The application of new technologies for karst surface and cave geological mapping

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Abstract

The aim of the study is to evaluate the relationships between karstified surface and subsurface geological structures. The study focuses on Planina Cave and the overlying surface where the geological structures are strongly affected by karstification. In order to achieve the objectives of the study, a detailed structural geological map of the cave and the surface was prepared. Modern surveying methods were used to obtain more information about the karst geostructural features and not only those obtained through conventional geological mapping techniques.

Povzetek

Namen raziskave je ovrednotenje odnosov med zakraselimi strukturno geološkimi elementi v jami in na površju. Raziskava se osredotoča na Planinsko jami in površje nad njo, kjer izdanjajo močno zakrasele geološke strukture. Rezultati raziskav so natančne strukturno geološke karte Planinske jame in površja. Z uporabo sodobnih geodetskih tehnik smo pridobili več informacij o strukturnih elementih, kot bi jih pridobili samo s klasičnimi metodami geološkega kartiranja.

Ključne besede: Slovenija, Planinska jama, geološko kartiranje, 3D terestrični laserski skener, dron.

Keywords: Slovenia, Planina Cave, karst, geological mapping, 3D terrestrial laser scanner, drone.

Introduction

The Planina Cave is located on the south-western edge of Planina polje, on the western edge of the Idrija fault zone in Slovenia. The cave is part of the Postojna-Planina cave system. It was formed in lower to middle Cretaceous dolomitized limestones. The 6,6 km long cave consists mainly of hydrologically active cave passages. The cave represents an important spring and an important underground confluence of two regional groundwater streams. In recent years, the cave has once again become the target of hydrological research in order to find a new suitable source of water for the inhabitants of the Notranjska and Primorska regions. While the cave has been the subject of many hydrological studies, it has not been the subject of many geological studies, especially tectonic and structural geological investigations..

After World War II the first modern geological mapping of the surface around the cave was carried out as part of the Basic geological map of Yugoslavia (1:100.000) project, Postojna sheet (Buser et al., 1967). The first comprehensive study of Planina Cave was made by Rado Gospodarič as part of his doctoral thesis. Gospodarič studied the cave development between the Pivka Basin and Planina polje during the Quaternary and made the first structural geological map of Planina Cave for his doctoral thesis (Gospodarič, 1973, 1976; Gospodarič and Pavlovec, 1974). Kogovšek and Habič studied infiltration and percolation through the ceiling of Planina Cave and identified and characterized the main

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conduits (fault zones) using tracer tests in the unsaturated zone of the cave. The surface above the cave was thoroughly mapped by Čar and Gospodarič (1984). They prepared two thematic geological maps, a tectonic map and a stratigraphic-lithological map, for the area between Postojna, Cerknica and Planina.

Methods

To achieve the objectives of the study, a detailed structural geological map of the entire Planina Cave is being prepared. So far, the entrance areas of the cave up to the confluence of the Pivka and Rak rivers and the corresponding surface above the cave have been mapped. The mapping is done according to the proven method of geostructural mapping of karstified carbonate rocks by Čar (1981, 1984, 2018). This method requires a more extensive and systematic collection of field data than ordinary geological mapping. The collection of extended structural, lithological and morphological data due to the complexity and karstification of tectonic deformation in carbonate rocks (Čar 1981, 1984, 2018).

In order to obtain additional geostructural information about the karst, which was not only obtained through conventional geological mapping techniques, modern surveying methods were used, such as a digital elevation model of the surface from airborne LiDAR data provided by the Surveying and Mapping Authority of the Republic of Slovenia; a detailed drone ortophoto map of the cave surface and a photogrammetric drone model of the rock face of the cave entrance; detailed dense point cloud data of the cave and parts of the surface acquired with a terrestrial 3D laser scanner.

Results and discussion

In the mapped area, at the surface and in the cave, Mesozoic marine carbonates outcrop, palaeogeographically belonging to the Dinaric Carbonate Platform and Quaternary continental sediments are present. The Mesozoic marine carbonates are represented by dolomitised micritic and laminated limestone and dolomitised limestone breccias. Their age ranges from the Aptian to the Cenomanian. The Quaternary sediments consist of alluvium from the Unica River, located in the cave or as valley fill, and colluvium on the slopes of the steephead valley leading to the cave entrance.

In 2014, the area around the Planina Cave was heavily affected by sleet, especially the forested areas. Due to the aforementioned geohazard, it is still possible to take detailed drone images of the surface. A drone campaign of the surface area above the cave entrance areas showed that the fissure zones can be mapped in detail using drone orthophotographs. In particular, the strike directions of larger fissure zones can be recorded, which is an important component of classical karst geostructural mapping (Čar, 1981, 1984, 2018). Therefore, more structural data can be included in the geological maps and the overall geological structure and interpretation.

On the surface above the Planina main passage, the bedding dips towards SW with 15° to 45°. There are some asymmetrical folds with axes running towards NW-SE, with gentle to open inter-limbs angles. between the legs. Normally they dip with 20° to 45° towards SE and NW. The most prominent and common geological structure on the surface above the main passages of the cave are the fissure zones, which are heavily karstified and dip steeply towards SW or NE. Most of the faults present have a Dinaric strike and a vertical or sub-vertical dip. Some of the faults were identified by surface morphology and fissure zones, with data obtained from drone imagery.

The Planina cave has been the subject of numerous mappings. The first cave map was drawn up by Ivan Rudolf in 1853. The cave map in use today consists mainly of Italian cave surveys from before the Second World War and partly of cave surveys from the 1980s and early 1990s. Comprehensive method of geostructural mapping of karstified carbonate rocks (Čar 1981, 1984, 2018) requires detailed topographic maps, including cave maps. As the lack of an accurate map of Planina Cave hinders the application of the above mentioned method, a detailed terrestrial scanning campaign of the cave is currently underway. Currently, all parts of the cave that can be reached without a boat have been scanned, which is about 15% of the cave. Compared to traditional cave surveying, from measurement to field data processing, the use of terrestrial laser scanning shortens the time from data collection to dense point cloud model and can reveal more structural information in large caves, especially where visibility is limited. The dense point cloud data enables the rapid export of detailed ground plans and cross-sections needed in classical geostructural karst research. In addition, the detailed 3D model of the cave enables improved modelling of the geological structure and hydrogeological modelling.

In the case of Planina Cave, the use of a terrestrial laser scanner supported classical geostructural field mapping by obtaining additional and unseen structural information. Especially in areas with limited visibility in large and high cave chambers that are normally full of aerosols, e.g. Visoka Dvorana, Golgota. Cave beds also generally dip towards SW, although dip angles are more moderate, ranging from 15° to 35°. Most of the mapped folds in the cave have an open shape with a larger wavelength, accompanied by smaller, narrow, parasitic folds with their axes running in the direction of SW-NE. The most common structural elements in Planina Cave, which are morphologically and numerically characteristic, are NW-SE trending faults with the characteristic fissure zones. Dinaric trending faults are vertical or steeply dipping to SW. NE-SW trending faults are less numerous and morphologically not as distinctive as Dinaric trending faults, they generally dip steeply to SE.

Conclusions

The proximity of the study area to two major regional tectonic structures, the Hrušica Thrust Fault, and the seismically active, NW-SE trending dextral strike-slip Idrija fault in combination with the voluminous cave passages and chambers, makes Planina Cave an ideal location for the application of classical geostructural and tectonic studies in combination with modern land surveying methods.

Detailed geostructural mapping (Čar 1981, 1984, 2018) has proved invaluable in identifying geological structures present in karstic rocks. Geostructural maps form the basis for understanding hydrogeological and tectonic processes in karstic areas. The use of modern surveying methods in combination with classical field research methods, such as geostructural mapping of karst areas, greatly improves our data collection in the field and can thus increase our knowledge of processes that make karst a unique geological phenomenon.

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Literature

Buser, S., Grad, K., Pleničar, M. (1967). Osnovna geološka karta SFRJ, list Postojna, 1: 100 000. Zvezni geološki zavod Beograd, Beograd.

Čar, J. (1981). Geološka zgradba požiralnega obrobja Planinskega polja. Acta carsologica, 10, 75–105.

Čar, J. (1986). Geološke osnove oblikovanja kraškega površja. Acta carsologica 14/15, 31–38.

Čar, J. (2018). Geostructural mapping of karstified limestones. Geologija, 61 (2), 133–162.

Gospodarič, R. (1976). Razvoj jam med Pivško kotlino in Planinskim poljem v kvartarju. Acta carsologica, 7, 5–139.

Gospodarič, R. (1973): Razvoj jam med Pivško kotlino in Planinskim poljem v kvartarju. Doktorska disertacija, Postojna, 171 p.

Gospodarič, R., Pavlovec, R. (1974). Izvor apnenčevega proda v Planinski jami. Acta carsologica, 6, 167–182.

Kogovšek, J. (1982). Vertikalno prenikanje v Planinski jami v obdobju 1980/81. Acta carsologica, 10, 110–125.

Kogovšek, J., Habič, P. (1981). The study of vertical percolation of water in the case of Postojnska jama and Planinska jama. Acta carsologica, 9, 129–148.