COBISS: 1.01, DOI: 10.3986/ac.v51i2.10788

ACTIVE AND RELICT CONTACT KARST MORPHOLOGICAL FORMS OF THE SLAVINA CORROSIONAL PLAIN

AKTIVNE IN RELIKTNE KONTAKTNE KRAŠKE MORFOLOŠKE OBLIKE SLAVINSKEGA RAVNIKA

Astrid ŠVARA[1, 3]*, Andrej MIHEVC[1, 2, 3] & Nadja ZUPAN HAJNA[1, 2, 3]

Abstract UDC 551.435.8:528.94(497.471)

Astrid Švara, Andrej Mihevc & Nadja Zupan Hajna: Active and relict contact karst morphological forms of the Slavina corrosional plain

The Slavinski ravnik corrosional plain is a small area of Dinaric karst in Slovenia, located at the contact between impermeable flysch and karstified carbonate rocks, where the most representative ponor contact karst features have formed. Due to erosion, multiphase regional tectonic uplift, and sedimentation, a paragenetic cave system, active and relict blind valleys can be observed, reflecting the different stages of the morphogenesis of this area. To obtain a better overview and detailed understanding of the past and present behaviour of a dynamic karst system, in which hydrology is closely related to the spatial distribution and the extent of contact karst (allogenic) morphological features, geomorphological and sedimentological mapping was conducted. Maps were digitized using ESRI ArcMap and Golden Software Surfer based on DEM and LiDAR imagery. During the survey, the active cave system Markov spodmol and Vodna jama v Lozi, the relict unroofed cave Brezstropa jama v Lozi, Biščevci blind valley, Sajevško polje blind valley, Ivačevci blind valley, and Sajevško polje sediment accumulation were studied, and active and relict karst features were determined. It is concluded that their location, interrelation, sedimentological record, and overall occurrence show different stages of development of these geomorphic features with their hydrological function, indicating different stages of formation of the northern margin of the Slavinski ravnik at least within the last 4 mil-

Izvleček UDK 551.435.8:528.94(497.471)

Astrid Švara, Andrej Mihevc & Nadja Zupan Hajna: Aktivne in reliktne kontaktne kraške morfološke oblike Slavinskega ravnika

Slavinski ravnik je manjše korozijsko uravnano območje Dinarskega krasa v Sloveniji in leži na stiku med neprepustnimi flišnimi in zakraselimi karbonatnimi kamninami, kjer so se oblikovale najbolj reprezentativne ponorno kontaktne kraške oblike. Zaradi erozije, večfaznega regionalnega tektonskega zvišanja območja in sedimentacije so se oblikovali paragenetski jamski sistem ter aktivne in reliktne slepe doline, ki kažejo morfogenetske stopnje raziskovanega območja. Za boljši pregled in podrobnejše razumevanje preteklega in sedanjega dogajanja na dinamičnem kraškem sistemu, v katerem je hidrologija tesno povezana s prostorsko razporeditvijo in obsegom kontaktnih kraških (alogenih) morfoloških značilnosti, smo izvedli geomorfološko in sedimentološko kartiranje. Zemljevidi so bili digitalizirani z uporabo ESRI ArcMap in Golden Software Surfer na podlagi DEM in posnetkov LiDAR. Pri raziskovanju smo proučevali aktivni jamski sistem Markov spodmol in Vodna jama v Lozi, reliktno jamo Brezstropa jama v Lozi, slepo dolino Biščevci, slepo dolino Sajevško polje, slepo dolino Ivačevci ter akumulacijo sedimentov na Sajevškem polju ter določali aktivne in reliktne (zakrasele) morfološke elemente. Njihova lega, medsebojna povezanost in pojavnost nakazujejo na različne stopnje oblikovanja severnega roba Slavinskega ravnika v vsaj zadnjih štirih milijonih let. Gre za edinstveno celovito študijsko območje, kjer lahko opazujemo izpostavljene in ohranjene el-

[1] Research Centre of Slovenian Academy of Sciences and Arts, Karst Research Institute, Titov trg 2, SI-6230 Postojna, Slovenia, e-mails: astrid.svara@zrc-sazu.si, zupan@zrc-sazu.si, mihevc@zrc-sazu.si
[2] UNESCO Chair on Karst Education, University of Nova Gorica, Glavni trg 8, SI-5271 Vipava, Slovenia, e-mails: zupan@zrc-sazu.si, mihevc@zrc-sazu.si
[3] University of Nova Gorica, Glavni trg 8, SI-5271 Vipava, Slovenia, e-mails: astrid.svara@zrc-sazu.si, zupan@zrc-sazu.si, mihevc@zrc-sazu.si
* Corresponding author

Received/Prejeto: 4. 5. 2022

lion years. In summary, this is a unique, comprehensive study site where we can observe exposed and preserved elements, that reveal a gradual development of a ponor-contact karst area, which in most cases is not well preserved due to erosion and karst denudation processes.
Keywords: Unroofed cave, blind valley, paragenesis, allogenic sediments, geomorphological mapping.

emente stopnjevanja v razvoju ponorno-kontaktnega krasa, ki je v večini primerov slabo ohranjen zaradi erozijskih in kraških denudacijskih procesov.
Ključne besede: brezstropa jama, slepa dolina, parageneza, alogeni sedimenti, geomorfološko kartiranje.

1. INTRODUCTION

The northern boundary of the Slavinski ravnik represents a narrow study area, but with numerous active and relict contact karst features, widely recognizable in relief (Figure 1). One of the most striking surface karst forms of this landscape is the Unroofed cave Loza (Brezstropa jama v Lozi), which is by far the longest known unroofed cave in Slovenia with more than 4 km of passages filled with allogenic sediments and speleothems. Also well expressed are three blind valleys (Biščevci, Sajevško polje, Ivačevci) and their hydrology, as well as various sediments preserved on the karst surface.

The area represents a unique ponor contact karst landscape in Slovenia, where we can observe exposed and preserved morphological elements. These geomorphological forms show a gradual development of the contact karst, which in most other cases are not preserved so extensively due to erosion and karst denudation processes.

Ponor contact karst develops where allogenic waters flow from a non-karst environment and sink into the adjacent karst, i.e. where allogenic waters modify karst landscapes by their volume, regime, and sediment load (e.g. Mihevc, 1991a, b, 2001; Sauro, 2001). This type of karst can be also defined as karst with allogenic input, formed under the influence of alluviation, where hydrological influence is the most important factor.

The most typical landforms found in a ponor contact karst are ponors (streamsinks, sinkholes), ponor steepheads, blind valleys, ponor caves and epiphreatic caves. In this environment, ponor caves tend to get actively filled by allogenic sediment and can be later transformed by paragenetic processes (Renault, 1958). Also surface alluviation is active, where allogenic sediment is washed into the karst over time, where only inactive or relict geomorphic features of the contact karst remain visible in the karst relief, i.e. unroofed caves, blind and dry valleys (e.g. Mihevc, 1996, 2001, 2010; Sauro, 2002, 2013).

Many of these phenomena have been also identified in the Slavinski ravnik corrosional plain (e.g. Mihevc, 1991a, b, 1999a, b, 2006; Stepišnik, 2006). The first studies of caves in the area were done by Hribar et al. (1955). They had surveyed all known caves and interpreted their contents, their formation, and their relationship to the geomorphological development of the area using the available methods and the prevailing scientific theories of that time. While geomorphological studies in the area started in 1964 by Habe and Hribar, who investigated the smaller part of the contact karst area, the Sajevško polje. Mihevc (1991a, b, 1999a, b) defined and studied active and relict blind valleys of that area: Sajevško polje blind valley, Ivačevci relict blind valley, and Biščevci blind valley, together with the unroofed cave Brezstropa jama v Lozi (Mihevc, 2006). The toponym "Sajevško polje" can be misleading, as it does not correspond to the definition of a karst polje (e.g. Gams, 1974), but has the meaning in the Slovenian language as "Sajevče field". The toponym "Sajevško polje" is used as a name for the Sajevško polje blind valley. A notion of contact karst of Slavinski ravnik was recently mentioned also in a structural/tectonic study by Placer et al. (2021). Numerous speleological and sedimentological studies were carried out during the research in the cave Markov spodmol (Slabe, 1995; Zupan Hajna et al., 2008, 2020; Švara et al., 2021) and explorations in the cave Vodna jama v Lozi (Cave Register, 2021).

While the studies cited have gathered some important information on the individual distribution of the forms and their hydrological function in the past and present, more detailed interrelated studies and a complete understanding of the morphogenesis of the Slavinski ravnik contact karst area are lacking.

Therefore, the aim of this work was to reveal the diversity of active and relict ponor-contact karst features of the Slavina corrosional plain and to obtain information on the main factors influencing karst system development. With this objective, we (1) record and describe all elements of active and relict contact karst geomorphic forms, (2) locate and describe various types of sediments found within these forms, and (3) identify various stages of development of these geomorphic forms based on the recognized elements, their interrelationships and their arrangement. Using this approach, we created a combined geomorphological map from geomorphological features and sediment deposits. By understanding the significance of different sediment types and revealing different stages in the development of active and relict contact karst features, we are one step closer to understanding past and present dynamics of the karst system with its hydrological and climatic factors and the changes in the evolution of the southern karst periphery of the Postojna Basin - a question that has not yet been properly answered.

In the classification applied within this study, contact karst features that still have some hydrologic function with active sedimentation are treated as active features, even if the processes are no longer exactly the same as when they were formed. The term "active" can be omitted from the naming because it is self-evident in this context. For relict contact karst features, the term "relict" indicates the lack of water supply with active sedimentation, or even implies the decomposition of the geomorphic forms mainly due to karst denudation, and therefore must be included in their naming.

Figure 1: Location of the study area in Slovenia in the NW part of the Dinaric karst with the constant hydrological network and toponyms. (DEM – LiDAR data, ARSO, 2021b).

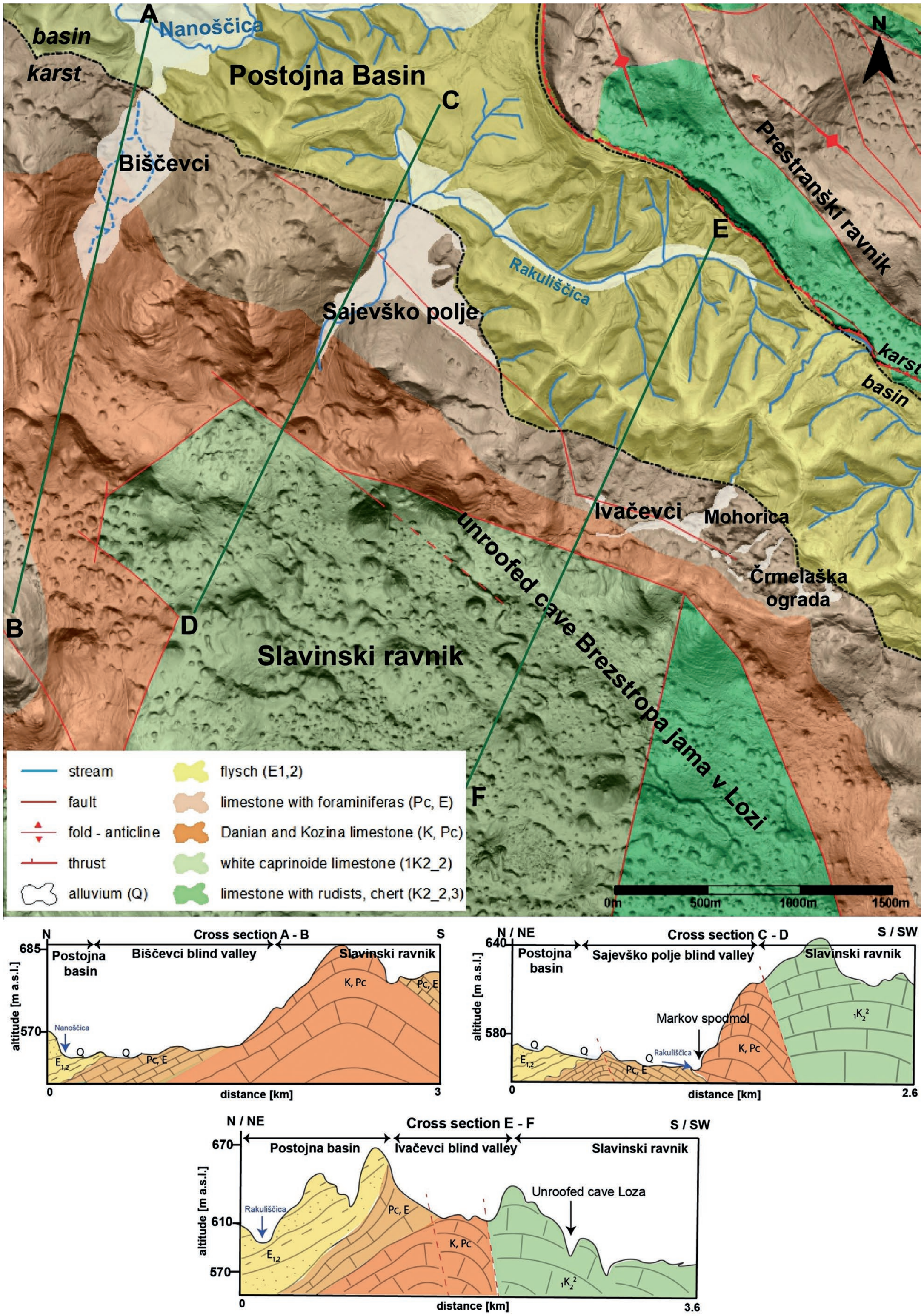

Figure 2: Simplified geological map of the Slavinski ravnik study area with toponyms and schematic cross-sections with the approximate placements of studied geomorphic forms. (DEM – LiDAR data, Geodetic department ARSO; 2021b; Geology – OGK 1:100000 Postojna, Geological Survey of Slovenia (Pleničar, 1963, 1970)).

2. GEOGRAPHIC, HYDROLOGICAL AND GEOLOGICAL SETTINGS

The study area represents the northern part of the karst corrosional plain Slavinski ravnik, which is dissected by numerous dolines. It is surrounded by non-karst Postojna Basin to the north, and karst landscapes of the corrosional plain Prestranški ravnik to the northeast, the Upper Pivka Basin to the east, Mount Vremščica and the valley Košanska dolina to the south. Slavinski ravnik is a levelled karst area with an average elevation of 610 m a.s.l., with the highest elevations reaching 750 m a.s.l. (Figure 1). The naming used for landscapes and geomorphological forms is established by geographical names and toponyms from the Register of Geographical Names of Republic of Slovenia.

The northern boundary of the Slavinski ravnik is influenced by allogenic water flowing into the karst from the impermeable rocks of the Postojna Basin (Hribar et al., 1955; Habe & Hribar, 1964; Mihevc, 1991b). The main sinking stream is Rakuliščica, which has a proven underground water connection from the ponor at the end of the Sajevško polje blind valley through Markov spodmol and Vodna jama v Lozi to the Timavo springs (Hribar et al., 1955). All sinking waters drain underground towards the Adriatic Sea (ARSO, 2021a). However, some of the ponors are also known to function as intermittent springs (i.e. estavelles) after a period of high rainfall with reversed water flows in the study area (i.e. in Biščevci). On such occasions, the waters are drained as surface water towards river Nanoščica and thus in the direction of the Black Sea.

The Postojna Basin consists of lower to middle Eocene flysch that forms flysch ridges and hills with extensive Quaternary alluvium cover and weathered flysch deposits, that often form river terraces (Melik, 1951; Pleničar, 1963, 1970; Gospodarič, 1988, 1989). Flysch outcrops are easily observed at the margins of the basin, while in the center of the basin they are mostly covered by alluvium. The Slavinski ravnik is in contact with the basin developed in limestones of the Adriatic Carbonate Platform from the Upper Cretaceous to the Eocene (Pleničar, 1963, 1970) (Figure 2). The sedimentary period from the Paleocene to the Eocene is characterized by white, highly karstified limestones with alveolinas and nummulites, while at the transition to the Cretaceous the limestone becomes more greyish and has additional shellfish fauna remains. The Upper Cretaceous is mainly characterized by grey limestones with chert nodules and rudists (Pleničar, 1963, 1970). Structurally, Slavinski ravnik represents the Komen Thrust Sheet predominantly with northwest-southeast Dinaric and transverse-Dinaric faults, common to the structural unit of the External Dinarides (Placer, 2008). The latter was triggered by the collision of the Adria Microplate with the Eurasian Lithospheric Plate, followed by its counterclockwise rotation, preserving faults and folding conditions (Placer, 1999, 2008; Weber et al., 2010).

3. MATERIALS AND METHODS

This study was based on geomorphological mapping of ponor contact karst features to gain a basic understanding of the extent of these surface and subsurface geomorphological forms. Mainly, we used the 1:5000 (TTN-5) and to a lesser extent the 1:25000 (TTN-25) topographic base maps available on the "Republic of Slovenia – Space Portal – Geodetic data portal", but also on our local data server. We combined the topographic map with the digital elevation model (DEM grid 5x5 m) and the high-resolution LiDAR images (LiDAR grid 1x1 m), available from the Slovenian Environmental Agency (ARSO), in order to achieve optimal identification of landforms.

Although DEM and LiDAR are helpful for detecting major relief differences, their sole use is usually not sufficient for spatial analysis, especially in a contact karst area where fluvial and karst systems overlap in a more complex "erosional-corrosion-depositional" environment. Therefore, geomorphological mapping was conducted using morphometric, morphographic, and morphostructural approaches (Gerasimov, 1946; Dvořák, 1995; Pavlopoulos et al., 2009; Otto et al., 2011). Field mapping of observed ponor contact karst features was performed on previously prepared base maps, using the elements established by Gams et al. (1985). Hydrologic conditions were noted and later digitized in ESRI Arcmap software. Morphometric data (e.g. length, width, elevation) and basic calculations (e.g. slope) were performed in the applied software. Slope calculations based on DEM unit cells were used only for a basic understanding of the margins of the geomorphic forms.

A revised geological map with cross-sections for a better view of the geological setting was created using Golden Software Surfer and ESRI Arcmap software.

Since there are many caves in the study area, relevant information was also taken from the Slovenian Cave Register (Cave Register, 2021), where information on previous speleological surveys and observed cave elements (cave forms and sediments) can be found.

Various allogenic sediments (e.g. pebbles, sand, silt/clay) and autochthonous sediments (e.g. various flowstone formations) observed in diverse geomorphological forms suggest the existence of specific past or present hydrological conditions. Those that provide information about the past are important since in some cases they are the only information left on the highly denuded karst surface. Therefore, sedimentological mapping, observations, and description of relevant sediments were also included.

By comparing the mapped features and combining their presence and interrelationship with the sedimentological findings, a morphogenetic conceptual model was created to be used for further investigation of the study area.

4. CONTACT KARST OF THE CORROSIONAL PLAIN SLAVINSKI RAVNIK

Regarding their shape, location and hydrological function we can assume, that the geomorphological forms on the northern margin of the Slavinski ravnik developed in different phases and were also remodeled under

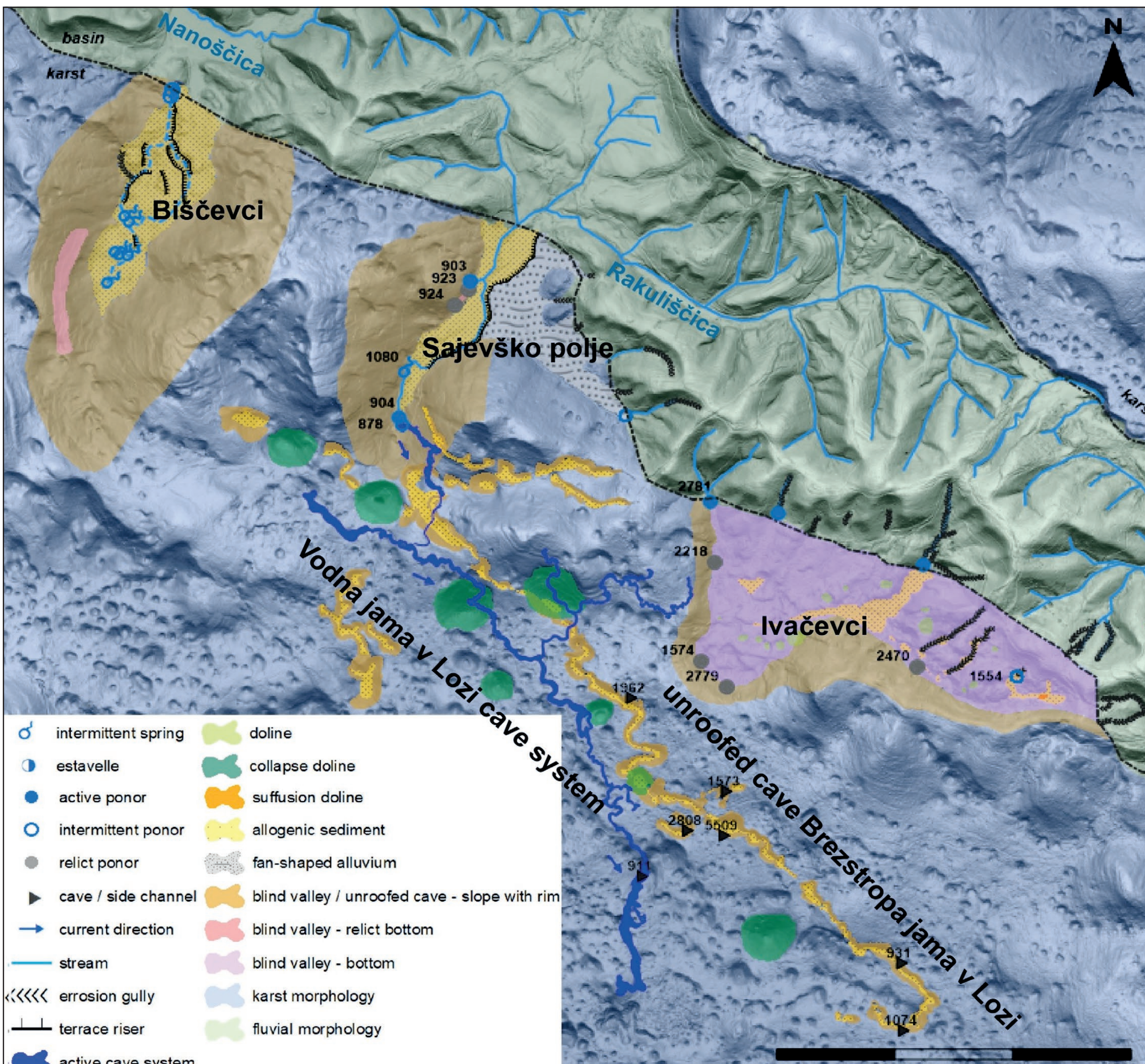

Figure 3: Geomorphological map of the study area with the locations of the cave entrances and the passages of the active and unroofed caves. (DEM – LiDAR data, ARSO, 2021b).

the influence of the allogenic input from the Postojna Basin. The allogenic sediments filled the blind valley bottoms, and the sediments were washed into the karst mainly through ponors, enlarging and filling existing cave passages and causing the formation of paragenetic caves. Descriptions of the studied subsurface and surface contact karst forms (Figure 3) are provided in the following chapter.

4.1. ACTIVE AND UNROOFED CAVES

In the research area of Slavinski ravnik, 77 caves are known, represented by (sub)horizontal caves, vertical caves, and caves with combined passages (Cave Register, 2021). Subhorizontal caves predominate, but there are also 23 vertical caves or caves with vertical entrances, scattered throughout the study area. The vertical caves or such entrances are thought to be vadose shafts related to regional uplift that forced water to shift vertically and follow the downward movement of the water table, or they are vertical ponor caves where sinking water had to adapt to a rapid drop in the water table.

The longest and best explored caves in Slavinski ravnik are the horizontal water caves **Markov spodmol and Vodna jama v Lozi**. Caves were explored separately and in 2009 were connected by cave divers through a siphon. Both caves together form a 7.7 km long cave system (Cave Register, 2021).

The cave Markov spodmol (reg. no. 878; Figure 3) has its entrance at WGS84 coordinates45.734627°N/14 .105311°E, which opens at the very end of the Sajevško polje blind valley. The cave is 868 m long and 61 m deep, which is consistent with the cave type of a horizontal intermittent ponor, which acts as a ponor of Rakuliščica only exceptionally and when the water level is very high. The active ponor of the stream is now located 26 m north of the entrance to Markov spodmol. The wide entrance to the cave is followed by a horizontal dry passage with small lakes, the area, and depth of which vary according

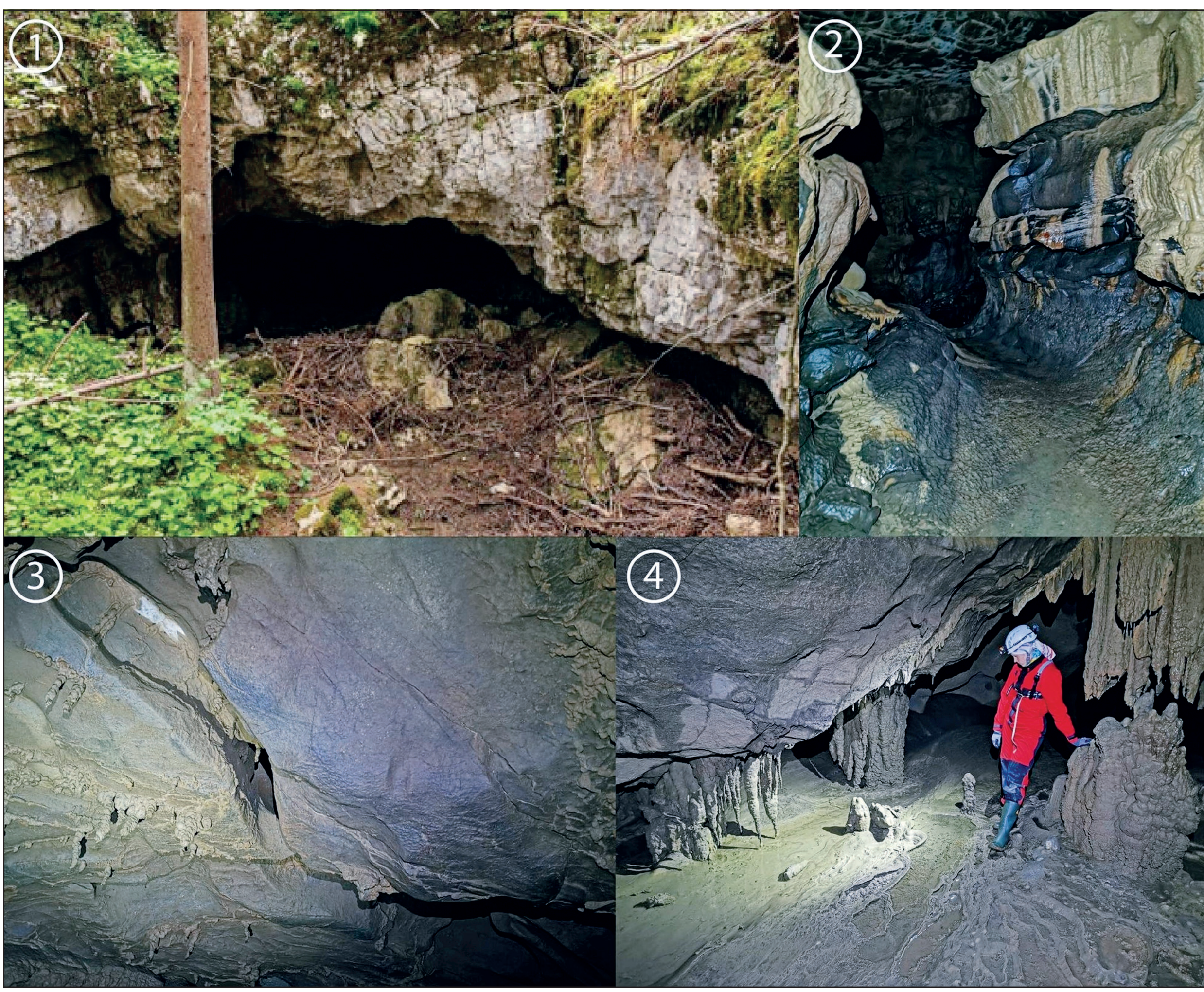

Figure 4: Markov spodmol – entrance (1), ceiling and wall pockets in Markov spodmol (2), anastomoses – up to 10 cm wide in the cave Vodna jama v Lozi near the entrance shaft (3), allogenic sediments coating of speleothems in Vodna jama v Lozi (4) (Photo 4.4: J. Tičar).

to precipitation. After about 550 m the explorable passage ends with a siphon. The walls and ceiling of the cave passage are full of phreatic rocky relief features (e.g. scallops, pendants; Slabe, 1995; Figure 4.2). Allogenic sediments are preserved mainly in the higher levels of the passage within several meters high accumulations (Zupan Hajna et al., 2020; Švara et al., 2021). A dated section of allogenic sediments (Zupan Hajna et al. 2008, 2020) shows that deposition in the Markov spodmol occurred in 2 distinct periods, lower sediment layers are older than 3.34 – 3.60 Ma and upper layers are younger than 0.78 Ma. The two-phased allogenic sedimentation was followed by sedimentation under more vadose conditions with occasional epiphreatic water pulses, which will be further investigated. There is no evidence of sedimentation in the intervening period, due to the erosion that is common in these high-energy cave settings.

The southeastern part of the cave system is represented by the cave Vodna jama v Lozi (reg. no. 911; Figure 3). Its 75 m deep vertical entrance is located at WGS84 coordinates 45.716671°N/14.118584°E. This part of the system is represented by 6880 m long subhorizontal channels mostly filled by water. A short horizontal passage following the vertical entrance is accessible only when the water level is low. This part is characterized by fine clastic sediment accumulations that cover most of the cave, as fluctuations in the water table still occur. Walls, ceiling, and speleothems are covered with sediments from recent flooding, while ceiling pendants and anastomoses are exposed in some places (Figures 4.3; 4.4). Since the sedimentation in this part is recent, there is no potential for further useful dating. The driest part of the cave (NW part, close to Markov spodmol) can be reached only by divers.

The cave system extends in a northwest-southeast direction between 556 m and 470 m a.s.l., and has a height difference of 80 m between the outermost parts. Its speleogenesis can be related to allogenic water input from the Postojna Basin, as evidenced by the directional scallops and the mineralogical composition of the allogenic sediments, with the ponors located at the contact between carbonates and flysch (Zupan Hajna et al., 2008; Švara et al., 2021). One of the main inputs to the active cave system today comes from the Sajevško polje blind valley, but in the past it could have come also from the Biščevci blind valley as shown by some sedimentological evidence southeast above the blind valley or the extent of the westernmost part of the cave system.

Above the currently active cave system in the Slavinski ravnik, where the altitudes are between 550 m and 630 m a.s.l., the relict, **unroofed cave Brezstropa jama v Lozi** exists on the surface between 630 m and 580 m a.s.l. (Mihevc, 1999b, 2006; Figures 1; 3; 5). Its presence on the surface is a result of chemical denudation of the karst surface above the pre-existing cave, which exposed all allogenic sediments and speleothems.

With a length of over 4.3 km (Figure 5) and a height difference of 50 m between the upstream and down-

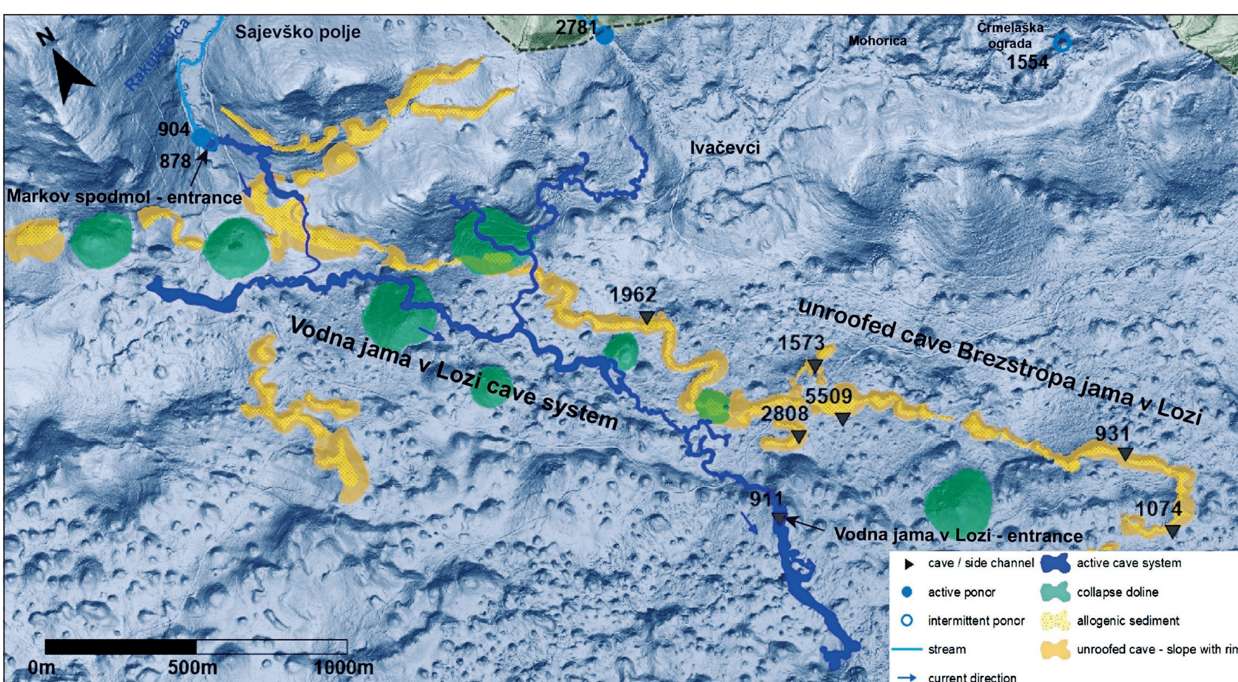

Figure 5: Location and geomorphological map of the cave system in Slavinski ravnik: active caves Markov spodmol and Vodna jama v Lozi and the unroofed cave Brezstropa jama v Lozi (DEM – LiDAR data, Geodetic department ARSO, 2021b).

stream ends, this horizontal cave is the longest known unroofed cave in Slovenia. The morphology of the cave appears as a mostly continuous trench with a passage up to 30 m wide and to 15 m high. The unroofed cave bottom part is mostly filled with allochthonous and autochthonous sediments. The predominant allochthonous sediments consist of allogenic flysch sediments (sandy/marly/clayey sediments) occasionally interbedded with partially cemented chert, while the autochthonous sediments are represented by speleothems, breakdown material, and cryoclastic breccia from the walls of the unroofed passage (Figure 6). The slopes and rim of the unroofed cave, as well as the cave fill, are covered in some places by collapsed debris from the rest of the cave ceiling and walls. In places where the rim of the cave is highest, the limestone blocks show rotation due to recent mass movement or tectonic activity, while in other places the slope is balanced with less rockfall and more alluvium (e.g. Figure 6.1). Due to its length and uniqueness, the unroofed cave was registered as an outstanding contact karst feature of natural value in 2015 (Nature Conservation Atlas, 2021).

In several places, there are smaller (sub)horizontal caves near the main unroofed channel (e.g. Jama pod Koško potjo – reg. no. 1962, Spodmol v Selški Lozi – reg. no. 1573, Spodmol ob Selški poti v Lozo – reg. no. 2808, Nova jama v Lozi – reg. no. 5509, Šimčev spodmol – reg. no. 931, and Markandelov spodmol – reg. no. 1074), which at some time probably served as side passages of the former active cave. The altitude of the passages, the thinness of their ceiling, and the content of allogenic sediments support this theory. The cave Spodmol v Selški Lozi at the entrance contains an allogenic sediment sequence, dated to an age of more than 3 Ma, which gives us the first information about the age of sedimentation of the unroofed cave itself (Zupan Hajna et al., 2020). For further research, an important site with allogenic sediments and speleothems was recently discovered in the lower part of the cave Šimčev spodmol and sampled for paleomagnetic and paleontological dating (Švara et al., 2021).

Figure 6: The main cave channel of the unroofed cave Brezstropa jama v Lozi (1), fallen stalactite in the unroofed cave (2) (Photo: J. Tičar), cemented allogenic sediment with pebbles in sandy/silty matrix (3), chert pebbles (4).

4.2. BLIND VALLEYS AND ALLUVIAL DEPOSITS

Blind valleys form at sinking points of allogenic rivers (e.g. Ford & Williams, 2007), and they deepen and enlarge over time in response to groundwater fluctuations, karst permeability, changes in the regime of sinking rivers, due to allogenic input, and changes in the regional hydraulic gradient. Blind valleys begin to cut into the corrosion plain with low transverse and longitudinal gradients because river valleys would otherwise develop (Mihevc, 2007).

Blind valley bottoms are usually filled with clastic sediments originating from nearby weathered impermeable rocks, deposited by allogenic waters and by intermittent ponding of their bottoms (e.g. Gams, 1962; Radinja, 1972; Mihevc, 1991a, b; Gunn, 2004). Allogenic streams drain at one or more points in the bottom, at the end, and/or sides of blind valleys through ponors in the alluvium or karst bedrock (Gunn, 2004). A relict blind valley forms as the flowing stream in a blind valley shortens due to subsidence of the erosional base or as a result of interruption of water inflow due to river piracy (Ford & Williams, 2007; Mihevc, 1991b, 2001, 2007). In these relict blind valleys allogenic sediments usually cover their bottoms partially, in dolines or small pockets in their karstified floor (Mihevc, 1991b, 2001, 2007).

On the northern boundary of the Slavinski ravnik three impressive blind valleys are expressed in the relief: the Biščevci blind valley, the Sajevško polje blind valley, and the Ivačevci blind valley, which have different characteristics today than at the time of their formation (Figure 3). The allogenic sediments were deposited in all blind valleys, as their presence indicates. Since the surface relief is constantly changing due to various processes, all contact karst features cannot be considered uniform, but have undergone their own process of evolution.

The Biščevci blind valley (Figures 1-3; 7-9) is the westernmost blind valley of the Slavinski ravnik corrosion plain. It is 1.76 km long and between 420 m and 1 km wide and has an area of 1.27 km^2. Its bottom lies between 541 m a.s.l. in the north and 553 m a.s.l. in the south. It is surrounded by a carbonate slope with a rim, the highest point of which is at 700 m a.s.l. on its eastern edge and 673 m a.s.l. on its western part. In the valley bottom, river terraces can be observed, whose slopes are between 543 m and 545 m a.s.l. The slopes near the bottom of the valley are stable, while the slopes towards the edge of the valley margin become steeper and are therefore active with rockfall and screes. On average, the slopes are inclined about 25° and tend to be steeper on the western edge. On the western slopes, a 20 m wide

Figure 7: Biščevci blind valley at the NE part of the Slavinski ravnik (photographed facing south; RI-SI EPOS drone). After a period of heavy rainfall, the nearby river Nanoščica overflows south into the northern part of the blind valley and collects the water from the estavelles.

remnant is observed as a karstified (relict) valley floor extending over 480 m, showing the former level of alluviation of an earlier phase of the blind valley.

Today, the hydrological function of the Biščevci blind valley is opposite to that in the neighbouring active blind valleys. Due to the opposite inclination of the valley floor (Figure 2, cross section A-B; Figure 3) combined with the present-day surface water runoff and fluctuation of the karst water table, the intermittent springs are now located on the relict ponor side of the blind valley. After prolonged periods of rain, the karst water table in the blind valley rises and groundwater floods the lowest depressions in the valley bottom. Surface water collects in two main streams flowing from the southern part of the blind valley towards the north into the river Nanoščica (Figures 1; 7-8). In the northwestern part of the blind valley, the water sinks into one or two ponors which act as intermittent springs (i.e. estavelles) during high water in the karst. Nevertheless, occasional hydrologic activity redeposits allogenic sediments once transported from the basin, keeping the blind valley hydrologically active.

The bottom of the Biščevci blind valley is covered with up to 4 m thick fine-grained allogenic sediments from the last accumulation (ponding) phases, in places with some sandstone pebbles and less frequently with chert pebbles. The limestone bedrock is often exposed by intermittent springs in the valley bottom during dry periods or in places where the alluvial cover is thinner. Along the slopes and rim of the blind valley, chert and sandstone pebbles are found at several higher elevations, possibly indicating the elevation of the former (older) blind valley bottom (Figure 9).

The **Sajevško polje blind valley** (Figures 1-3; 10-11) is located east of the Biščevci blind valley and covers an area of 0.64 km^2. It is 1.2 km long and up to 620 m wide, with the lower part, which is 966 m long and up to 210 m wide, lying between 573 m a.s.l. in the northern part and 558 m a.s.l. in the south, and is completely covered with allogenic sediments. It is surrounded by a slope with a rim that reaches its highest point at 680 m a.s.l. on the western side below the Učičnik hill and at 675 m a.s.l. on the eastern side below the Strmec hill (Figure 1). The western slopes are the steepest, with an inclination of up to 60°, while the slopes on the eastern edge of the blind valley have an inclination of up to 20°. Active slopes with rockfall and slope material are prevalent on both sides. A 4 m wide relict bottom of the blind valley and the highest relict ponors are present on the western edge (Figure 11), but these cannot be precisely identified due to recent active slope movements.

Figure 8: Flooding on the October 12, 2020 in the Biščevci blind valley, photographed towards the south (1), a small intermittent spring and stream in the background (2), and an intermittent spring at the southern part of the blind valley (3).

The leveled floor of Sajevško polje blind valley still has an active stream, Rakuliščica stream, which flows from the northeast/north to the south. In its northern part the stream was slightly diverted into a ponor represented by the cave Ponikve pri Sajevčah (reg. no. 903), but in general it sinks near a mill 300 m to the north and only at high water further south in the cave Požiralnik pred Markovim spodmolom (reg. no. 904). At the highest water level, the stream overflows its banks 20 m further and can sink into the cave Markov spodmol (reg. no. 878), whose entrance is 4 m higher (Figure 10). On the western edge of the lower part of the blind valley are two relict ponor caves, the caves Ogrizkov spodmol (reg. no. 923) at 568 m a.s.l. and Županov spodmol (reg. no. 924) at 575 m a.s.l, that may once have drained the water of the blind valley, the higher relict ponor being considered the oldest (Habe & Hribar, 1964). An intermittent spring Bruhalnik pred Markovim spodmolom (reg. no. 1080) is known on the blind valley`s western boundary but is active only during high water.

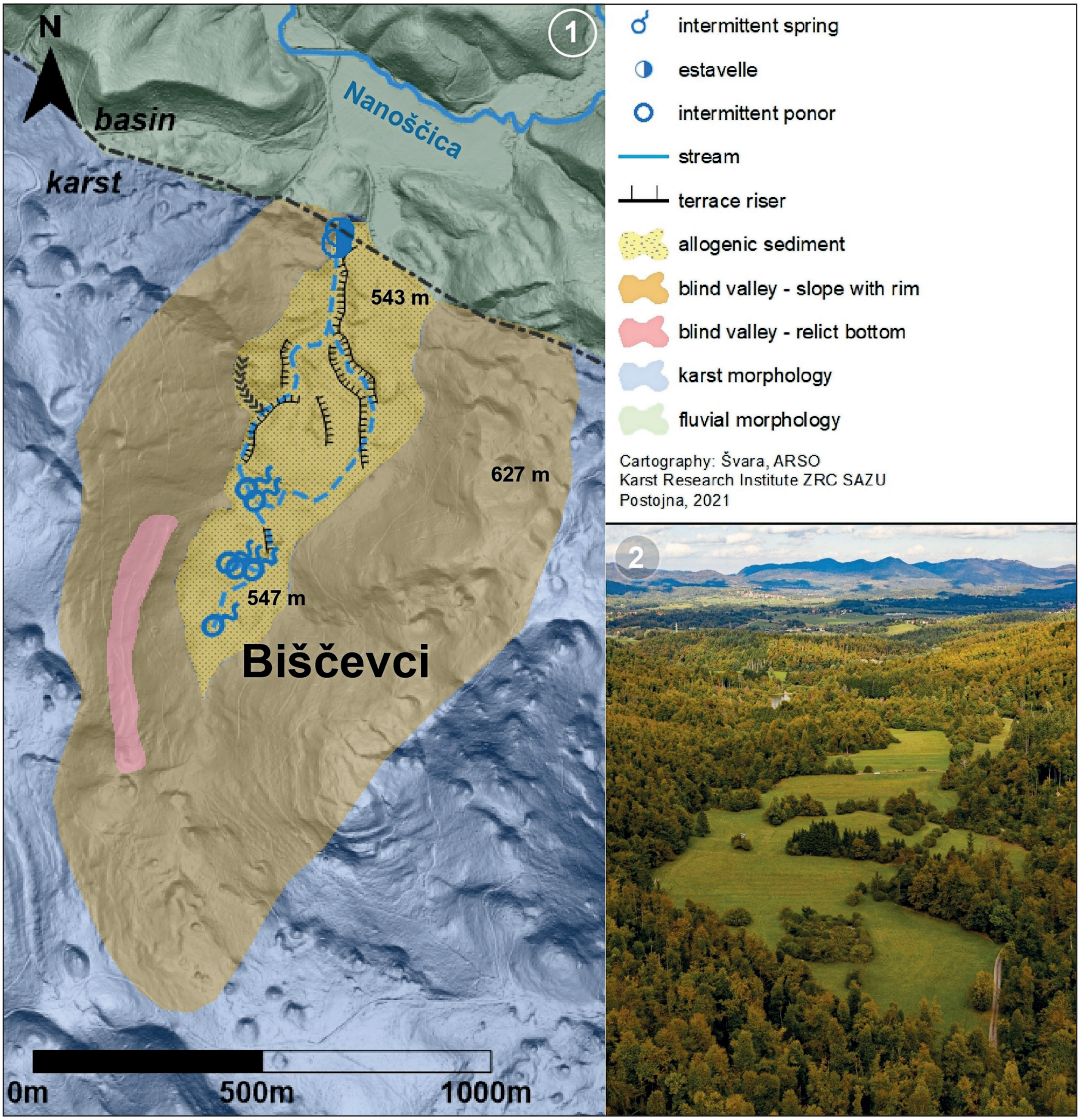

Figure 9: Geomorphological map of the Biščevci blind valley (DEM – LiDAR data, ARSO, 2021b) (1), Biščevci blind valley towards the north in dry season (2; RI-SI EPOS drone).

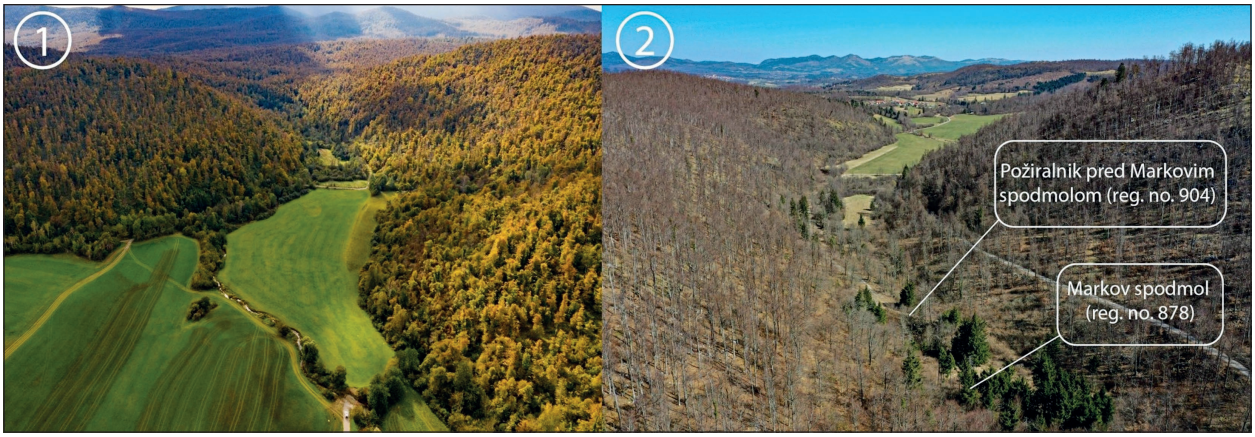

Figure 10: Sajevško polje blind valley photographed facing the south (1), Sajevško polje blind valley photographed facing the north, with approximate locations (2) of the active ponor Požiralnik pred Markovem spodmolom - reg. no. 904, and the cave Markov spodmol -reg. no. 878 (RI-SI EPOS drone).

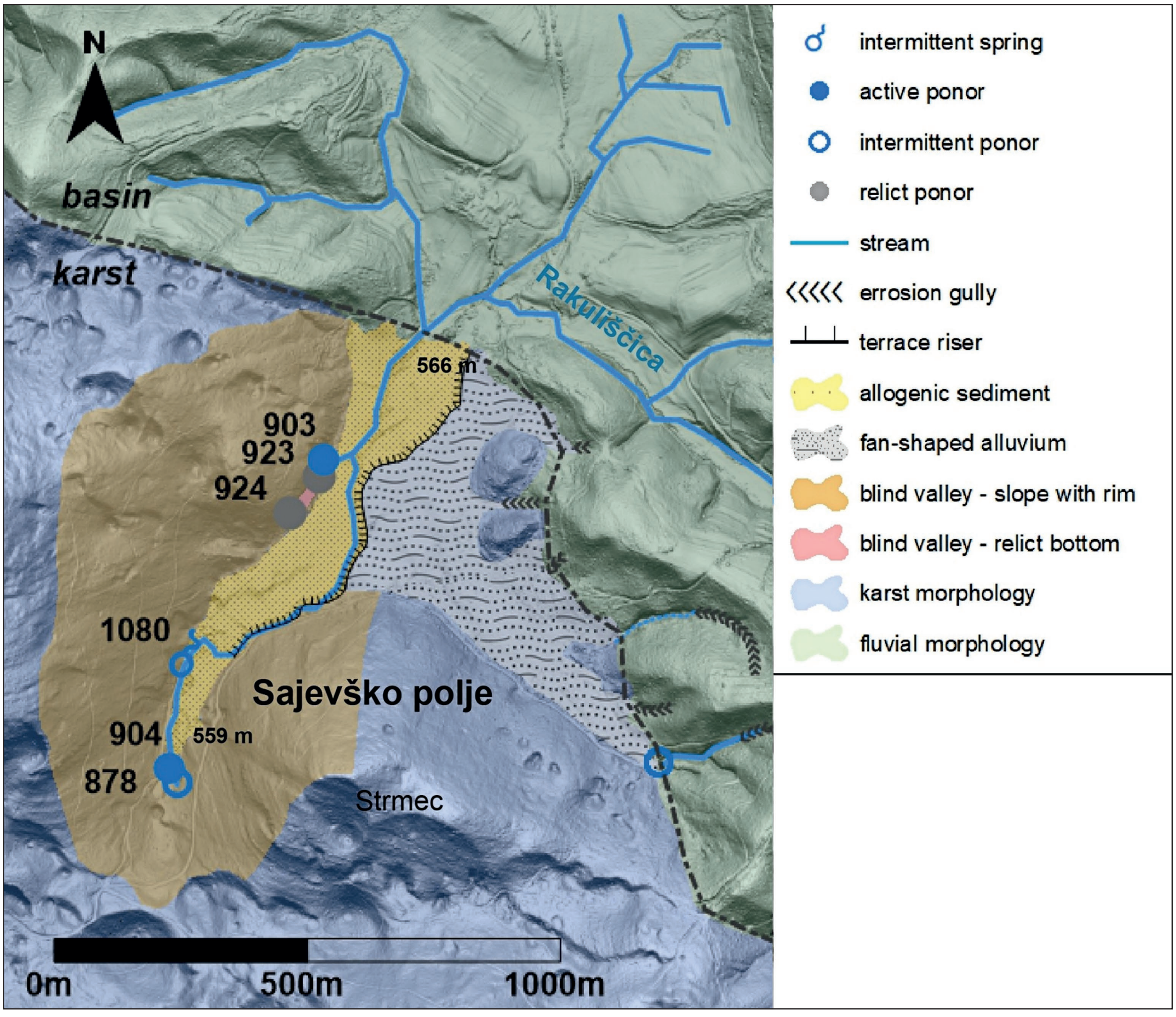

Figure 11: Geomorphological map of the Sajevško polje blind valley with well-expressed fan-shaped alluvial deposits in its NE part (DEM – LiDAR data, ARSO, 2021b).

In the easternmost part of Sajevško polje, two periodic streams may appear after a rainy period. The southeastern stream sinks into the alluvium and flows into an intermittent ponor, while the second discharges allogenic sediment onto the alluvium cover (Figures 11-12).

The bottom of the blind valley is entirely covered with fine-grained allogenic sediments, with flysch pebbles exposed near the stream channel. On the western boundary, the alluvium cover is up to 8 m thick (Habe & Hribar, 1964).

The eastern part of Sajevško polje contains an alluvial accumulation consisting of sediments originating from six erosional gullies in the flysch hinterland. Streams flow periodically in two of them, cutting their streambeds into the sediment (Figure 11). The western edge of the fan-shaped alluvial deposit ends with the terrace, which was formed by the Rakuliščica stream. The alluvial deposits cover the entire Sajevško polje, comprising an area of 1.78 km^2 that is up to 835 m long and about 470 m wide (Figure 12). It generally slopes 5° from southeast to northwest, and lies between 595 m and 565 m a.s.l. Its thickness is more than 7.5 m. In the borehole in the central part of the alluvial deposit (Habe & Hribar, 1964) and in a nearby field, mainly coarse sediments were detected.

The **Ivačevci blind valley** (Figures 1-3; 13) is the easternmost blind valley. It is up to 845 m long in its western part and up to 560 m long in its eastern part, and up to 1.9 km wide on its northern margin and up to 485 m wide in its southwestern part. It covers an area of about 5.1 km^2. Its karstified bottom with dolines reaches from 670 m in its easternmost part to 610 m a.s.l. It is surrounded by a slope with a rim that reaches its highest point on its southeastern side below Jančarija Hill, while its western edge reaches 645 m a.s.l. The slopes have an inclination of up to 20° and are quite balanced with little slope material.

There is no active watercourse (Figure 13) in the blind valley that could have been involved in its formation, so it is a (hydrologically) relict blind valley. The flysch hinterland contains several erosional gullies, some of which include periodic streams, the westernmost of which terminates in the active ponor of Požiralnik v Ivačevcih (reg. no. 2781) at the contact between limestone and flysch. Potential relict ponors that once drained water from the blind valley are located on the margins of the valley floor and are represented by Spodmol 1 v Ivačevcih (reg. no. 2218), Spodmol v Ivačevcih (reg. no. 1574), Jama v Ivačevcih (reg. no. 2779) and Brezno pri

Figure 12: The upper part of the alluvial deposit at SE margin of Sajevško polje; photographed towards SE of blind valley (RI-SI EPOS drone).

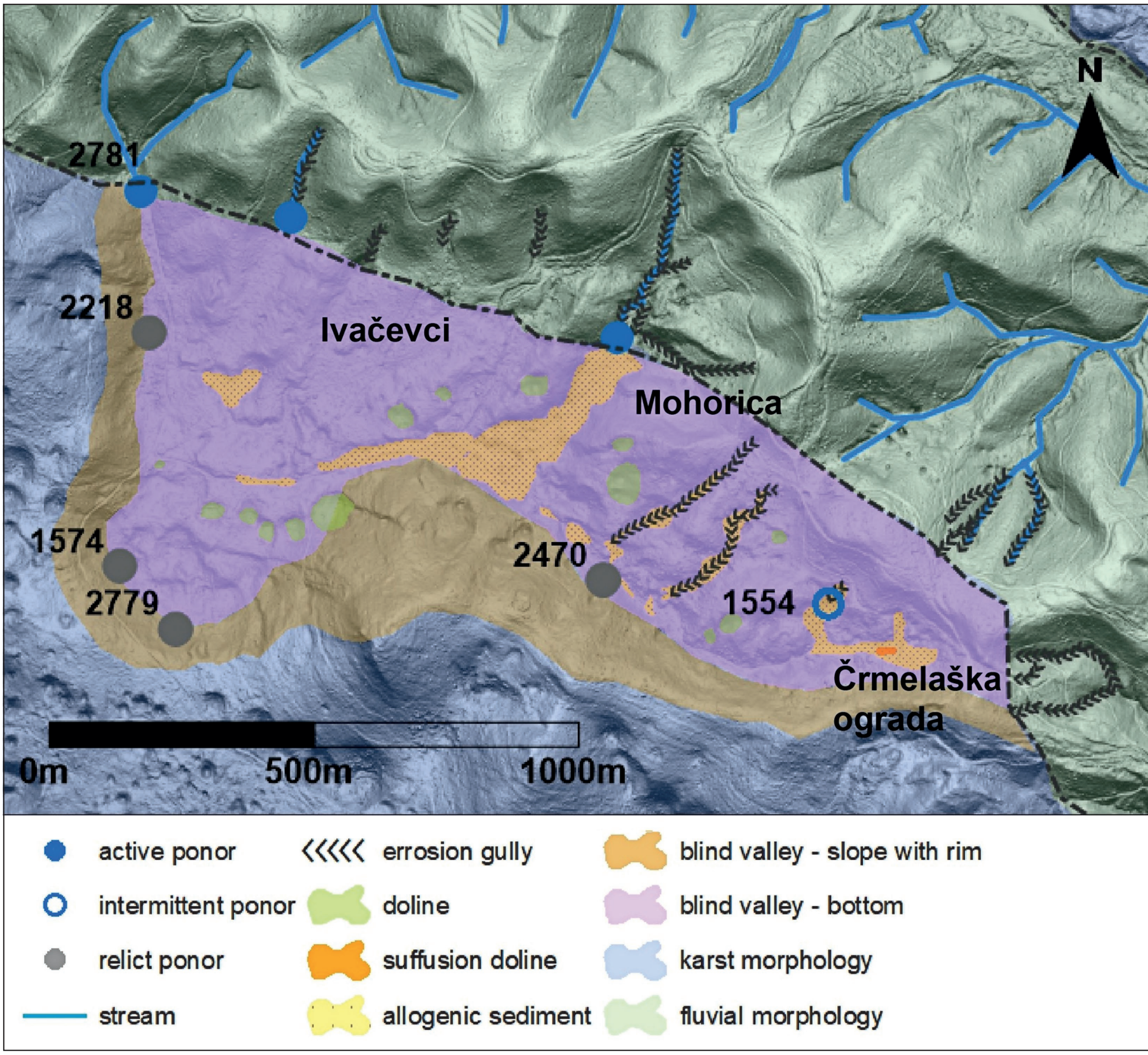

Figure 13: Geomorphological map of the Ivačevci blind valley (DEM – LiDAR data, ARSO, 2021b).

Jančariji (reg. no. 2470). After a rainy period, a small local stream forms and sinks into the intermittent ponor of Brezno v Črmelaški ogradi (reg. no. 1554).

A big part of the blind valley bottom is rocky. Fine-grained allogenic sediments present only in some dolines or other karst depressions, where they have not yet been washed into the subsurface. In the central and eastern part of the blind valley, alluvium is preserved in elongated patches where gullies form during rainy periods and wash sediment down the 5° slope to the southwest. The central stream still occasionally supplies some allogenic sediment from the flysch, while others have no direct connection to the hinterland (Figure 13). In the easternmost part, in the Črmelaška ograda, a suffosion doline has developed in the thick alluvium deposit, washing the sediment into the karst (Figures 13-14).

Figure 14: The alluvium with the suffosion doline in the eastern part of the Ivačevci blind valley, photographed towards west (RI-SI EPOS drone).

5. DISCUSSION

Due to regional tectonic uplift caused by neotectonic processes (e.g. Placer et al. 2021), changes in denudation (e.g. Mihevc 2001), related to changes in climate and hydrological conditions (e.g. Zupan Hajna et al. 2008, 2020), and consequently alteration in the balance between sedimentation and erosion, contact karst forms are not fully preserved in their original shape. Therefore, they can now be observed as active and relict geomorphological features that can be distinguished in surface relief as hydrologically active or inactive forms at the surface or in the subsurface. Due to past alluviation of these forms, allogenic sediments are fully or partially preserved (Figure 3). Geomorphological, speleological, and sedimentological mapping revealed three groups of ponor contact karst forms within the Slavinski ravnik research area:

(1) Caves: There are 77 known caves in the Slavinski ravnik research area. They are present in all hydrological zones of a karst system (vadose, epiphreatic, phreatic). Active water caves, including the best-explored **cave system of two connected caves Markov spodmol and Vodna jama v Lozi** (Figure 5) present the epiphreatic part of karst. This horizontal water cave system is 7.7 km long. The main entrance is an intermittent ponor at the end of the blind valley Sajevško polje. The cave walls and ceiling forms show phreatic conditions at the time of cave formation and paragenesis at the time of cave filling by sediments. There are many vadose shafts, and also relict caves, e.g. Šimčev spodmol. On the karst surface the best-expressed form is the **unroofed cave Brezstropa jama v Lozi**. It is a more or less continuous 4.3 km long denuded relict cave, with preserved allogenic cave sediments and different speleothems (Figure 5). The studied active and unroofed caves represent the main outflow routes for water and allogenic sediments from the Postojna Basin at least during the last 3.6 Ma (e.g. Zupan Hajna et al. 2020).

(2) Blind valleys: In the studied area there are three well expressed blind valleys filled with sediments. The **Biščevci blind valley** is the westernmost blind valley, 1.76 km long and up to 1 km wide (Figure 9). The bottom of the blind valley is currently slightly tilted to the north

and almost completely covered with allogenic sediments. Evidence of hydrological function from the time of its formation is not preserved; instead, intermittent springs and streams originate occasionally in its southern part and flow and sink towards the north. The former extent of the blind valley is indicated by pebbles on the slope and on the edge in the south-western to eastern part, as well as by a relict blind valley bottom on the western slope. Due to the large dimensions of the Biščevci blind valley, the large amount of allogenic sediments, and the fact that there is no present-day sinking stream, we can assume that the hydrological function of the blind valley was quite different in the past (Figure 9). A stream that formed the blind valley to this extent should also have been capable of transporting a large amount of allogenic sediments. The current situation is showing as, that there are springs in the blind valley that eroded and washed away the old sediment, which can be a typical transformation path from an active to a relict blind valley. The **Sajevško polje blind valley** is 1.2 km long and up to 620 m wide and contains the active Rakuliščica stream, which now incises its channel into the alluvial sediments and sinks mainly into the ponor Požiralnik pred Markovim spodmolom, rarely into Markov spodmol (Figure 11). An old remnant of the higher former blind valley bottom is preserved on its western edge, with relict ponors. The blind valley bottom is completely covered with allogenic sediments, while the eastern part of the Sajevško polje form a large sediment accumulation where six smaller alluvial deposits merge (Figure 11). The **Ivačevci blind valley** is the easternmost blind valley, up to 845 m long and up to 1.9 km wide (Figure 13). It no longer contains active watercourses, indicating that it is a relict feature. Periodic streams now sink mainly at the lithological contact on the northern edge of the blind valley. Possible former ponors are located along the boundary between the floor and the slope with rim. Relics of allogenic sediments are present mainly in patches in the deepest parts of the blind valley bottom. The blind valley shape, the location of the sediment, and its past and present hydrological function indicate a complex evolution. From all this we can assume that in the past, two separate blind valleys developed in the Ivačevci area. These later merged into one due to a change of the gradient related to tectonic events that affected the hydrology of sinking streams. However, over time, surface water flows completely disappeared from the blind valley.

The catchment area of all described contact karst geomorphic features of the Slavinski ravnik corrosional plain is represented by the impermeable flysch of the Postojna Basin. Blind valleys and large ponor caves were formed at a time when the northwestern part of the corrosional plain functioned as an active contact karst with considerable allogenic input. Because the landforms are quite extensive, the rivers that once formed them must have been larger than those of today. This suggests a different hydrogeological function of the Postojna Basin and a larger impermeable catchment area with a steeper inclination (Placer et al., 2021) than at present.

In the present, relict and active contact karst forms intertwine on the surface and underground, representing different hydrological activities over time. The corrosion plain along with ponors has been controlled by the karst water level. This is indicated by the relative elevations at which these geomorphic contact karst forms are located. The hydrological regime from the time of blind valley and paragenetic cave formation has changed in comparison with the present situation. It shows an alteration most likely due to the regional tectonic uplift that led to disconnection from the main source of water and clastic sediment supply from the Postojna Basin. Combined with extensive erosion of flysch deposits, this resulted in a lowering of the erosion base.

A reversed hydrological function with intermittent springs can be observed today in the Biščevci blind valley, showing a slight deformation of this western part, while the karstification of the Ivačevci blind valley indicates an uplifted eastern part, that is on average 75 m above the Biščevci blind valley. There present streams sink on the northern edge of the blind valley, at the contact between flysch and limestones. Both cases show significant neotectonic activity (regional uplift) related to the collision and counterclockwise rotation of Adria Microplate (e.g. Le Brenton et al., 2017), which is also evidenced by the stream incision and erosion instead of sediment deposition.

The overall arrangement of active and relict contact karst features shows similar patterns. Those located at higher elevations, embedded in the karst morphology, or features further from the sediment source tend to be relict, while hydrologically active features are found at lower elevations or closer to the Postojna Basin. Active ponors are located at the lowest point of the sinking stream (e.g. the ponor of Rakuliščica in Ponikve pri Sajevčah, or the ponor of a local intermittent stream in Požiralnik v Ivačevcih), whereas relict ponors are located higher in the karst terrain and are detached from the present contact with the alluvium, indicating relationships to a previous drainage system. For example, caves Ogrizkov spodmol and Županov spodmol indicating the level of drainage in the past, from the Sajevško polje blind valley and/or fan-shaped alluvial deposit. This pattern is also observed where active blind valley bottoms with river terraces are located at lower elevations, while relict blind valley floors can be observed at higher elevations, also indicating a shift of active forms to lower elevations. Blind valleys that formed on the northeastern edge of the corrosion plain functioned as predominant sinking paths of allogenic streams, whose sediments filled the ponor caves and bottoms of the blind valleys. The amount and type of allogenic sediments varied over time with changes in climate and in the karst erosional base, and the lowering of the tributary drainage due to the erosion of flysch. The allogenic sediment, washed into the karst mainly through ponors, enlarged the caves and filled their channels and passages, which also led to the formation of paragenetic caves.

Ponor caves, such as the former active ponor of Markov spodmol, are the main infiltration points for water draining from the non-karst areas, bringing a large amount of allogenic sediment into the karst. These long horizontal ponor caves exhibit a turbulent flow regime with large channels (e.g. Gams, 1974; Ford & Williams, 2007). When large amounts of allogenic sediment accumulate in cave passages and accumulation predominates over erosion, the caves usually reform through the process of paragenesis (Renault, 1958, 1968), which has been the case of the cave system Vodna jama v Lozi. Paragenetic caves are connected to ponor caves by bypass channels that form in the phreatic zone with a vaulted ceiling and sediment in the lower river canyon or other passages, where streams flow on the sediment just below the ceiling (Ford & Williams, 2007). If the water table is continually declining it forces new channels to develop in vertical, parallel planes that represent successive stages in cave development (e.g. Audra & Palmer, 2011). Where the allogenic fills are eroded, many paragenetic cave forms are revealed, e.g. ceiling channels and meanders, paragenetic rifts, suballuvial dissolution features, anastomoses, etc. (Bretz, 1942; Renault, 1968; Slabe, 1987; Mihevc, 2001a; Pasini, 2009). A similar arrangement of active and relict features may therefore apply to ponor caves affected by paragenesis and karst denudation. Active water caves, such as the described cave system move deeper in the karst, and consequently lower the ponor point. Relict caves, on the other hand, such as the unroofed cave Brezstropa jama v Lozi, tend to become a surface geomorphic form 80-100 m above the active cave system as karst denudation removes their ceiling and exposes horizontal passages with sediments. Further surface erosion completely removes them.

6. CONCLUSIONS

The aim of this work was to reveal the diversity of active and relict ponor-contact karst features of the Slavinski ravnik corrosional plain and to obtain information on the main factors influencing the development of the karst system. This was achieved by the survey of hydrologically active and inactive features with fully or partially preserved allogenic and autochthonous cave sediments shown in the geomorphological map (Figure 3).

By locating and describing the various forms and recognizing their interrelationships, phases of formation of the southern karst periphery of the Postojna basin were recognized. By the acknowledgement of active and relict forms, i.e. relict and active ponors at the end of blind valleys, relict and active caves within the cave system with the sedimentary record, etc., we determined their extent, the course of formation and sedimentation. With the knowledge of the hydrological situation and their general transformation, the genesis of the northern border of the Slavinski ravnik was outlined.

The geomorphic features represent different stages of contact karst formation and are distinguished as active and relict contact karst features. The forms studied in the Slavinski ravnik are the active cave system of Markov spodmol and Vodna jama v Lozi (Figure 5), the relict unroofed cave Brezstropa jama v Lozi (Figure 5), the active Biščevci blind valley (Figure 9) and Sajevško polje blind valley (Figure 11), and the relict Ivačevci blind valley (Figure 13). The cave system Loza was formed by the Rakuliščica river, flowing from the Postojna basin. The cave system consists of active caves Markov spodmol and Vodna jama v Lozi, by partially and fully denuded Unroofed cave Loza and Spodmol v Selški Lozi, and bypass channels/connecting caves i.e. Šimčev spodmol. The cave system clearly shows a great history of phreatic, epiphreatic, and paragenetic development, which is confirmed by past and present water activities, cave features, sedimentological records, and dating results. The Biščevci blind valley shows a former hydrological activity to a great extent, with neotectonic activity resulting in tilting of the valley floor with reversed hydrologic activity. The Sajevško polje blind valley shows a vast past and recent hydrological activity with allogenic sedimentation from the Postojna basin in the last few million years. The placement of several relict and active ponors shows the evolution of the blind valley and represents significant past and present drainage from the basin to the corrosional plain. The Ivačevci blind valley is a wide relict blind valley, that is uplifted above the other two blind valleys. This was induced by neotectonic compression of the area, where allogenic sediments that once covered the valley floor infiltrated into the karst underground, and streams that once flowed towards the valley end began to sink at the lithostratigraphic contact.

In this study, using data from DEM, we investigated relict and active ponors, caves and segments of a cave system, elements of blind valleys, and the hydrological situation of the area, which were mapped in detail geomorphologically and digitized in ESRI Arcmap and Golden Software Surfer. The spatial distribution of the detected allogenic and autochthonous sediments helped us to determine the mutual connection of the geomorphological forms in the contact karst area of Slavinski ravnik. Based on their comparison and with the help of the knowledge about neotectonic impact on this area, we were able to determine their interdependence and deduce their genetic connection.

Prior to this research, separate studies were conducted with limited knowledge, mainly focusing only on specific and local problems within the Slavinski ravnik. This paper combines all speleological, geomorphological, and sedimentological aspects of the most representative ponor contact karst features, providing a more comprehensive understanding of the morphogenesis of the Slavinski ravnik area, rather than focusing only on the recognition of individual forms. This study will be further deepened with the upcoming sedimentological and chronological analyses that are currently in progress and will be presented in the near future.

ACKNOWLEDGEMENTS

The cooperation of Domen Turk (student at the Department of Geography, UL) and dr. Jure Tičar (Anton Melik Geographical Institute ZRC SAZU) during fieldwork is highly appreciated. The work of Astrid Švara was financed by the Young Researchers Programme of the Slovenian Research Agency (ARRS). The research was partly founded by the Slovenian Research Agency [core funding No. P6-0119].

The drone photographic material was recognized by the project »DEVELOPMENT OF RESEARCH INFRASTRUCTURE FOR THE INTERNATIONAL COMPETITIVENESS OF THE SLOVENIAN RRI SPACE – RI-SI-EPOS«. The operation is co-financed by the Republic of Slovenia, the Ministry of Education, Science and Sport, and the European Union from the European Regional Development Fund.

REFERENCES

ARSO, 2021a. Drainage Basins. http://gis.arso.gov.si/atlasokolja/profile.aspx?id=Atlas_Okolja_AXL@Arso [Accessed 24 October 2021].

ARSO, 2021b. Lidar data fishnet in D96TM projection. http://gis.arso.gov.si/evode/profile.aspx?id=atlas_voda_Lidar@Arso&culture=en-US [Accessed 1 September 2021].

Audra, P., Palmer, A.N., 2011. The pattern of caves: controls of epigenic speleogenesis. Noveaux paradigmes de la karstologie, mise en perspective, 17(4): 359-378. https://doi.org/10.4000/geomorphologie.9571

Bretz, J.H., 1942. Vadose and phreatic features of limestone caverns. The Journal of Geology, 50(6): 675-811. https://doi.org/10.1086/625074

Cave register, 2021. Cave Register of the Karst Research Institute ZRC SAZU and Speleological Association of Slovenia. Postojna, Ljubljana.

Dvořák, L., 1995. Application of Modern Geomorphological Methods in Theory and Practice: Case Study of the Bohemian Highlands (Czech Republic). GeoJournal, 35(4): 425-430. https://doi.org/10.1007/BF00824351

Ford, D.C, Williams, P., 2007. Karst Hydrogeology and Geomorphology. John Wiley & Sons, Chichester, 562 pp. https://doi.org/10.1002/9781118684986

Gams, I., 1962. Kraška terminologija. Geografski vestnik, 34: 115-137.

Gams, I., 1974. Kras, zgodovinski, naravoslovni in geografski oris. Slovenska matica, Ljubljana, 359 pp.

Gams, I., Zeremski, M., Marković, M., Lisenko, S., Bognar, A., 1985. Uputstvo za izradu detajlne geomorfološke karte SFRJ 1: 100 000, Beograd.

Gerasimov, I., 1946. Opyt geomorfologičeskogo strojenija SSSR. Problemy fizičeskoj geografii, 12: 33-46.

Gospodarič, R., 1988. Paleoclimatic record of cave sediments from Postojna karst. Annales de la Société géologique de Belgique, 111: 91-95.

Gospodarič, R., 1989: Prispevek k vodnogospodarskim osnovam Pivke = The contribution to water economy bases of Pivka. Acta carsologica, 18: 21-37.

Gunn, J., 2004. Valleys in karst. In: Gunn, J. (Ed.), Encyclopedia of Caves and Karst Sciences, Taylor & Francis Books Inc., London, New York, 1940 pp. https://doi.org/10.4324/9780203483855

Habe, F., Hribar, F., 1964. Sajevško polje. Geografski vestnik, 36: 13-14.

Hribar, F., Habe, F., Savnik, R., 1955. Podzemeljski svet Prestraniškega in Slavenskega ravnika. Acta carsologica, 1: 91-147.

Le Brenton, E., Handy, M. R., Molli, G., Ustaszewski, K., 2017. Post-20 Ma motion of the Adriatic plate: New constraints from surrounding Orogens and implications for crust-mantle decoupling. Tectonics, 36: 3135-3154. https://doi.org/10.1002/2016TC004443

Melik, A., 1951. Pliocenska Pivka. Geografski vestnik, 23(1): 17-39.

Mihevc, A., 1991a. Morfološke značilnosti ponornega kontaktnega krasa: izbrani primeri s slovenskega krasa [Master thesis]. Faculty of Arts, Department of Geography, Ljubljana, 206 pp.

Mihevc, A., 1991b. Morfološke značilnosti ponornega kontaktnega krasa v Sloveniji. Geografski vestnik, 63: 41-50.

Mihevc, A., 1996. Brezstropa jama pri Povirju. Naše jame, 38: 65-75.

Mihevc, A., 1999a. Unroofed caves, Cave sediments and karst surface Geomorphology – Case study from Kras, W Slovenia. Naš krš, 19(32): 3-11.

Mihevc, A., 1999b. Unroofed caves of Slavenski ravnik. In: Mihevc, A. (Ed.), 7th International Karstological School, Classical Karst, Roofless caves, Guide-booklet for the excursions, June 1999, Postojna, Speleological Association of Slovenia and Karst Research Institute ZRC SAZU, Postojna, pp. 9-14.

Mihevc, A., 2001. Speleogeneza Divaškega krasa. Založba ZRC, ZRC SAZU, Ljubljana, 180 pp. https://doi.org/10.3986/9789610503224.

Mihevc, A., 2006. Brezstropa jama na Slavenskem ravniku. In: Boštjančič, J. (Ed.), Slavenski zbornik. Slavina, Kulturno društvo Slavina, pp. 27-34.

Mihevc, A., 2007. The age of karst relief in West Slovenia. Acta carsologica, 36(1): 35-44.

Mihevc, A., 2010. Geomorphology. In: Mihevc, A., Prelovšek, M., Zupan Hajna, N. (Eds.), Introduction to the Dinaric Karst. Karst Research Institute at ZRC SAZU, Postojna, pp. 30-43.

Nature Conservation Atlas, 2021. Jama v Lozi – brezstropa jama. https://www.naravovarstveni-atlas.si/web/profile.aspx?id=NV@ZRSVNJ&culture=en-US [Accessed 9 November 2021].

Otto, J. C., Gustavsson, M., Geilhausen, M., 2011. Cartography: design, symbolization, and visualization of geomorphological maps. In: Smith, M. J., Paron, P., Griffiths, J. (Eds.), Geomorphological Mapping: Methods and Applications. Elsevier, London, 610 pp. https://doi.org/10.1016/B978-0-444-53446-0.00009-4

Pasini, G., 2009. A terminological matter: paragenesis, antigravitative erosion or antigravitational erosion. International Journal of Speleology, 38: 129-138. https://doi.org/10.5038/1827-806X.38.2.4

Pavlopoulos, K., Evelpidou, N., Vassilopoulos, A., 2009. Mapping Geomorphological Environments. Springer, Berlin, 236 pp. https://doi.org/10.1007/978-3-642-01950-0

Placer, L., 1999. Contribution to the macrotectonic subdivision of the border region between Southern Alps and External Dinarides. Geologija, 41 (1998): 223-255. https://doi.org/10.5474/geologija.1998.013

Placer, L., 2008. Principles of the tectonic subdivision of Slovenia. Geologija, 51(2): 205-217. https://doi.org/10.5474/geologija.2008.021

Placer, L., Mihevc, A., Rižnar, I., 2021. Tectonics and gravitational phenomena (Nanos, Slovenia) – Tektonika in gravitacijski pojavi (Nanos, Slovenija). Geologija, 64(1): 35-63. https://doi.org/10.5474/geologija.2021.003

Pleničar, M., 1963. Osnovna geološka karta - tolmač za list Postojna L33-77. Geološki zavod Ljubljana.

Pleničar, M., 1970. Tolmač osnovne geološke karte 1:100.000, List Postojna. Zvezni geološki zavod, Beograd.

Radinja, D., 1972. Zakrasevanje v Sloveniji v luči celotnega morfogenetskega razvoja. Geografski zbornik, 13: 199-242.

Register of Geographical Names, 2021. Toponyms. https://eprostor.gov.si/imps/srv/api/records/0f5fd804-9073-42d9-ad3c-b273f59fc16c [Accessed 20 June 2021].

Renault, P., 1958. Eléments de spéléomorphologie karstique. Annales de Spéléologie, 13(1–4): 33-48.

Renault, P., 1968. Contribution à l`étude des action mécanique et sédimentologiques dans la spéléogenèse. Annales de spéléologie, 23(3): 529-596.

Sauro, U., 2001. Aspects of contact karst in the Venetian Fore-Alps. Acta carsologica, 30(2): 89-102.

Sauro, U., 2002. The Monti Berici: Apeculiar type of karst in the Southern Alps. Acta carsologica, 31(3): 99-114. https://doi.org/10.3986/ac.v31i3.382

Sauro, U., 2013. Landforms of mountainous karst in the middle latitudes: reflections, trends and research

problems. Acta carsologica, 42(1): 5-16. https://doi.org/10.3986/ac.v42i1.629
Slabe, T., 1987. Jamske anastomose v Dimnicah. Acta carsologica, 16: 167-179.
Slabe, T., 1995. Cave Rocky Relief and its Speleogenetical Significance. Zbirka ZRC, Znanstvenoraziskovalni center SAZU, Ljubljana, 128 pp.
Stepišnik, U., 2006. Udornice na Slovenskem krasu [PhD thesis]. Oddelek za geografijo, Univerza v Ljubljani, Ljubljana, 192 pp.
Švara, A., Mihevc, A., Zupan Hajna, N., 2021. Active water cave Vodna jama v Lozi and Loza Unroofed Cave – a case of morphogenesis in the Slavinski ravnik (SW Slovenia). In: Blatnik, M., Gabrovšek, F., Mayaud, C., Mihevc, A., Petrič, M., Ravbar, N., Zupan Hajna, N. (Eds.) 28th International Karstological School, Classical Karst, Regional Karstology – Local and general aspects*, within International Year of Caves and Karst, Abstracts & Guide Book, 14th-17th June 2021, Postojna, Slovenia. Založba ZRC, Ljubljana, Postojna, 128 pp.
Weber, J., Vrabec, M., Pavlovšič-Prešeren, P., Dixon, T., Jiang, Y., Stopar, B., 2010. GPS-derived motion of the Adriatic microplate from Istria Peninsula and Po Plain sites, and geodynamic implications. Tectonophysics, 483: 214-222. https://doi.org/10.1016/j.tecto.2009.09.001
Zupan, H. N., Mihevc, A., Pruner, P., Bosák, P., 2008. Paleomagnetism and Magnetostratigraphy of karst sediments in Slovenia. Carsologica, Založba ZRC, Ljubljana, Postojna, 266 pp.
Zupan, H. N., Bosák, P., Pruner, P., Mihevc, A., Hercman, H., Horáček, I., 2020. Karst sediments in Slovenia: Plio-Quaternary multi-proxy records. Quaternary International, 546: 4-19. https://doi.org/10.1016/j.quaint.2019.11.01