SCIENCE

Geomorphology of Blidinje, Dinaric Alps (Bosnia and Herzegovina)

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ABSTRACT

Blidinje is tectonically derived lowland in the Dinaric Alps within Bosnia and Herzegovina. It is surrounded by Vran, Čvrsnica and Čabulja Mountains. The Blidinje study area is predominantly built of carbonates, where karst, fluvial and glacial geomorphological systems interact. We present a 1:25,000 geomorphological map covering a 100 km² with an elevation range of 1200–1900 m. The map results from a combination of a fieldwork mapping, interpretation of orthophotos and an analysis of a digital elevation model. This map presents a distribution of landforms and sediments associated with the past and present karst, glacial and fluvial processes, such as different varieties of karst depressions, conical hills, erosional gullies, alluvial fans and large amphitheatre-like moraines. The focus of the presented map is to assist ongoing studies in this part of the Dinaric Alps that seek to understand the dynamics of former glaciers and associated palaeoclimate.

1. Introduction

The Dinaric Alps are a range of the Alpine orogen parallel to the eastern Adriatic coast from Slovenia to northern Albania. They extend across western Croatia, and the majority of Bosnia and Herzegovina, and Montenegro. The study area is located in the centre of this mountain range in southwestern Bosnia and Herzegovina. It consists of three interconnected lowered relief units which are predominantly built of carbonate bedrock: Svinjača in the southwest, Dugo Polje in the centre and Brčanj in the northeast. The area also includes the southern slopes of Vran Mountain (2074 m a.s.l.), northern slopes of Čvrsnica Mountain (2226 m a.s.l) and northern slopes of Čabulja Mountain (1776 m a.s.l) (Figure 1). The investigated area has several names; local people call it Polja (plural of polje), while in the literature the toponyms Dugo Polje, Blidinje Polje and Blidinje are to be found. The latter has its origin in Blidinje Lake (Figure 2(a)), located in the southern part of Dugo Polje. Also the Blidinje Nature Park, established in 1995, was named after the lake. Therefore, our study area is referred to as Blidinje after Blidinje Nature Park.

The Blidinje study area, along with its surrounding mountains Vran, Čvrsnica and Čabulja, belongs to the structural belt of the Outer Dinarides of Bosnia, specifically to the zone of Bosnia and Herzegovina high karst (Buljan, Zelenika, & Mesec, 2005). Čvrsnica Mountain is a syncline, disturbed by young fault lines, positioned transverse to the dominant northwest–southwest direction of the main structure. Vran Mountain is a similar morphostructural feature dissected by numerous folds, faults and thrusts (Šimunović & Bogner, 2005). The Blidinje area between Vran, Čvrsnica and Čabulja Mountains is a tectonically derived lowland. The study area is predominantly built of more or less permeable Cretaceous and Jurassic carbonate rocks and their Quaternary re-depositions, that retain surface water in the form of the above mentioned extensive but shallow Blidinje lake, and some intermittent streams in the Brčanj area (Račić & Papeš, 1968; Šimunović & Bogner, 2005; Sofilj & Živanović, 1979).

The initial geomorphological research of Čvrsnica Mountain and the surrounding areas was carried out by Cvičić (1899). He studied karst and mass movement landforms in the entire area of Čvrsnica and found traces of glacial action around the highest peaks. According to Cvičić (1899), the lowest terminal moraines are present at an elevation of 1900 m. Grund (1902) identified glacial deposits at Dugo Polje and terraces of at least three separate glacial phases on the slopes of Vran Mountain. Milojević (1935) partially confirmed the earlier findings of Cvičić (1899) and Grund (1902), but misinterpreted moraine ridges on the eastern side of Dugo Polje as fluvioglacial deposits. Moreover, he identified moraine ridges on the eastern side of Svinjača. Traces of glaciation in the area of Blidinje were studied in detail by Roglić (1959) who noted that the distribution of moraines east of Svinjača was a result of at least two separate glacial phases, while younger phase deposits covered the eastern part of Dugo Polje (Roglić, 1959). He also identified extensive glacial accumulations on the northern plateau of Čvrsnica Mountain and outwash deposits covering

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part of Brčanj. Šimunović and Bognar (2005) argued that glaciers from Čvrsnica Mountain descended towards the south and southeast towards deeply incised valleys. The authors ascribed upper and lower Würm age to the identified palaeoglaciers. Miličević and Prskalo (2014) mentioned a total of 26 preserved cirques on the Čvrsnica massif.

Besides Vran, Čvrsnica and Čabulja, other mountainous areas in Bosnia and Herzegovina were affected by Quaternary glaciations (e.g. Čvijić, 1899; Grund, 1902; Milojević, 1935; Žebre & Stepišnik, 2015b), as well as other elevated sections of the Dinaric Mountains in Albania (Milivojević, Menković, & Čalić, 2008), Montenegro (Hughes, Woodward, van Calsteren, & Thomas, 2011; Žebre & Stepišnik, 2014), Croatia (Marjanac & Marjanac, 2004) and Slovenia (Žebre & Stepišnik, 2015a; Žebre, Stepišnik, Colucci, Forte, & Monegato, 2016). They not only hosted cirque and valley glaciers, but also large ice caps, which were some of the largest in the Mediterranean owing to a sustained moisture supply during cold stages (Adamson, Woodward, & Hughes, 2014). Although a great progress has been made on the palaeoglaciaion studies, the Dinaric Alps still lack a precise glacial chronology and a

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**Figure 1.** Location of Blidinje in a regional and local context. Study area is marked with a black line.
comprehensive palaeoclimate interpretation. The only glacial chronology in the Dinaric Alps has been provided for coastal (Hughes, Woodward, van Calsteren, Thomas, & Adamson, 2010) and central Montenegro (Hughes, 2010), using uranium series dates from secondary carbonates of tillites. These studies indicate four glacial phases, with the largest glaciers occurring before 350 ka, being significantly larger than during the Last Glaciation.

The aim of this map is to present the geomorphological complexity of the Blidinje area (Main Map). Many studies have already described this area from a

Figure 2. (a) Blidinje Lake located in the lowest part of Dugo Polje. The view towards the NE. (b) The karst polje Brčanj in the NE side of the Blidinje area. The view towards the NE. (c) Slightly elevated karst surface between Brčanj and Dugo Polje covered by doline-sized depressions.
geographical, geological and geomorphological perspective; however, their cartographic presentations do not offer a comprehensive insight into fluvio-karst, glacio-karst and karst landscape interactions. With this map we aim to present the results obtained through exact and thorough fieldwork as well as the study of the aforementioned literature.

2. Methods

The geomorphological map of the Blidinje area (Main Map) is a result of a fieldwork mapping, accompanied by the analysis of a 20 m-resolution digital elevation model (DEM), orthophotos (‘Geoportal Web Preglednik’, 2016), GoogleEarth images and topographic maps at a scale of 1: 25,000 (‘Geoportal Web Preglednik’, 2016).

The methods used in this research follow the concept of morpholithostratigraphy (Hughes, 2010). A 100 km² study area was mapped in detail during fieldwork campaigns over the course of the summers of 2014 and 2015. Geomorphological mapping was supported by the use of topographic maps and a global positioning system navigation device. Maps of landmine contamination from the 1992–1995 war, which were provided by the Bosnia and Herzegovina Mine Action Centre, were also essential while performing field surveys. Fieldwork data accompanied with the analysis of Yugoslavian basic geological maps at a scale of 1:100,000 (Papeš, 1972; Raičić, Ahac, & Papeš, 1976; Sofilj & Živanović, 1979) assisted us in distinguishing between different geomorphological systems. Apart from geomorphological mapping, special attention was placed in describing glacial and alluvial deposits. The latter are of very diverse origin in the Blidinje area owing to the interchanging characteristic of karst, glacio-karst and fluvio-karst geomorphological systems and related processes. The final morphogenetic interpretation of the mapped geomorphological features was made taking into account the scarce geomorphological and geological bibliography about this area (Milojević, 1935; Milićević & Prskalo, 2014; Roglić, 1959).

The Main map was prepared using ArcGIS 10.3.1, utilising shaded relief and 50 m interval contours derived from the 20 m DEM as a base layer. Yugoslavian basic geological maps at a scale of 1:100,000 served as a source for cartographic presentation of a simplified distribution of lithological units in the Main map. The geographic datum used is WGS 1984 and the projection of a Transverse Mercator.

3. Results

The Blidinje area can be divided into four main morphographic units. The central unit is the area of lowered relief, which is elongated in a southwest–northeast direction. It consists of three detached, predominantly flat areas that are separated by zones of slightly elevated relief. The three flat areas are engulfed within surrounding high mountain massifs. The most dominant one is Čvrsnica Mountain towards the southeast. To the north is Vran Mountain and to the south is the western part of Čabulja Mountain.

General relief outlines are strongly influenced by geological structure. The whole area of Blidinje with the surrounding high mountain plateaux is part of one overthrust nappe. The nappe is dissected by a number of regional faults into separate uplifted areas within compression zones. The central part of the study area is lowered relief, which was formed along extension zone. The entire area consists of carbonate bedrock or carbonate-derived Quaternary deposits. Geomorphological processes and features on the surface are diverse, regardless of the relatively uniform lithological settings. Local variations in surface gradients, type of bedrock, tectonic settings and past environments of colder climates influence the typical functioning of different areas as karst, fluvio-karst and glacio-karst.

Karst landscape is located within limestone and some dolostone areas that have moderate surface gradients. A well-developed subsurface drainage within karst results in vertical runoff of precipitation, chemical weathering and the formation of typical rounded depressions on the surface (Gams, 2003; Williams, 2003). Fluvio-karst landscape is typical for tectonically deformed limestone areas as well as for the majority of dolostone areas. This type of landscape is generally functioning as karst with subsurface drainage. Nevertheless, intense mechanical weathering of the surface, owing to intense frost action in colder climate periods or tectonic deformation, has caused thicker regolith cover to develop. As a result, temporary local surface streams appear, causing local erosion and deposition of material. Active and non-active erosional gullies on carbonate slopes with high gradients and alluvial fans further down the gullies are typical features of a well-developed fluvio-karst (Field, 1999; Gunn, 2004; Roglić, 1958). Glacio-karst areas are actually just de-glaciated karst areas, where the functioning of geomorphological processes is generally limited to chemical weathering of the surface and almost complete subsurface drainage. As a result, geomorphological features, products of past glaciations, are well-preserved (Smart, 2004; Zebre & Stepišnik, 2015a, 2015b). Glacial deposits, mostly carbonate-derived till and tillite, are widespread in the study area. They commonly consist of matrix-supported diamicton with subangular to subrounded clasts. They form large terminal moraines likely of different generations. Some of the moraines resemble a regular amphitheatre-like shape, hosting up to 150 m deep depressions. Even though they are deposited within karst and behave as a karst surface,
streams sporadically appear due to their thick semi-permeable layer. These streams, which were active during glacial retreat or intense weather events, conditioned the formation of gullies and dry riverbeds.

The Blidinje study area is an elongated depression between Čvrsnica, Vran and western Čabulja Mountains. It is oriented in a southwest–northeast direction and is ∼20 km long and 2–5 km wide. The Blidinje depression is further divided into three lowered relief units, infilled by various sediments derived from the surrounding slopes. The northeasternmost unit is known as Brčanj (Figure 2(b)). It has a completely level floor, surrounded by Vran Mountain in the west and Čvrsnica Mountain in the east. It limits are an elevated, slightly levelled karst area towards south, while towards north a narrow ridge separates Brčanj from a deeply entrenched canyon of the Doljanka River, a right tributary of the Neretva River. The flattened floor of Brčanj is situated at an elevation of ∼1200 m and is ∼3 km long and nearly 1 km wide. It consists mostly of fine-grained sediments. Its eastern and southern slopes are comprised of limestone bedrock covered by characteristic karst features. The northern slopes are composed of dolostone, and therefore dissected by a number of non-active gullies. The eastern slopes are covered with an extensive proglacial fan (∼2.2 km²) that is situated below an extensive (∼4.4 km in diameter) terminal moraine complex, deposited from the northern Čvrsnica Mountain. A number of small streams emerge from the foot of the fan. They meander towards the southeast margin of the flattened floor, where streams are submerging inside ponors situated on the contact with limestone bedrock. The entire area of Brčanj is filled with fluvial deposits from the fan and possibly periglacial deposits from inert gullies on the northern fluvio-karst slope, and can be thus considered a piedmont-type polje according to the hydrological function classification system (Bonacci, 2004a, 2004b, 2013; Ford & Williams, 2007; Gams, 1978; Williams, 2003).

South of Brčanj, a levelled karst area, is situated ∼60 m above the polje floor. This limestone surface is completely covered by various doline-sized karst depressions and non-distinct conical hills (Figure 2 (c)). Towards the east and west, there are a limited number of proglacial and fluvio-karst fans that are situated at the footslope of surrounding mountains. Southern limits of this area present extensive glacial deposits that are part of a central depression of the Blidinje area, which is referred to as Dugo Polje. Its floor is elongated in a northeast–southwest direction. The polje is enclosed by the steep slopes of Vran Mountain to the north and by large moraines covering the footslopes of Čvrsnica Mountain to the south. The southwest margin of Dugo Polje, separated by a couple of ridges from the prolongation of the Blidinje lowland, is less clear. The floor of Dugo Polje gradually descends from ∼1240 m a.s.l. in northeast to 1180 m a.s.l. in southwest, where Blidinje Lake inundates lower sections. These are covered with fine-grained sediments. Stretches of abrasion terraces close to the southern and eastern shores are positioned up to 7 m above the mean lake level and indicate the larger extent of the flooded area during past periods. Upper sections of the Dugo Polje floor to the northeast and north are completely covered with fluvio-karstic and proglacial fans. Northern slopes above Dugo Polje are built of limestone and dolostone bedrock. The limestone slopes have a steeper gradient and are dissected by gullies that are predominantly present within tectonically deformed bedrock. The density of gullies in dolostone is much higher and the slopes are completely remodelled by gullying. Slopes in the south and east are also made of limestone, but are dissected by fewer gullies. Nevertheless, the majority of the Dugo Polje area is covered with extensive glacial deposits. Three major moraine complexes cover this area. The easternmost is the most extensive terminal moraine complex. It forms a large amphitheatre-like shape of parallel moraine ridges, with a total diameter of ∼3 km. These moraines were not disturbed by any significant postglacial process owing to a glaciokarst environment, and are therefore well-preserved (Figure 3(a)). In addition, the outer rim of the moraine loop is dissected by non-active riverbeds, formed by proglacial or postglacial streams. Below them are extensive fans covering parts of Dugo Polje. The largest fan has an area of 3.4 km². Two similar, but smaller loops of terminal moraines cover Dugo Polje to the west. The depression of Dugo Polje can be defined as a karst polje regarding its morphometry and hydrological function. It can be further classified as a border-type polje because of inflows from fluvio-karst areas or as a piedmont-type polje due to former inflows from glaciated areas (Ford & Williams, 2007; Gams, 1978).

The elevated area southwest of Dugo Polje that separates it from the south-westernmost depression is referred to as Svinjača. Svinjača is surrounded by foothills of Vran Mountain to the north and western Čabulja Mountain to the south. It is ∼3.5 km long and up to 1.5 km wide, having a flat floor at an elevation of ∼1170 m. The lowest section of this depression in the northwest is filled with fine-grained sediments, while other parts of the floor are built of coarser deposits, such as sands and gravels. The majority of the surrounding slopes are built of dolostone hosting a fluvio-karst landscape with well-developed gullies and alluvial fans. All fans beneath the northern slopes are merged into one compound alluvial fan with an area of 3.7 km². The northwestern section of this large fan is predominantly built of cemented alluvial deposits with dry riverbeds and dolines on the surface (Figure 4(a)–(c)). This type of fan can be termed a relic alluvial fan (Stepišnik,
where deposition of alluvium along with erosion in the hinterland of the fan is inert. The southeastern slopes are built of typical hummocky moraines, originating from Čvrsnica Mountain (Figure 3(b) and 3(c)). Below them is a proglacial fan, covering a large section of the Svinjača floor. There are no surface streams in the Svinjača depression. Even though we can define its hydrological function in the same way as in the case of Dugo Polje, Svinjača is a combination of a piedmont and border-type polje owing to the presence of fluviokarst and proglacial deposits filling the polje (Ford & Williams, 2007; Gams, 1978).

4. Discussion and conclusions
The Blidinje area was occupied by piedmont-type glaciers (Figure 5) as can be recognised from the palaeoglacial landform morphology, which exhibit large

Figure 3. (a) Amphitheatre-shaped terminal moraine on the eastern side of Dugo Polje below Čvrsnica Mountain. (b) Hummocky moraines east of Svinjača. View towards the north. (c) Lateral moraine east of Svinjača.
Figure 4. (a) Orthophoto (Geoportal Web Preglednik, 2016) and (b) photo of relict alluvial fan in the NW part of Svinjača, dissected by dolines (c).

Figure 5. Cross section from the upper (Y–Y') and lower (X–X') part of large lobate moraine ridges and a sketch of the palaeopiedmont glacier thickness (in blue) in Blidinje. For locations of the two cross-sections, refer to the Main map.
lobate moraine ridges or hummocky moraines on a predominantly levelled surface. The exceptionally well-preserved moraines indicate that the largest piedmont glacier lobe was ~3 km wide and more than 100 m thick. Piedmont glaciers in Blidinje formed due to an unconfined plain, adjacent to the mountain (Barr & Lovell, 2014). However, the majority of moraines surrounding Čvrsnica and Čabulja Mountains were deposited by steep outlet glaciers, which drained the ice fields into narrow basins, preventing the development of extensive glacier lobes. These moraines are significantly less preserved than the lobate moraines in Blidinje, because they were reworked or completely washed away by fluvial erosion. This situation is particularly common for the mountains in southwestern Bosnia and Herzegovina, where non-carbonate rocks underlie carbonate massifs, forming fluvial relief with restricted space for the formation of a piedmont-type glacier. However, several past glaciated high plateaux in the Dinaric Alps are surrounded by karst poljes, containing some of the thickest and best-preserved glacigenic deposits in the Mediterranean (Adamson et al., 2014; Žebre et al., 2016). An example of well-preserved outwash and till deposits is Orjen Mountain in Montenegro (Adamson et al., 2014; Hughes, 2010).

The presented geomorphological map illustrates the distribution of landforms related to glaciations, fluvial action and karst processes in Blidinje, located in the central Dinaric Alps. This map provides a framework for ongoing geomorphological investigations in the wider Blidinje area, including Vran, Čvrsnica and Čabulja Mountains. The acquired data suggest a complex nature of the study area, characterised by the interchanging karst, fluvial and glacial geomorphological systems that are worthy to be investigated further. Especially large amphitheatre-like moraine complexes and alluvial fans identified in the study area are noteworthy for storing a sedimentological record of past glaciations that can be used for dating, glacier reconstruction and implications for palaeoclimate in this part of the Dinaric Alps.

Software

ESRI ArcGIS 10.3.1. was used for map production, including digitising, georeferencing, DEM analysis and the final layout.

Acknowledgements

We express gratitude to referees O. Bonacci, P. D. Hughes and B. Cattoor for constructive comments which helped us improve the quality of this paper.

Disclosure statement

No potential conflict of interest was reported by the authors.

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