N. Zupan Hajna – Barka depression, a denuded shaft in the area of Snežnik Mountain, southwest Slovenia. *Journal of Cave and Karst Studies,* v. 69, no. 2, p. 266–274.

BARKA DEPRESSION, A DENUDED SHAFT IN THE AREA OF SNEŽNIK MOUNTAIN, SOUTHWEST SLOVENIA

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Abstract: On the southern slope of Dedna gora, Slovenia, at an elevation of 1147 m, an interesting large closed depression referred to as Barka (Barge) is developed. It is about 40 m long, 25 m wide and 20 m deep, with smooth, almost polished precipitous walls. It is developed in Upper Cretaceous limestones and affected by several faults and fissure zones. The feature lies within a large karren field (about 10^4 m^2) with many closed depressions of various dimensions. In the winter time, snow accumulates in the bottoms giving the appearance of snow-kettles, such as those found in the Alps. The size and especially the shape of the walls suggests that these features are the remains of shafts. After their primary genesis as the inner vadose shafts of one or more caves, their upper parts would have been denuded. Walls and bottoms were subsequently remodeled by snow and ice action during the last glaciations, and this continues today as winter snow accumulates at their bottoms. This is indicated by silt fragments (gelifraction) and frost rubble accumulated in portions of the depression, and the development of sorted and nonsorted polygons. Shafts that have been exposed at the surface are a potentially important morphological element of karst topography. They can represent a significant portion of closed depressions of different sizes, including many snow-kettles.

Introduction

The aim of this paper is to clarify the genesis of a large, unusual closed depression in the karst massif of Snežnik-Javorniki in the area of Dedna gora, Slovenia. The area is situated in the southwest of Slovenia, between the town of Postojna and the Croatian border. The massif is bounded on the eastern side by the Idrija fault, along which the well-known karst Cerknica and Loško poljes have developed. To the northwest, it is delimited by Eocene flysch of the Pivka basin, and to the southwest by the Ilirska Bistrica basin (Fig. 1). The name of the depression, Barka, derives from its shape, as it resembles a barge hull (Fig. 2) at an elevation of 1147 m. Dedna gora, 1293 m above sea level, is the summit of the central part of the massif, lying between Javorniki Mountain on the north and Snežnik Mountain to the south. The highest peak of the area is Mt. Snežnik at 1796 m.

The massif of Snežnik - Javornik is a high karst plateau belonging to the High Dinaric karst physiographic province according to Habič (1969). The massif is dissected by large closed depressions and conical summits, formed in Jurassic and Cretaceous limestone and dolomites and their breccias. In caves whose entrances lie higher than 900 m above sea level, ice is present during the whole year. The Snežnik region was under ice during the last glaciation and boundary-line permanent snow was at the elevation of 1250 m (Šifrer, 1959). This is the reason why glacial and periglacial sediments are found in the area. Karstification, glacial, periglacial, and fluvio-glacial processes were significant geomorphic agents in the area in the past. In the present day, karstification is the main process. Various dolines and closed depressions of larger dimensions are present, as well as smaller forms such as karren and micro-karren.

Geologic Setting

The Javorniki and Snežnik area is within the Outer Dinarids geologic sub-province (Placer, 1981). From a tectonic point of view (Placer, 1981), the studied area is on the Snežnik thrust sheet (Javorniki and Snežnik mountains), which is overthrusted on another relatively autochthonous thrust sheet with a displacement of about 7 km. An important aspect of this overthrusting is that about 1000 m of carbonate rocks (limestone and dolomite of Jurassic and Cretaceous age) are placed over imperme-able Eocene flysch sediments.

In the context of the regional tectonic development of the area, the Snežnik- Javorniki karst massif is a part of the Alpine-Mediterranean Orogenic Belt, formed by the convergence of the Africa and Europe Plates. The spatial and temporal histories are rather complicated. The main period of thrusting and folding of the area is post Eocene, mostly younger then 30 Ma, being the result of post-collision processes between the Africa and Europe Plates. At 6 Ma the latest tectonic phase in the region started with counter-clockwise rotation of the Adria Microplate. The rotation caused reactivation of Dinaric faults, which had previously formed as dextral strike-slip faults related to the aforementioned thrusting (Vrabec and Fodor, 2006). The general WNW-ESE trending compression in the area is due

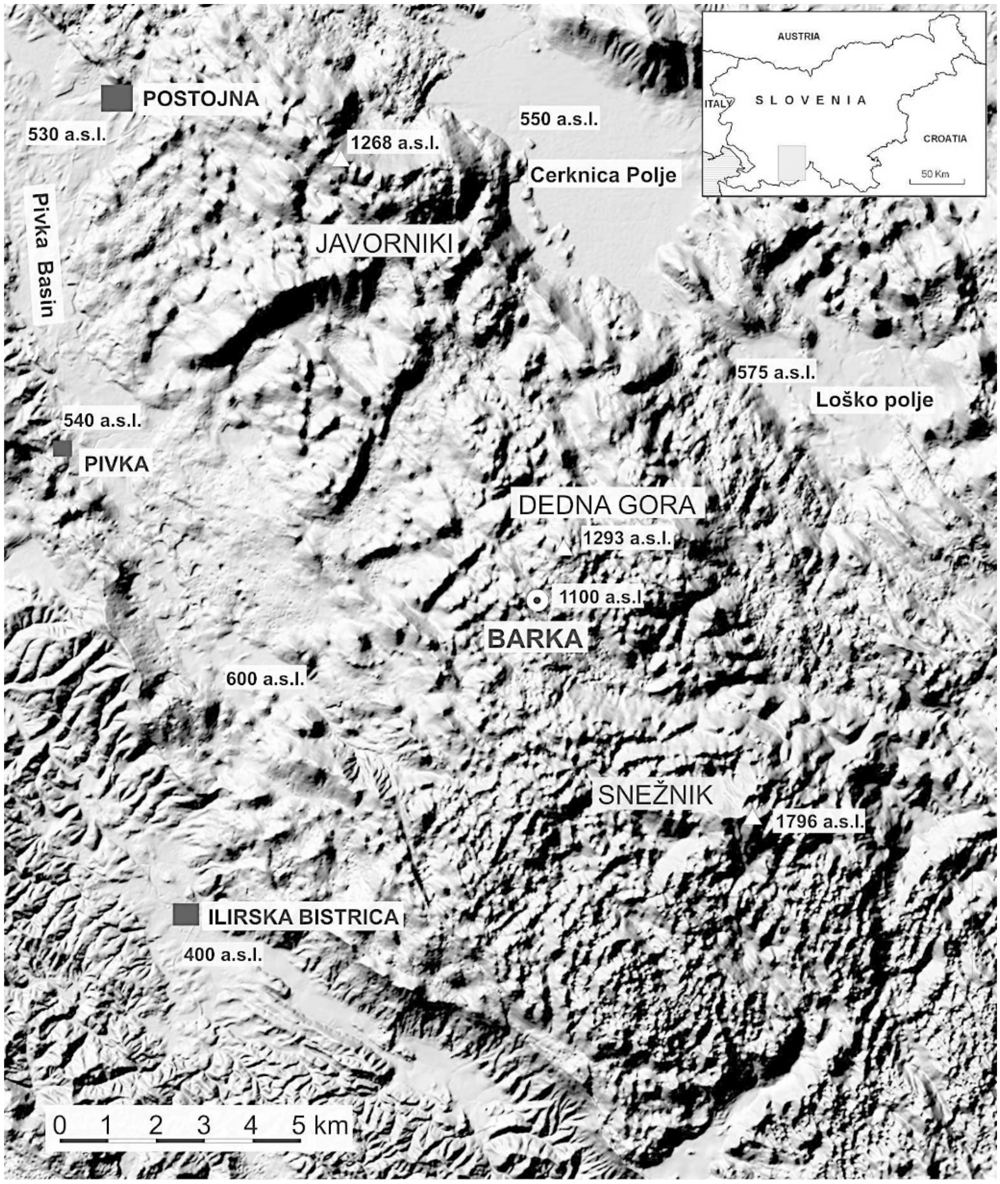

Figure 1. Shaded digital elevation rendering of the Barka depression area.

to the counter-clockwise rotation of the Adriatic Microplate. This motion is still active, and it is the main factor in regional relief formation. The main tectonic patterns of the area are fault zones of Dinaric (NW-SE) and Cross-Dinaric (NE-SW) directions, fissures in the S-N and NE-SW directions, and deformations of the carbonate rocks due to overthrust structures.

The Snežnik-Javorniki massif consists of carbonate rocks of Jurassic and Cretaceous age (Buser et al., 1967; Šikić et al., 1972). Javorniki Mountain (the northern part of the massif) consists mainly of Lower Cretaceous limestones with inliers of granular bituminous dolomites, Upper Cretaceous limestones with zoogeneous breccias (Turonian), and Senonian limestones with rudists. Snežnik Mountain (the southern part of the massif) consists mainly of Jurassic and Cretaceous limestones and dolomites.

In the Quaternary, Snežnik Mountain was glaciated at elevations above 1250 m, and the glaciated area was separated from the Alps (Šifrer, 1959). From the ice cap on Mt. Snežnik, small glaciers moved in different directions towards closed karst depressions in which they were stopped. This is inferred from terminal and lateral moraines present in the area (Zupan Hajna, 2007). Glaciation in the Snežnik area was previously noticed by Pleničar (1957) and was described in detail by Šifrer (1959). Habič (1978) wrote about remodeling of karst depressions by ice in the area of karst plateaus in Slovenia; he also studied glaciation at Risnik and found some glacial sediments south of Mašun. Only Šifrer (1959) systematically studied the Quaternary glaciations in the area of Snežnik and moraine deposits. He did not distinguish the sediments by age, but only the extent of

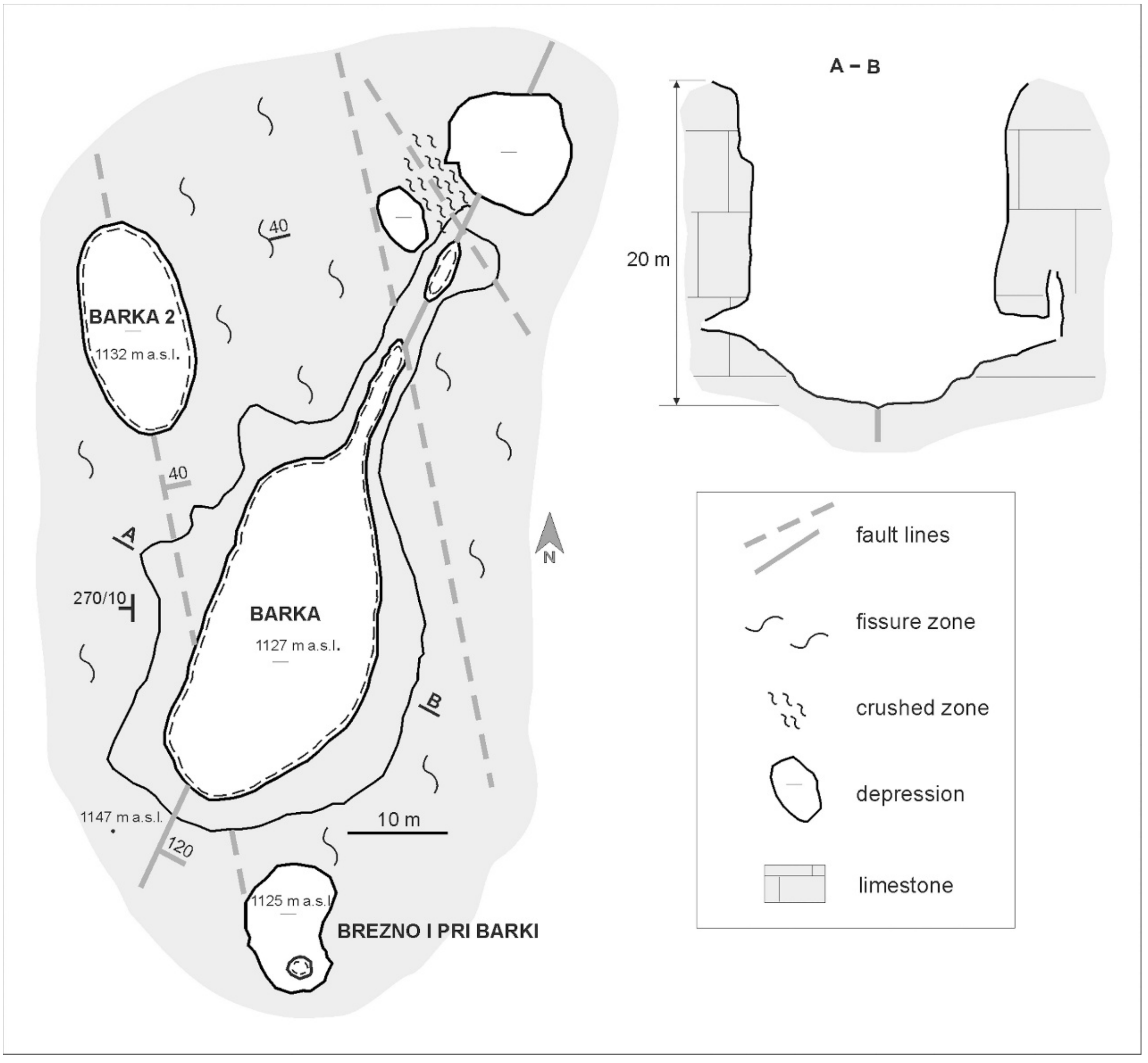

Figure 2. Geologic map of the Barka area. Upper Cretaceous limestone ($K_2^{2,3}$) is fractured by tectonic zones in different directions. Barka is formed along a fault line in which continuation as a small cave (with window in ceiling) is located in another depression. In the fissure, which crosses Barka, Barka 2 and the shaft Brezno I pri Barki are developed.

glaciation and directions of glacier movements. According to Šifrer (1959), during the glacial maximum the ice covered large karst depressions (named draga) in the area; their bottoms are now located at about 1100 m above sea level. Some of these moraines are cemented and some of them are not. From this we can conclude that probably they are different in age. The surrounding area of Dedna gora and the Barka depression was not covered by ice, but perhaps Barka was filled by snow or ice during peaks of the glaciations.

Climate and Vegetation of the Area

A mountainous climate is typical of the area. Precipitation is rather high, with an average of 2928 mm in the southern slopes of Snežnik and, according to an estimation (Ogorelec and Mastnak, 1999), about 4219 mm at the summit. Thus, Snežnik Mt. is one of the wettest regions in Slovenia. Precipitation is either rain or snow and snow cover lasts for several months. Temperature depends on altitude; the bottoms of deep depressions are colder due to temperature inversion, a fact easily observable in the vegetation distribution. At the meteorological station south of Snežnik Mountain (Gomance, at about 1100 m a.s.l.), the average annual temperature is 6.7 °C, the average temperature in July is 15.5 °C, and the average temperature in January is −3.5 °C. In a year there are on average 127 days with temperatures below 0 °C. Forest covers more than 90% of the plateau. Dinaric *Abies–Fagetum* forest between 700 and 1200 m prevails.

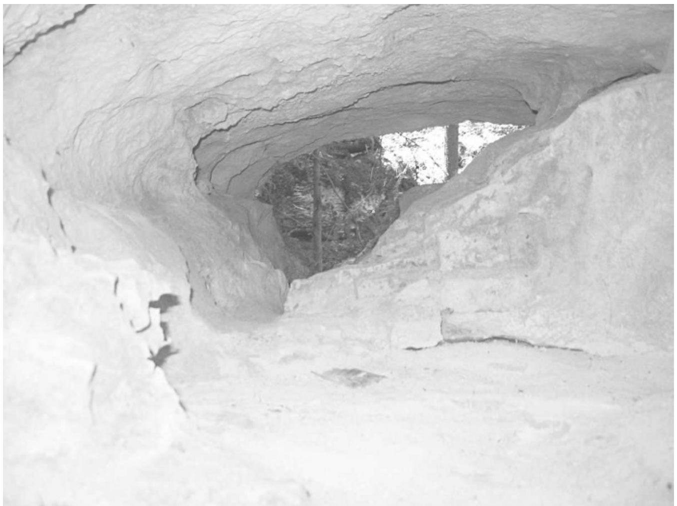

Figure 3. Open channel along one of the bedding planes in the limestone between the Barka depression and Barka 2.

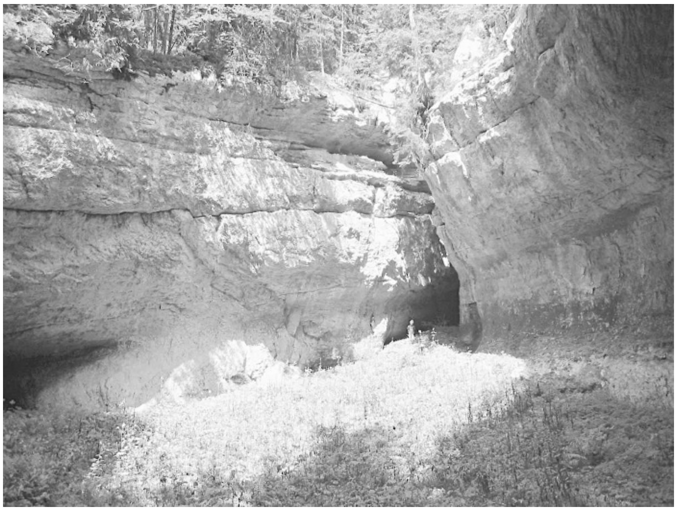

Figure 5. On the walls of the Barka depression there are distinctive bedding planes and on the northwest side a small cave is developed along the main fault plane.

KARST AND HYDROLOGY OF THE AREA

The area of the Snežnik-Javorniki karst massif is fed by diffuse infiltration of precipitation water over the whole surface. Rainwater immediately disappears underground into karstified land and feeds a vast aquifer. At the surface there are only short streams originating from local perched springs. The large springs around the massif appear at about 600 m a.s.l., at the contact with impermeable flysch rocks, or at the borders of karst poljes (Cerknica polje, Loško polje, etc.). The vadose zone is about 1000 m thick, although it varies according to precipitation, relief, and structural elements. Karst bifurcation in different direc-

Figure 4. The shape of the Barka depression resembles a barge hull. Its bottom is covered with snow, April 2005.

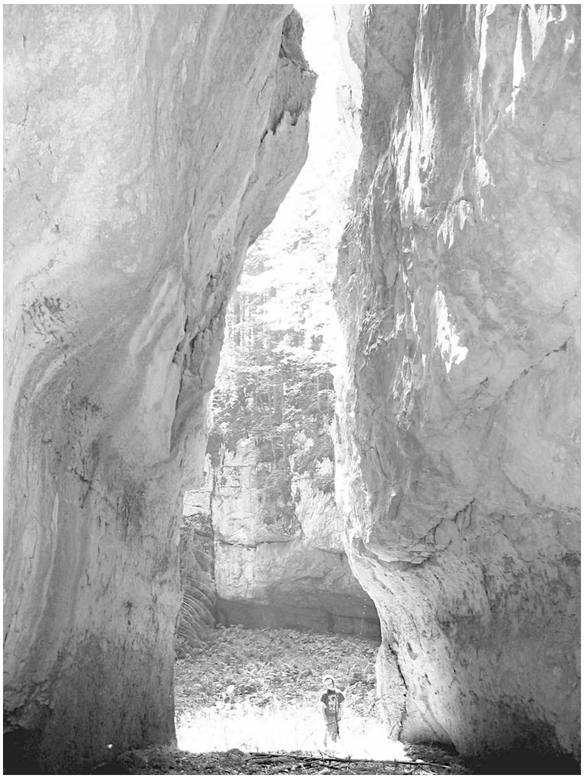

Figure 6. Short cave in the continuation of the Barka depression at its northwest side.

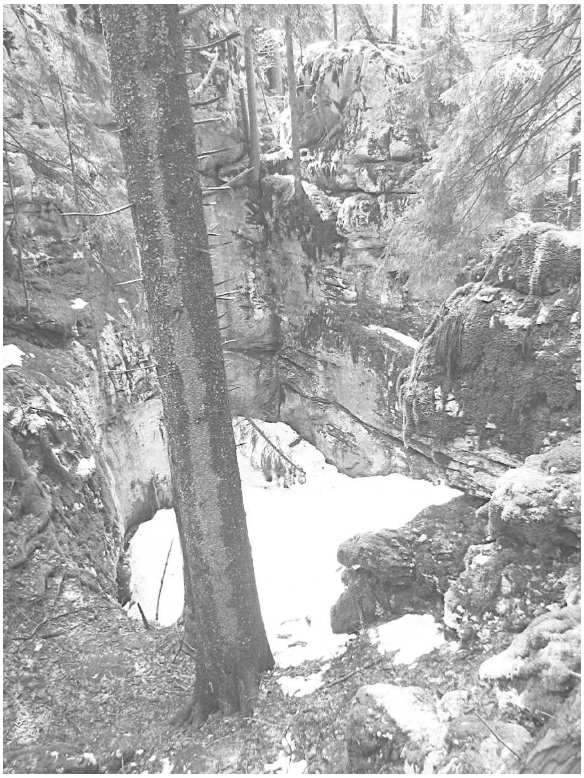

Figure 7. Closed depression in the continuation of the same fault line as the Barka depression, and a short cave.

tions is typical of the area and was proved by several water tracing tests (Habič, 1989). From the Pivka basin, water mostly flows towards the Black Sea watershed, or else towards the Adriatic Sea.

Vast plateaus, deep closed depressions, and clusters of more or less conical summits (Habič, 1981, 1986; Šušteršič, 1975) are typical of the Javorniki - Snežnik massif. The surface displays all the typical karst features from karren, solution flutes, dolines, to huge depressions, so-called Draga, formed amidst cone shaped peaks. On the southern Snežnik slopes, there are deep and narrow depressions, named Ždrocle, which are more like remains of vadose shafts than solutional dolines (Zupan Hajna, 1997). In big karst depressions (drage) in the Snežnik area, moraines are present, representing the combined actions of small glaciers and concurrent karstification.

Many caves were discovered and described 30 years ago during the Speleological Map of Slovenia project by the Karst Research Institute (Šušteršič, 1975). Today 560 caves are registered in the area (Cave Register of Karst Research Institute ZRC SAZU and Speleological Association of Slovenia). These are mostly deep shafts (up to 100 m or more) due to vadose drainage from the karst surface towards the regional base water level. In the Register, the deepest shaft is Brezno Bogomira Brinška on the east-southern part of Snežnik Mountain, which is 506 m deep. There are almost no horizontal caves in the area.

Figure 8. Along the bottom of the Barka depression a shelter opens in the wall. The floor of the shelter is covered by rubble and silt.

Study Area

The study area, Dedna gora and surroundings, is located between Javorniki Mountain on the north and Snežnik Mountain on the south (Fig. 1). The Barka depression is situated southwest of the top of Dedna gora

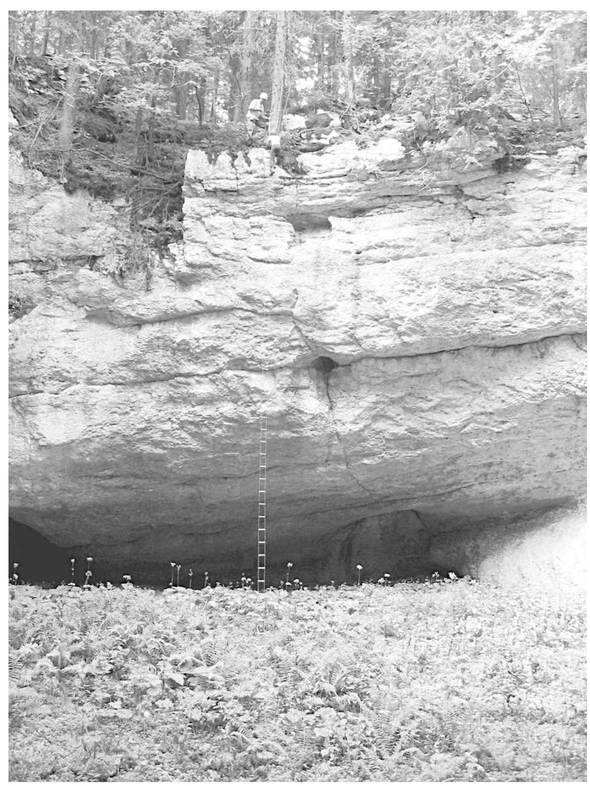

Figure 9. Detail of a shelter along one of the bedding planes in the Barka depression.

Figure 10. Patterned ground on the bottom of a shelter below the Barka depression walls: sorted (a) and non-sorted (b) polygons are developed.

Figure 11. Within an area of 100 × 100 m, many smaller depressions are found. Barka 2, with vertical walls and snow at its bottom is one of them (April 2005).

at the elevation of 1147 m a.s.l. (45°39′7.9″N, 14°22′57.6″E). During fieldwork for the Speleological Map (Šušteršič, 1975) Barka was included in the Cave Register. For the purpose of the present research, I have done a detailed survey of the Barka depression and the surrounding area, as well as basic geological mapping.

In the area nearby, the Upper Cretaceous limestones are densely fractured and faulted (Fig. 2). The fault zones generally run in the directions NW-SE, NE-SW and E-W, while the fissured zone displays N-S orientation. South of the Barka depression the dark limestone is thin bedded and tectonically fractured. Closer to the depression the limestone is as thick bedded, with white calcite veins. The limestone layers are almost horizontal, dipping slightly south. Along fissures deep karren are developed. The whole area, about 10^4 m^2 in the vicinity of Barka, is a huge karren-field with larger or smaller depressions in between the karren, with the appearance of big snow-kettles. Within open bedding planes in the vicinity, there is copious silt due to gelifraction. The clay is moist even in summer. In some of the bedding-planes, there are traces of water flow, as water remains after snow thawing at different levels and flows through opened bedding-planes and fissures in the limestone (Fig. 3).

Barka is a closed depression about 40 m long, 25 m wide and 20 m deep, with precipitous walls. The walls are smooth, but the bedding planes of the limestone can be clearly seen. Barka's shape resembles a barge hull (Fig. 4), with a volume of about 1500 m^3. The bottom of Barka is covered by silt, sand, and rubble, inclined towards the center where a smaller sinkhole exists. While in summer the bottom is overgrown by coltsfoot, winter snow remains long into springtime. The present form of Barka results from the remodeling of its walls, which were, and still are, affected by ice, snow, and frost. The shape and smooth surface of walls indicate a large quantity of snow that probably remained in its bottom in the past.

The longer Barka axis is oriented along a subvertical fault oriented NE-SW (Fig. 2). The fault continues in a short cave at the northern side of the depression (Fig. 5). The cave (Fig. 6) has a small window in the ceiling and ends after a few meters. Along the same fault, further northeast from the end of the cave, there are two smaller depressions. Only some of their walls are vertical and their steep-sided slopes are covered by boulders (Fig. 7).

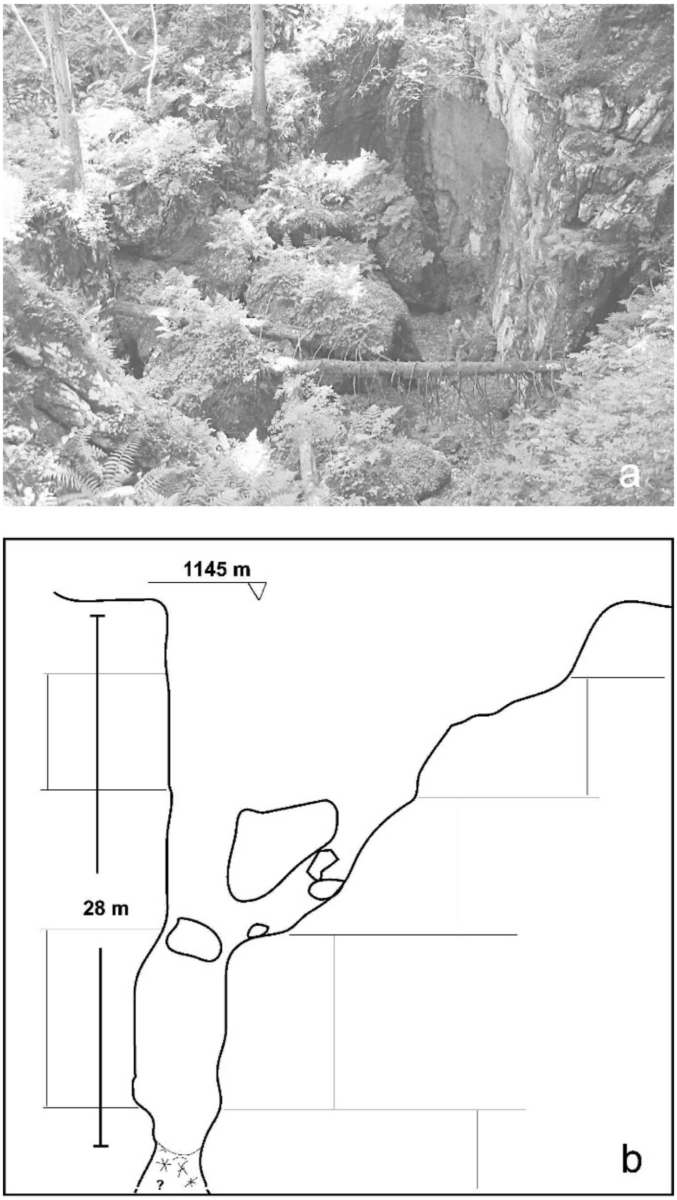

Figure 12. Entrance to the cave Brezno 1 pri Barki is below the precipitous wall of a smaller depression covered by collapse blocks (a, b).

Approximately four meters above Barka's bottom, a ledge opens in its rim (Fig. 8) along one of the bedding planes (Fig. 9). The ledge ends as a shelf below an overhanging wall. On the shelf floor, silt and rock debris are collected as a result of gelifraction and freezing. The material on the shelf floor is exposed to freezing during the winter (frost action). Repeated freezing and thawing of the ground causes a movement of its coarser elements towards the freezing surface. Sorted and non-sorted polygons are formed because of that process. The polygons in some places are fully developed and well sorted (Fig. 10), which is very rare in these latitudes, even higher in the Alps. A few polygons have been described before from cave entrances on the Kras plateau (Mihevc, 2001).

On the western side of Barka, in a fissured zone, another closed depression is situated (Fig. 11). Barka 2 is smaller in dimensions, 26 × 10 m, and about 15 m deep, with a similar shape of walls and bottom as Barka. Also, the ledge is present around the whole depression, upon which silt material is accumulated.

On the eastern side of Barka, in the same fissure as Barka 2, the shaft Brezno I pri Barki is situated (Fig. 2). The entrance to the shaft opens in the bottom of a closed depression where the slopes are covered by breakdown rubble and big blocks of limestone (Fig. 12). The depression where the entrance to the shaft Brezno I is situated is only ten meters from the Barka rim. Shaft Brezno I pri Barki is 28 m deep. In the entrance, ice remains for the whole year, in some years obstructing the entrance. In the shaft there are remains of old wooden ladders used to extract ice.

DISCUSSION AND CONCLUSION

During the last glaciation, the snow line was not much higher than the location of Barka, between 1250–1300 m (Šifrer, 1959). At that time the region was not covered by forest, and thus Barka could have been filled and covered by snow, which probably thawed in warmer periods, with water flowing between snow and walls. Even now, the air at the bottom of the depression is cooler and snow remains for quite a long time.

The genesis of Barka can be explained by several hypotheses. One possible mode of origin is the development of a vast karren-field on suitably fissured sub-horizontal limestone with interlying closed depressions, snow-kettles shaped by snow. Such a case would be the classic development of snow-kettles in high mountainous karst (Kunaver, 1983; Gams, 2003). However, closed depressions in the vicinity, and in particular Barka itself, are much too large to be snow-kettles, and their walls are too even and smooth. Therefore, a more probable explanation would be that these closed depressions were caves in the past, most probably inner shafts such as those in the Alps or High Dinaric karst plateaus such as Trnovski gozd (shafts in Velika ledena jama v Paradani described by Mihevc (1995)). These shafts were then uncovered by surface denudation and exposure to superficial conditions, as is seen in innumerable examples from Classical karst (Mihevc, 1996; Mihevc, Zupan Hajna, 1996; Mihevc, 1998a, 1998b, 1999a, 1999b, 1999c; Šušteršič, 1999; Mihevc et al., 2002; Knez and Slabe, 2002; Mihevc, 2006, 2007).

Mihevc (2001) described such cases with examples from Divaški karst, where denudation of the karst surface exposed caves and their contents to the surface. That author stressed the importance of inherited forms, inside caves in the past and on the surface at present. According to Mihevc (1996) the denudation rate of the karst surface

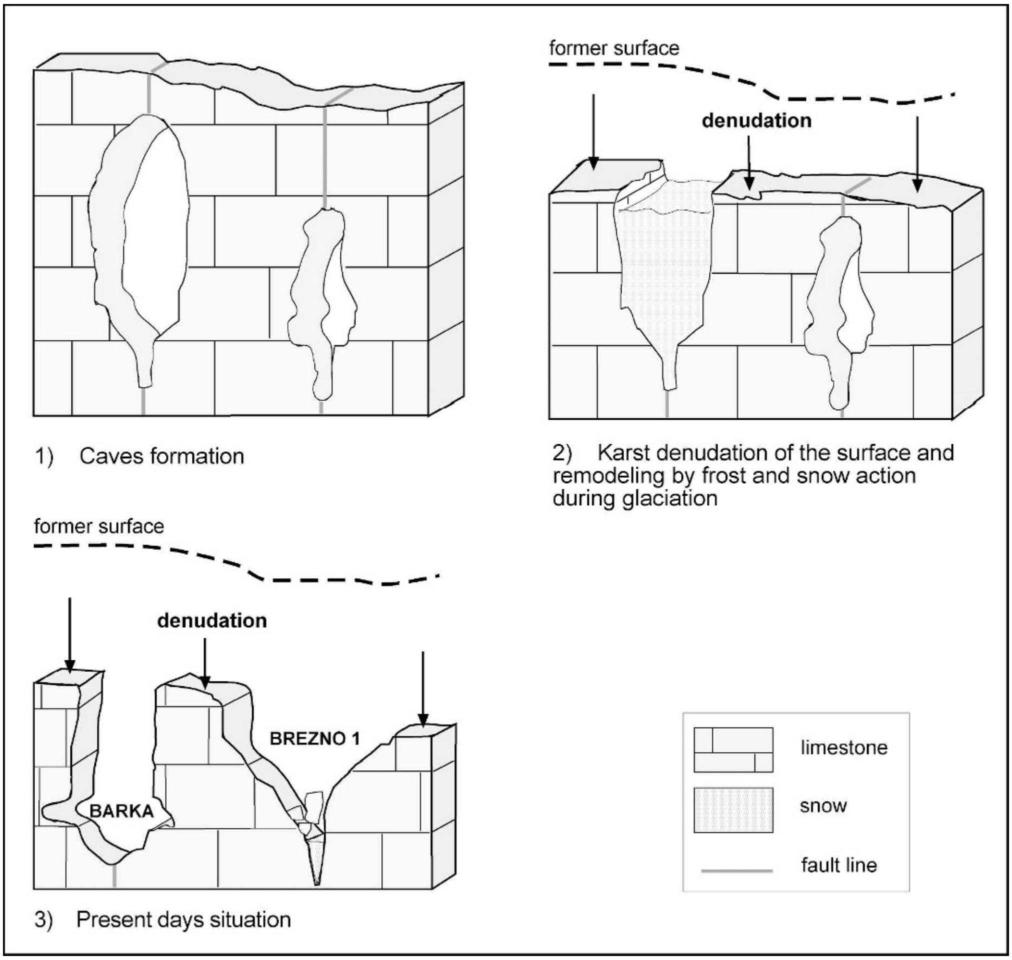

Figure 13. Schematic model of the transformation of earlier caves into kettle-shaped depression by karst denudation and frost/snow action.

on the Kras plateau and the Reka river watershed is about 50 m per Ma. Denudation rates can be lower or higher, depending on the amount of precipitation, etc. (Gams, 2003). Audra et al. (2002) describe in Austria the denudation of carbonate rocks above old caves, their exposure to weathering, and their remodeling into kettle-shaped dolines, acting as snow-pits as a result of periglacial activity. Different types of denuded shafts have been studied by Klimchouk et al. (2006); they describe the exposure of shafts in vertical walls as mainly due to intense gravitational processes induced by removal of the ice supporting the cliffs.

The shape and location of Barka depression suggest that this is an inherited feature of a former shaft, transformed during glaciation to a kettle-shaped depression, and still influenced by freezing effects during winter (Fig. 13). It is also likely that all smaller depressions in the vicinity are remaining clusters of smaller shafts with denuded ceilings. In the present day, all these closed depressions act as traps for snow. Snow can remain in them more than six months per year. Considering that denudation of the karst surface is continuous and constantly exposes underground features to the surface, this is the most probable explanation of the origin of Barka.

I conclude that exposure of shafts due to denudation is a significant process. Denuded shafts can be an important morphological element of karst relief, especially expressed as closed depressions of different sizes, including many snow-kettles in high mountains.

Acknowledgements

The research was carried out under the auspices of the program Karst Research funded by the Slovenian Research Agency. France Šušteršič, as one of the reviewers, provided useful suggestions to improve this paper.

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