedrock, however just below them, extensive glacial accumulations with distinct lateral moraines are preserved. Lateral moraines in the study area are up to 80 m high and 1.1 km long. The lateral moraines increase in height downwards, where they separate from the valley walls and converge in the lowest section above the polje, forming a lateral–terminal moraine complex. In the lower section of the valley is a small non-active gully between the lateral moraines. The gully terminates at the apex of an extensive fluvio-glacial fan which covers the whole area of Jerkuše, the highest section of the Krasno polje. Traces of proglacial streams are preserved in a well-expressed dry riverbed which begins at Jerkuše and extends through a narrow gap towards Veliko polje and further on towards Malo polje (Fig. 3).

The whole flattened floor of the Krasno polje is composed of two proglacial fans. The most extensive is the fan with its apex below the lateral–terminal moraines of the Žestikovac valley, which covers all three enlarged sections of the polje: Jerkuše, Veliko polje and Malo polje. An additional fan which originated from proglacial streams from Splitvina and Ripljevica cirque glaciers covers the western part of Veliko polje. There is no geomorphological evidence which would support suggestions that the dry riverbed of proglacial stream would have been active in Holocene and that it drained during the Dubrovnik earthquake in 1667 (Glavičić, 1981). The proglacial stream drained after retreat of the glacier towards the end of Pleistocene. Since the Krasno polje was filled by extensive quantities of proglacial alluvium during the Pleistocene, we can conclude that according to hydrological functions typology (Gams, 1978) the Krasno polje is *a piedmont polje.*

Within our research, we identified complex depositional structures in the outer section of Žestikovac's extensive lateral–terminal moraine ridges. Lower sections of moraine ridges are built of two sets of moraines separated by periods of erosion or non-deposition. Older external moraine ridges are composed of well cemented material on the surface, remodelled by karren; meanwhile the inner ones, which are younger, are neither remodelled by small-scale karst features nor cemented near the surface. Even though the chronology of glacial events in the Dinaric Alps remains unclear, the time frame of those glacial accumulations can be derived through analogy to uranium-series dating of secondary carbonates cement within moraines in the southern Dinaric Alps (Hughes et al., 2010; Hughes et al., 2011), to ^{10}Be exposure dating of glaciogenic deposits in the Šar Planina Mountain (Kuhlemann et al., 2009) and to some other studies concerning glaciations of the Dinaric Alps (Stepišnik et al., 2009; Stepišnik, Žebre, 2011; Žebre, Stepišnik, Kodelja, 2013). It was established that cemented, well-karstified deposits preserved only in patches are the product of older glacial events, while non-lithified well preserved accumulations are of LGM. Therefore, we conclude that non-lithified moraine ridges in the study area are neither MIS 12 nor MIS 6, but in fact belong to the LGM. Meanwhile, cemented, well-karstified moraine ridges, composed of poorly preserved patches in the lowest section of the Žestikovac valley, are of older glacial events, presumably of MIS 6. On the basis of the Žestikovac moraine ridge chronology, we can establish that the formation of the Krasno polje is connected to at least two major glacial events. The karst depression in the area of the polje was partially filled with proglacial alluvium in the earlier MIS 6 glacial event, while the today's alluvial cover of the polje can be connected to LGM.

Figure 6: Veliko polje from the east (photo: U. Stepišnik)
Slika 6: Veliko polje od vzhodne strani (foto: U. Stepišnik)

6. CONCLUSIONS

The Dinaric Alps are extensive mountains dissected by large, levelled corrosion plains, canyons and intramontane basins hosting poljes. The Krasno polje is embedded in the northern part of Velebit Mountain which is the largest continuous mountain belt in the Dinaric Alps. On the basis of morphographic and morphometric field data and comparison with the records from the literature, we established:

- The Krasno polje is a closed depression filled by Quaternary sediments with its rim being higher than its floor; therefore, by its dimensions and morphographic and morphometric characteristics it can be defined as a polje.
- The position of lowered relief in which the polje is situated is along the Krasno polje fault. The long axis of the polje is also orientated along this geological structure.
- Southern and southeastern slopes above the polje were intensively modified by glacial action. Two cirque glaciers and an outlet glacier were positioned on these slopes. Glacial accumulations cover vast areas of the slopes. Some glacial accumulations in the Žestikovac valley are organized in specific type of glacial depositional landforms referred to as lateral–terminal moraine complexes.

- Extensive lateral–terminal moraine complexes in the Žestikovac valley are believed to be a product of several glacial events. Older external moraine ridges are composed of well cemented material, while the inner ones (which are younger) are well preserved and not cemented near the surface. On the basis of analogy to the morphochronology of glacial deposits from the southern part of the Dinaric Alps (Hughes et al., 2010; Hughes et al., 2011), we assume that non-lithified moraine ridges in the study area derive from the LGM. Meanwhile, cemented moraine ridge in the lowest section of the Žestikovac valley are of MIS 6.
- The whole polje floor is filled with proglacial deposits. The most extensive section is the proglacial fan which extends away from Žestikovac valley through the whole of Jerkuše and most of the Veliko polje area. A smaller proglacial fan extends over the western part of the Veliko polje area. Fluvio-glacial material also covers the lowest part of Malo polje.
- There is no evidence that the dry riverbed in the polje floor would have been active up to the Dubrovnik earthquake in 1667, as literature suggests (Glavičić, 1981). We believe that the riverbed hosted Pleistocene proglacial stream because it extends from the middle part of Žestikovac valley further down along the whole length of the polje. On the other hand, it is highly unlikely that extensive surface stream would emerge on the surface so high above phreatic zone after Pleistocene.
- Since the Krasno polje is thoroughly filled by fluvio-glacial deposits, we can suggest that it is a *piedmont polje* according to the hydrological function classification system (Gams, 1978).

(Translated by the author)

References

Bognar, A., Faivre, S., Pavelić, J., 1991a. Glacijacija Sjevernog Velebita. Senjski zbornik, 18, 1, p. 181–196.

Bognar, A., Faivre, S., Pavelić, J., 1991b. Tragovi oledbe na Sjevernom Velebitu. Hrvatski geografski glasnik, 53, 1, p. 27–39.

Coe, A. L., 2010. Geological field techniques. Milton Keynes, Wiley-Blackwell, 323 pp.

Cvijić, J., 1900. Karsna polja zapadne Bosne i Hercegovine. Glas Srpske kraljevske akademije nauka, 59, p. 59–182.

Dimitrijević, M., Karamata, S., Sikošek, B., Veselinović, D., 1970. Tumač za list Otočac, K 33–115. Beograd, Savezni geološki zavod, 38 pp.

Evans, D., Benn, D., 2004. A practical guide to the study of glacial sediments. London, Arnold, 266 pp.

Faivre, S., 2007. Analyses of the Velebit Mountain ridge crests. Hrvatski geografski glasnik, 69, 2, p. 21–40.

Ford, D., Williams, P., 2004. Karst hydrology and geomorphology. Chichester, John Wiley & Sons, 562 pp.

Gams, I., 1978. The polje: the problem of definition – with special regard to the Dinaric karst. Zeitschrift für Geomorphologie, 22, 2, p. 170–181.

Gams, I., 2003. Kras v Sloveniji v prostoru in času. Ljubljana, Založba ZRC, 515 pp.
Gavrilović, D., 1974. Srpska kraška terminologija. Beograd, Savez geografskih institucija Jugoslavije, 74 pp.
Glavičić, A., 1981. Nalazi kamenih gromila na Velebitu. Senjski zbornik, 9, 1, p. 33–42.
Grund, A., 1903. Die Karsthydrographie. Studien aus Westbosnien. Geographischen Abhandlungen, 7, p. 103–200.
Hughes, P. D., Woodward, J. C., van Calsteren, P. C., Thomas, L. E., Adamson, K. R., 2010. Pleistocene ice caps on the coastal mountains of the Adriatic Sea. Quaternary science reviews, 29, 27–28, p. 3690–3708. DOI:10.1016/j.quascirev.2010.06.032
Hughes, P. D., Woodward, J. C., van Calsteren, P. C., Thomas, L. E., 2011. The glacial history of the Dinaric Alps, Montenegro. Quaternary science reviews, 30, 23–24, p. 3393–3412. DOI:10.1016/j.quascirev.2011.08.016
Jennings, J. N., 1985. Karst geomorphology. Oxford, Blackwell, 293 pp.
Kuhlemann, J., Milivojević, M., Krumrei, I., Kubik, P. W., 2009. Last glaciation of the Šara Range (Balkan Peninsula). Increasing dryness from the LGM to the Holocene. Austrian journal of Earth sciences, 102, p. 146–158.
Lehmann, H., 1959. Studien über Poljen in den venezianischen Voralpen und im Hochapennin. Erdkunde, 13, 4, p. 258–289.
Medvedović, J., Milković, J., Tomaić, M., 2009. Neke značajke vremena i klime Krasna i okolnog područja. Šumarski list, 11–12, p. 613–622.
Mihevc, A., 2010. Geomorphology. In: Mihevc, A., Prelovšek, M., Zupan Hajna, N. (Eds.). Introduction to Dinaric karst. Postojna, IZRK SAZU, p. 30–43.
Mojsisovicz, E., 1880. Zur Geologie der Karsterscheinungen. Jahrbuch der Geologischen Reichsanstalt, 30, 3, p. 1–30.
Monroe, W. H., 1970. A glossary of karst terminology. U. S. Geological Survey. Water supply paper, 1889-K, 26 pp.
Pavlopoulos, K., Evelpidou, N., Vassilopoulos, A., 2009. Mapping geomorphological environments. Berlin, Springer, 236 pp.
Perica, D., Bognar, A., Lozić, S., 2002. Geomorphological features of the Baške Oštarije karst polje. Geoadria, 7, 2, p. 23–34.
Perica, D., Orešić, D., 1999. Klimatska obilježja Velebita i njihov utjecaj na oblikovanje reljefa. Senjski zbornik, 26, 1, p. 1–48.
Roglić, J., 1964. Les poljés du karst dinarique et les modifications climatique du quaternaire. Revue belge de géographie, 88, 1, p. 105–125.
Šerko, A., 1947. Kraški pojavi v Jugoslaviji. Geografski vestnik, 19, 1, p. 43–66.
Stepišnik, U., Ferk, M., Kodelja, B., Medenjak, G., Mihevc, A., Natek, K., Žebre, M., 2009. Glaciokarst of western Orjen. Cave and karst science, 36, 1, p. 21–28.
Stepišnik, U., Kosec, G., 2011. Modelling of slope processes on karst. Acta carsologica, 40, 2, p. 267–273.
Stepišnik, U., Žebre, M., 2011. Glaciokras Lovčena (Zbirka E-GeograFF, 2). Ljubljana, Znanstvena založba Filozofske fakultete, 82 pp.
Sweeting, M. M., 1972. Karst landforms. London, The Macmillan Press, 362 pp.

Velić, I., Velić, J., 2009. Od morskih plićaka do planine. Geološki vodič kroz Nacionalni park Sjeverni Velebit. Krasno, Nacionalni park Sjeverni Velebit, 143 pp.

White, W. B., 1988. Geomorphology and hydrology of karst terrains. Oxford, Oxford University Press, 464 pp.

Žebre, M., Stepišnik, U., Kodelja, B., 2013. Sledovi pleistocenske poledenitve na Trnovskem gozdu. Dela, 39, p. 157–170. DOI: 10.43121/dela.39.9.157-170

GEOMORFOLOŠKE ZNAČILNOSTI KRASNEGA POLJA, SEVERNI VELEBIT, HRVAŠKA

Povzetek

Velebit je najizrazitejša topografska enota v Dinarskem gorstvu. Nahaja se med Liko in Jadranskim morjem na Hrvaškem in obsega površino 2274 km^2. Razteza se v dolžini 145 km in ima povprečno širino okoli 15 km. Krasno polje leži v severnem Velebitu na nadmorski višini od 660 do 850 m. Je izrazito razpotegnjeno v smeri severozahod – jugovzhod. Sestavljajo ga tri večje razširitve, ki jih povezuje enotno, sklenjeno dno. Dno je popolnoma zapolnjeno z naplavino, ki je blago nagnjena v smeri jugovzhoda. Največja širina polja je 800 m, njegova dolžina pa meri 1700 metrov. Celotna površina polja obsega 1,7 km^2. Obod polja je višji od dna, zato po definicijah literature izpolnjuje vse teoretične morfografske, morfometrične in funkcijske kriterije za uvrstitev med kraška polja (Cvijić, 1900; Grund, 1903; Gams, 1978).

Položaj Krasnega polja je pogojen s prelomom Krasnega polja, ki je ena od najbolj izrazitih tektonskih enot na območju Severnega Velebita. Kraško polje se nahaja v območju znižanega površja ob tem prelomu med prelazom Oltari in Kosinjskim poljem (Dimitrijević in sod., 1970; Bognar, Faivre, Pavelić, 1991a; 1991b; Faivre, 2007).

Južna in jugovzhodna pobočja kraškega polja so bila v času pleistocena izrazito preoblikovana z ledeniškim delovanjem. Na tem območju smo identificirali dve izraziti krnici in dolino odtočnega ledenika. Obe krnici, Splitvina in Ripljevica, se nahajata na jugovzhodnem pobočju tik pod grebenom Nadžik bila. Nekaj izrazitih moren je ohranjenih na najnižjem obodu krnic, pobočja pod njima pa prekriva ledeniško in predledeniško gradivo. Zaradi intenzivnih pobočnih procesov je nemogoče opredeliti dolžine nekdanjih krniških ledenikov. V spodnjem delu tega pobočja je izrazit erozijski jarek, ki se zaključi na vrhnjem delu vršaja. Vršaj prekriva srednjo razširitev Krasnega polja s toponimom Veliko polje.

Dolina odtočnega ledenika s toponimom Žestikovac je bila v predhodni literaturi neustrezno interpretirana kot krnica (Bognar, Faivre, Pavelić, 1991a; 1991b). Obsežni ledeniški plato, ki je prekrival večji del planote Jezera, je delno odtekal preko te doline. Na robu te planote, tik nad dolino Žestikovac, so ohranjene obsežne ledeniške akumulacije. Višje dele doline gradi predvsem karbonatna živoskalna podlaga, v spodnjih delih doline pa so ohranjene obsežne ledeniške akumulacije v dveh izrazitih bočnih morenah. Bočni

moreni sta visoki do 80 m in dolgi do 1,1 km. V spodnjem delu se bočni moreni zbližata in tvorita bočno-čelni morenski kompleks. V spodnjem delu doline Žestikovac je med bočnima morenama oblikovan globok erozijski jarek in se zaključi ob izteku moren v obsežnem vršaju, ki prekriva celotno severozahodno razširitev Krasnega polja s toponimom Jerkuše. V nadaljevanju erozijskega jarka je ohranjeno suho rečno korito, ki poteka preko Jerkuš in Velikega polja vse do Malega polja.

Celotno uravnano dno Krasnega polja prekrivata dva predledeniška vršaja. Največji ima vršni del pod dolino Žestikovac in prekriva vse tri razširitve polja: Jerkuše, Veliko polje in Malo polje. Manjši vršaj je nastal pod erozijskim jarkom, ki je dovajal predledeniške tokove iz območij Splitvine in Ripljevice, in prekriva zahodni del Velikega polja. V okviru terenske analize nismo našli geomorfoloških dokazov, da bi bilo suho rečno korito, ki poteka po celotni dolžini Krasnega polja, aktivno po pleistocenu. Čeprav lokalne zgodbe in nekatera literatura (Glavičić, 1981) navajajo, da je po koritu tekla reka Krasica, ki naj bi presahnila po dubrovniškem potresu leta 1667, teh navedb ne moremo potrditi. Ker je Krasno polje zapolnjeno izključno s predledeniškim materialom, ga po hidrološki funkcijski tipizaciji kraških polj (Gams, 1978) uvrščamo med piedmontska kraška polja.

V okviru naše raziskave smo v dolini Žestikovac identificirali kompleksne akumulacijske strukture na zunanjem delu bočno-čelnih morenskih kompleksov. Spodnji del morenskih kompleksov na vzhodni strani gradita dva vzporedna grebena moren. Zunanji, starejši greben je iz sprijetega ledeniškega gradiva, ki je v zgornjem delu preoblikovano z drobnimi kraškimi oblikami. Notranja grebena sta mlajša, nesprijeta in nepreoblikovana s kraškimi oblikami.

Kljub temu da časovni okvir poledenitev Dinarskega gorstva ni dokončno pojasnjen, lahko na podlagi kronoloških analiz ledeniških akumulacij na južnem delu Dinarskega gorstva (Hughes in sod., 2010; Hughes in sod., 2011) in na Šar planini (Kuhlemann in sod., 2009) sklepamo o starosti akumulacij na območju Žestikovca. Ugotovljeno je bilo, da so slabo ohranjene starejše morene, ki so dobro sprijete in prekrite s manjšimi kraškimi oblikami, nastale v času starejših poledenitev, medtem ko so dobro ohranjene nesprijete morene rezultat viška zadnje poledenitve. Tako na podlagi analogije sklepamo, da so nesprijete morene na preučevanem območju nastale ob višku zadnje poledenitve, medtem ko je bil ohranjen greben sprijetih moren najverjetneje odložen v MIS 6. Na podlagi kronologije odlaganja moren na Žestikovcu lahko zaključimo, da je bilo oblikovanje Krasnega polja vezano na sedimentacijo predledeniškega gradiva vsaj dveh poledenitev. Kraška kotanja je bila tako delno zapolnjena v času poledenitve MIS 6, medtem ko sta današnja oblika in obseg polja rezultat sedimentacije predledeniškega gradiva ob višku zadnje poledenitve.