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CAVES IN BRECCIA AND FLYSCH BELOW MOUNT NANOS IN THE VIPAVA VALLEY (SLOVENIA)

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ABSTRACT

Characteristic although relatively rare karst phenomena, as far as Slovenia is concerned, were discovered for this type of karst in breccia that lies on a sloping foundation of impermeable flysch. We distinguished characteristic types of caves and initial stages in the development of dolines. The largest and most frequent are caves that developed in breccia above the contact with flysch. Smaller and most often filled with fine-grained sediment are caves that occur in the middle of breccia. Of special origin are fissure caves across the slopes. Traces of continuous vertical percolation of water are less distinct. Caves are also formed in the flysch.

Key words: karstology, motorway construction, relief forms, karst caves, breccia, flysch, Slovenia

GROTTE IN BRECCIA E FLYSCH SOTTO IL MONTE NANOS NELLA VALLE DEL VIPACCO (SLOVENIA)

SINTESI

Fenomeni carsici caratteristici ma relativamente rari, almeno per quanto riguarda la Slovenia, sono stati documentati nella breccia che giace su fondamenta inclinate di flysch impermeabile. Gli autori hanno distinto tipi caratteristici di grotte e stadi iniziali di doline in sviluppo. Le più larghe e frequenti sono le grotte che si sviluppano nella breccia che si trova subito sopra al contatto con il flysch. Le più piccole e spesso colme di sedimento fine sono le grotte che si formano nel mezzo della breccia. Di origine particolare sono invece le grotte a fessura che attraversano i pendii. Tracce di continua percolazione verticale d'acqua sono meno distinguibili. Alcune grotte si sono inoltre sviluppate nel flysch.

Parole chiave: carsologia, costruzione di autostrade, forme in rilievo, grotte carsiche, breccia, flysch, Slovenia

INTRODUCTION

In the studying and planning of the Slovene motorway construction, karstologists have taken part (Kogovšek 1993, 1995; Knez *et al*. 1994, 2003, 2004, 2008; Knez & Šebela 1994; Šebela & Mihevc 1995; Mihevc 1996, 1999; Mihevc & Zupan Hajna 1996; Slabe 1996, 1997a, 1997b, 1998; Kogovšek *et al*. 1997; Mihevc *et al*.1998; Šebela *et al*.1999; Bosak *et al*. 2000; Knez & Slabe 2000, 2001, 2002, 2004a, 2004b, 2005, 2006, 2007). A large part of the motorway system runs across karst areas. Our mission is to identify and describe the newly discovered natural heritage, and our knowledge, especially about the caves in the karst, is frequently of technical help to road builders.

The Vipava Valley lies between the high karst plateaus of Trnovski gozd and Mount Nanos to the north and the low plateau of the Classical Karst to the south. Mount Nanos is overthrust on flysch. Below its steep western edge on the sloping flysch, scree material accumulated and consolidated into breccia that developed into a special young karst (Fig. 1).

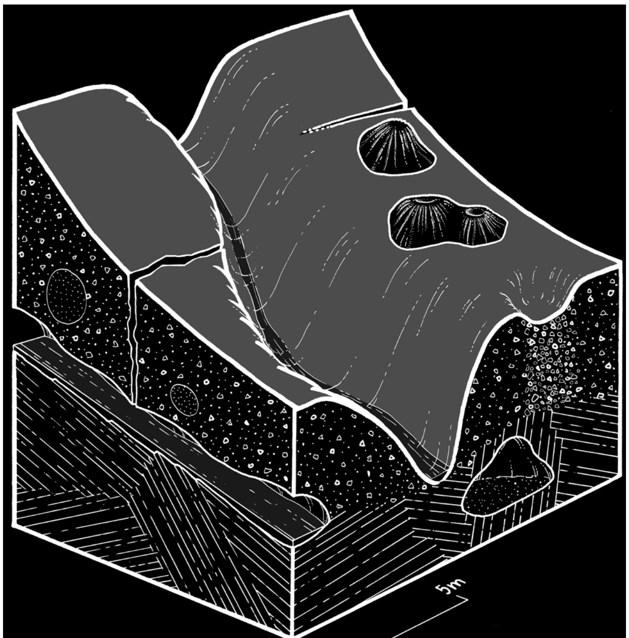

Fig. 1: Karst in breccia and flysch below Mount Nanos in the Vipava Valley: surface karren, with small doline and washed belt of breccia below it and caves in breccia, at the contact of breccia and flysch, and in flysch.
Sl. 1: Zakraselost breče in fliša na pobočjih Nanosa v Vipavski dolini: s škrapljami na površju, z manjšo vrtačo in s pasom izprane kamnine pod njo ter jamami v breči, na stiku breče in fliša in v flišu.

During the thorough and long-term motorway construction monitoring, characteristic although for Slovenia relatively rare karst phenomena were discovered in breccia that lie on a sloping foundation of impermeable flysch. We distinguished characteristic types of caves and early stages in the development of dolines.

GEOMORPHOLOGICAL DEVELOPMENT OF THE SITE AND GEOLOGICAL CONDITIONS

Geomorphology

The motorway alignment runs across three geomorphologically diverse units along the southwestern slopes of Mount Nanos (Rebrnice and Breg) and the floor of the Vipava Valley (Fig. 2). The Breg and Rebrnice slopes are distinct geomorphological units. Mihevc (2001) geomorphologically mapped the slopes of Mount Nanos in detail over part of the motorway alignment that runs through the landscape park area. A specific geological thrust structure and specific slope processes and sediments are reflected here in the morphology of the slopes and in botanical anomalies. These features have led to the proclamation of a landscape park covering the southern and western slopes of Mount Nanos.

The surface of the slopes was formed by the mass movement and mechanical weathering of rock, which was accompanied on the flysch bedrock by landslides. Water that flowed above the flysch also dissected the slopes (Fig. 3). The thickness of the layers of scree material or breccia varies from place to place. More or less vertical fissures developed in the breccia that indicate tensions in the slopes. During the motorway construction, the contact between scree material and breccia and the flysch bedrock showed an extremely fragile balance where the alignment cuts deeply into the slope. After abundant precipitation, numerous smaller streams appeared along the contact between flysch and breccias revealed by the cuts. Many of these streams are exploited for water supply.

Water percolates from the surface in a more or less evenly dispersed fashion through mostly well permeable breccia to the contact with flysch. However, in individual places, traces of continuous percolation of water can be clearly seen in the cross section of breccia and scree material. These are one- to two-meter wide belts of washed scree and breccia, the beginnings of dolines (Fig. 4). Above them, small sinkholes formed whose diameters do not exceed three meters. They are covered with soil. The water from the surface also carries soil containing organic material that further accelerates the dissolving of carbonate rock.

Rainwater has carved rock relief forms on the larger rocks that protrude from the karst surface, the most distinct being flutes and solution pans. Mature flutes take

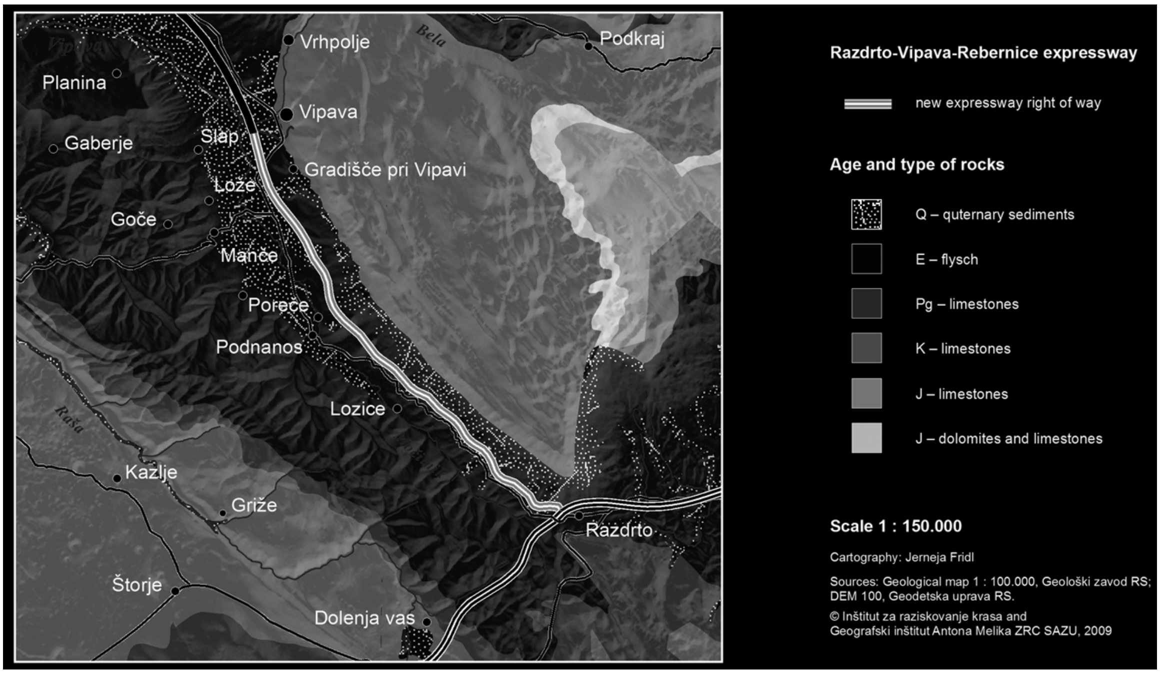

Fig. 2: Motorway alignment along the slopes of Mount Nanos.
Sl. 2: Potek avtoceste po pobočju Nanosa.

Fig. 3: Valley cut in breccia above impermeable flysch.
Sl. 3: Dolina, vrezana v breči nad neprepustnim flišem.

two thousand years to develop (Gams, 1990). Therefore, the surface of mass movements and landslides on parts of the slopes has not changed significantly for a long time.

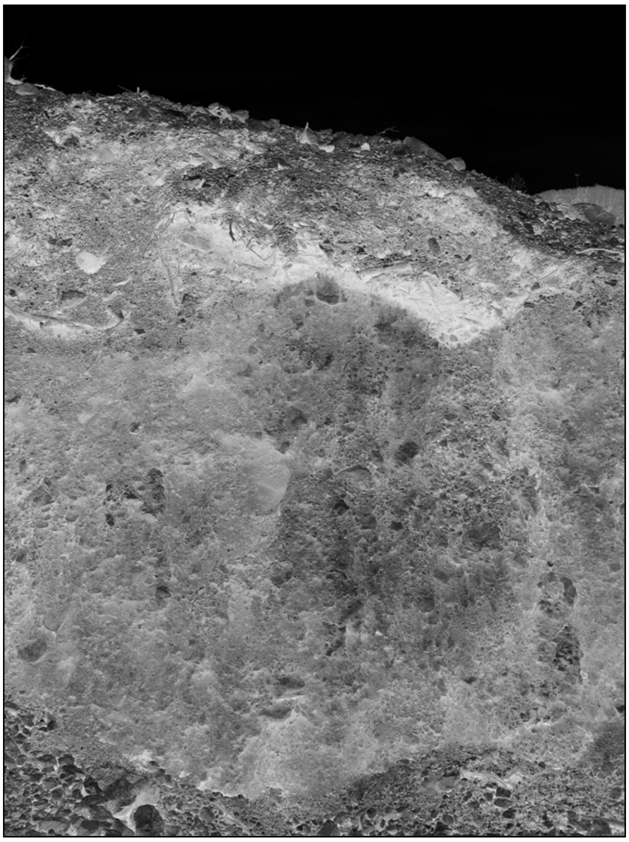

Fig. 4: Early stage of doline development.
Sl. 4: Začetno obdobje razvoja vrtače.

Geology

Geologists first studied the slopes of Mount Nanos and the Trnovski gozd range during the geological mapping of the area. On the slopes they established, in detail, the contact between flysch and limestone and the distribution of the Quaternary cover of scree material and larger mass movements (Buser *et al.*, 1967; Mlakar, 1969; Placer 1981). They also studied the contact between limestone and flysch on the eastern side of Mount Nanos along the edge of the Pivka basin (Čar, 1980). Jež (2007) described slides of scree material and breccia. The younger talus that formed below the wall pushed older scree material and breccia that slid downward. Melik (1960) described distinctive slopes in his monograph, while Habič (1968) studied the slopes of Mount Nanos in his examination of the Nanos and Trnovski gozd high karst plateaus. He described various slope materials, scree material, conglomerate, remains of mass movements, and larger talus and fans. In the Rebrnice area, he observed inverse relief where thicker layers of scree material and breccia in former ravines carved into the flysch bedrock. Around Črniče Radinja (1961), observed various slope sediments and sliding of slope scree material on flysch and attempted to determine individual genetic types of gravel.

Limestone outcrops in the vicinity of the motorway alignment in only a few places. In the Mlake area at the military firing range, limestone composed of nummulitic breccia has built a smaller elevation between flysch layers. Several smaller areas in the slopes are composed of Cretaceous rudistid limestone, for example at Šembijski zatrep above Podnanos and the smaller patch of Cretaceous limestone near Orešje and Lozice.

Breccia

In the cross sections of the slope exposed by cuts for the motorway, it is frequently possible to observe many layers of scree material and breccia (Fig. 5). Their total thickness often exceeds ten meters, and in individual places exposed during the digging of foundations for the viaduct pillars even reached twenty-five meters. As a rule, the layers differed relative to the degree of cementation of the breccia. Only individual layers were relatively well cemented. The carbonate cement connected scree material in breccia first and most firmly around larger rocks. The excavation work frequently revealed chunks of breccia several cubic meters in size, surrounded by uncemented or poorly cemented scree material. Between the larger and smaller pieces of scree material and rock forming the breccia were hollow spaces partly filled with flowstone. The degree of cementation of breccia is therefore the consequence of the age of the mass movements, a deep or shallow position below the surface, the sliding and breaking of older breccia, and the characteristics of the water that percolated regularly from the surface, which is covered by a thin layer of soil and vegetation. Of course, in individual places the breccia is already uniquely karstified.

The water that percolates through the scree material and breccias carries dissolved calcium carbonate. The cement between clasts of breccia is almost exclusively carbonate in nature. Pieces in the breccia are fragments of Senonian, Turonian, and Cenomanian limestone and most probably of Lower Cretaceous limestone as well. The Lower Cretaceous layers in the upper half of the Mount Nanos slopes developed similarly to the Upper Cretaceous Cenomanian limestone (Pleničar, 1970; Buser, 1973) and therefore are not shown separately on the maps (Buser *et al.*, 1967; Buser 1968).

The porosity of breccia varies according to the composition of the material forming it and the local percolation. The spaces between clasts do not contain any fine material and the clasts are not covered with flowstone. A similar structure is observed in seemingly similar breccias, except that their clasts are completely covered with a millimetre or two of layered, mostly porous or white flowstone. There is also no fine material between them. This type of breccia is very porous. Only partially porous breccias were formed where the water between the clasts brought weathered debris and fewer fine limestone clasts from the surface. In places where fine limestone fragments the size of sand accumulated between clasts that are several centimetres in diameter, breccia is substantially less porous. It also contains weathered debris cemented in flowstone. In some cases, calcium carbonate in which water deposited major quantities of weathered debris served as a cementing agent to bind the clasts. Even in this case, the breccia is poorly or almost non-porous, and the cement is of characteristic

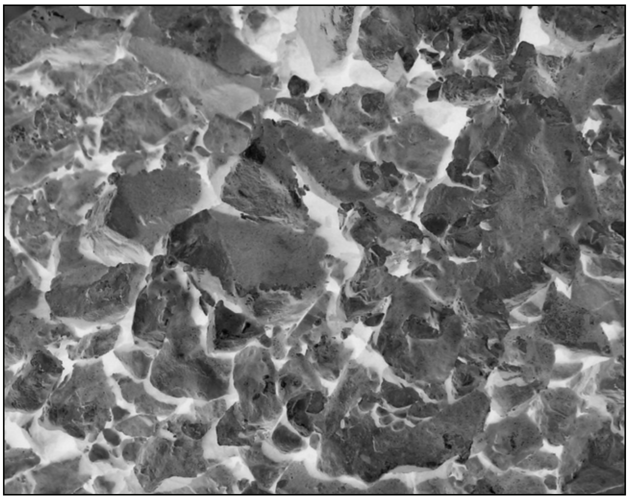

Fig. 5: An example of porous breccia. Width of picture is 25 cm.
Sl. 5: Primer porozne breče. Širina slike je 25 cm.

Fig. 6: Contact between scree material and flysch. Width of picture is 4 m.
Sl. 6: Stik grušča in fliša. Širina slike je 4 m.

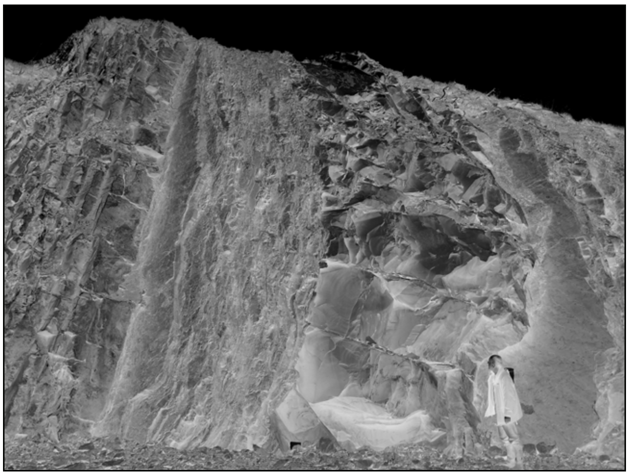

Fig. 7: Layers of flysch.
Sl. 7: Plasti fliša.

red-brown colour. In places, cavities were formed between the clasts, where the beginnings of larger calcite crystals can be observed.

Flowstone often fills the smaller spaces between the rock fragments that compose breccia. Where there is room, straws form on the ceiling of cavities. When parts of the breccia are composed of rocks, smaller flowstone domes are formed whose stratification indicates, in places, the originally filled cavity. A ribbed flowstone coating occurs on the walls of slope fissures. Larger domes of flowstone were naturally discovered in caves originating along the contact with flysch.

Flysch

Flysch layers lie beneath the breccia (Fig. 6). On the south side of Mount Nanos, in the area near Razdrto and in the Rebrnice slope, the flysch layers dip generally toward the southeast. Near Podboršt, northwest of Podnanos, where they dip in the same direction, they slant much more steeply. Farther to the northwest near Vipava, the layers of limestone and flysch are almost vertical (Fig. 7).

In the flysch rocks, the dominant grey to black shale marlstone and massive marlstone alternate with carbonate and quartziferous sandstone. The latter contains a significant amount of carbonate particles and carbonate cement. Occasionally, the almost black marlstone laterally transforms into brown ochre. In most cases, it has a characteristic conchoidal fracture.

In places, we observed that the marlstone layers alternated with thicker layers of dark grey calcarenite, siltstone, and claystone. The clastic rocks have a very steep dip, lying between 70º and 80º relative to the slope, and the general direction of the dip is toward the north or northeast. In places, the layers are subvertical.

The lithological contact between Cretaceous limestone and Eocene flysch runs mainly high up on the slopes of Mount Nanos, mostly around two hundred meters above the motorway alignment. The contact is morphologically distinct, since the slopes are steep or even vertical on limestone and more gently sloping on flysch rock.

CAVES IN BRECCIA AND FLYSCH

Many characteristic types of caves were formed in the breccia that developed on steep and dissected flysch slopes. The largest and most frequent are caves (20) that developed in the breccia above the contact with flysch, while caves (10) that occur in the middle of the breccia are smaller and most often filled with fine-grained sedi-

Fig. 8: Cave in breccia at the contact with flysch.
Sl. 8: Jama na stiku breče in fliša.

ment. Fissure caves (10) that cross the slopes are of special origin. Traces of continuous vertical percolation of water are less distinct. Caves (5) also occur in the flysch.

Remškar (2006) collected data on caves in breccia in the Vipava Valley, specifying types of caves and their origin. He divided them into those that developed along fissures, those formed by streams of water, and rock shelters.

Caves at the contact of breccia and flysch

These are the most frequently discovered caves in this young karst. The diameter of smaller tubes measures only a decimetre, while the height of the largest tubes can reach two meters and their width three meters (Fig. 8). The largest parts of the passages are cupola-shaped widenings. These are narrower and higher along fissures. The size and shape of their cross sections vary distinctly from meter to meter along the length of the passage. In places, the shape of the cave reflects the different stages of breccia cementation. The more consolidated the breccia, the smaller the cross sections of passages in the same condition. The composition of the rock also dictates the fine dissection of the circumference of the passages. The floors of caves, through which water flows, are flysch that is only partly covered with pieces of scree material, while the floors of dry caves are covered by scree material and domes of flowstone, since breccia tends to disintegrate. There are smaller stalactites on the longer enduring part of the circumference. The thicker layers of flowstone found at various heights in the cave bear witness to times when the caves were filled with fine-grained sediment.

In most cases, individual passages were opened and their connection to a branched network was revealed in only a few places. The largest cave revealed was fifteen meters long. Its central part, a dome-shaped dissected passage was found (Fig. 9). The diameter of the largest dome measured three meters. On the floor, which was largely covered with scree material, a larger stalagmite had formed. We did not observe any traces of water, but a small quantity of water could have percolated through the scree material covering the cave floor.

The part of the cave with a permanent stream preserved during the excavation work was ten meters in length. It was three meters wide and one and a half meters high, and a small stream flowed through it.

Individual caves are filled with fine-grained flysch sediment. Water flowing along the contact carves the flysch bedrock and fills poorly permeable parts of the caves. It appears that some of the caves were formed while they were in the process of filling with sediment that is preserved in places and was elsewhere washed away due to the increased conductivity of the caves. Traces of earlier fillings are found in the flowstone crusts preserved at different heights in the cross sections of the passages. The lower parts of larger caves are carved deeper into the flysch rock.

Often, only smaller continuous streams that have not yet formed distinctive caves are evident in the cross sections of the slopes. After abundant precipitation, they

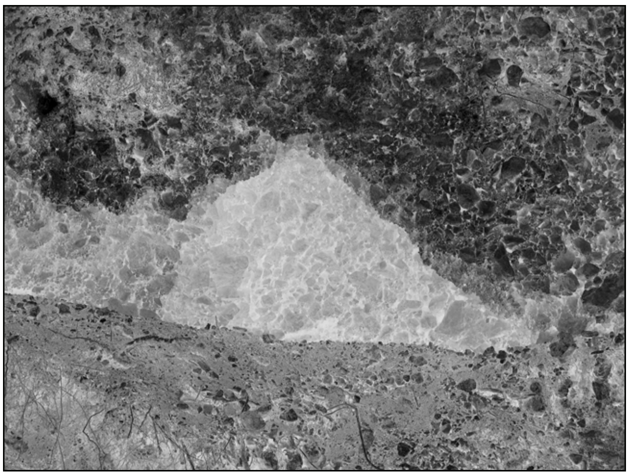

Fig. 9: Cupola-shaped widenings of cave passage. Width of picture is 3 m.
Sl. 9: Kupolasta razširitev rova. Širina slike je 3 m.

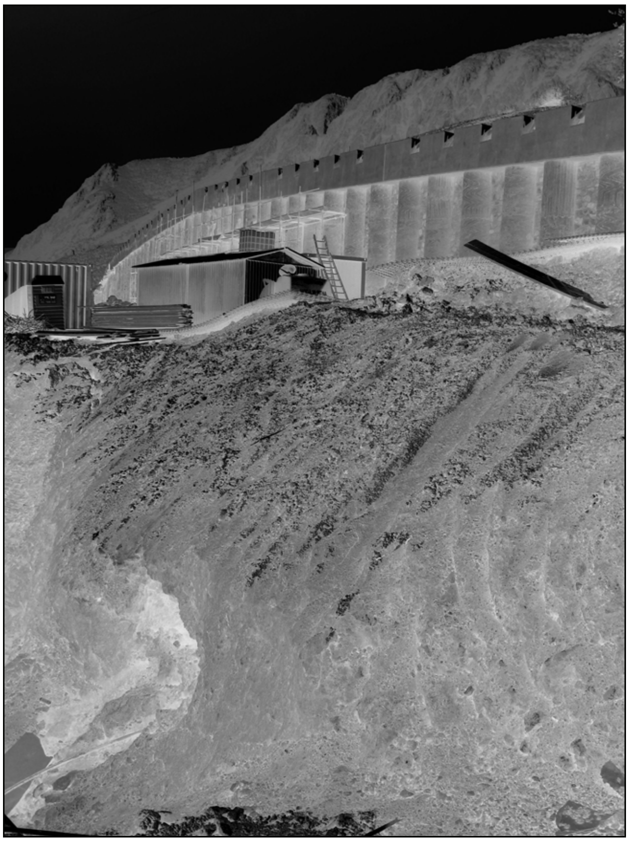

Fig. 10: Contact cave with water flow.
Sl. 10: Jama z vodnim tokom na stiku breče in fliša.

flow side by side. This is the consequence of high porosity of breccia and its contact with flysch. In most cases, the flysch proves to be a poorly permeable rock, especially its upper layer, which is weathered and clayey.

The passages of the revealed caves run down the slope. They occurred due to the flowing of water at the contact of breccia and the flysch covered by breccia (Fig. 10). The water permeating through the scree material and breccia congregates on the sloping flysch. Conditions for the formation of caves occur along larger continuous streams. Breccia was carried away in a number of places, and smaller valleys formed alongside the streams.

Sediment-filled caves

The diameters of these caves do not exceed one meter, and as a rule they are smaller (Fig. 11). The cross sections of the caves are more or less circular or elliptical in shape, as they were usually formed along the contacts between layers of different types of breccia and along fissures. They are found in all the cross sections of breccias, but primarily in the most consolidated and least porous parts of breccia. As a rule, they are filled with brown sediment and soil washed from the surface by water.

The contact between the flysch at the bottom and the breccia above is not flat but distinctly undulating and finely dissected. This is the consequence of the diverse geological structure of flysch, its variously lying layers, and the erosive action of water that has flowed and continues to flow either on the contact with breccia or in smaller valleys on the flysch. Even though there is very porous karst on a slope, less permeable sections, sometimes even flooded zones, are formed locally and occasionally in places where caves were formed in the breccia. Sediments, mainly soil washed from the surface, are deposited in them, and the caves widen along the sediments. In one of the wells used as a foundation for a bridge, water began to appear in the breccia several meters above the contact with flysch.

Fissure caves

Fissure caves are formed along fissures that developed in breccia (Fig. 12). As a rule, they cross the slopes. The largest caves, which are several meters or even several dozen meters long and in places up to one meter wide are accessible. Most of them, however, are narrower and do not exceed one decimetre in width. The depth of such caves is conditioned by the thickness of the breccia layers and the characteristics of the fissure. They are shaped by the water percolating in them. Some of these caves are filled with fine-grained sediments and soil where the rock dissolves more rapidly, and the walls of other caves are coated with flowstone. The smallest caves can be completely filled with flowstone.

Fig. 11: Cave filled with sediment.
Sl. 11: Jama, zapolnjena z naplavino.

Fig. 12: Fissure caves.
Sl. 12: Špranjaste votline.

Caves in flysch

In addition to caves that opened at the contact of breccia and flysch, we also encountered caves that formed within the framework of flysch rock at the contact of marlstone and quartziferous sandstone and of carbonate sandstone and calcarenite.

In some places, we observed significant water flow at the contact of carbonate and non-carbonate rock. The contact with non-carbonate rock is not only a water barrier but also an area where water can stagnate and where its level can fluctuate. This causes the material being washed and carried away, changes in pressure can occur here, and the water can form larger channels. Both limestone and flysch particles are transported along these paths.

In addition, we determined in many places that a small number of underground conducting channels had formed in flysch rock. In places where flysch layers are fractured or folded, water flows along the fissures or spaces between the layers. There is a flow of water along the interbedded contacts due to the almost vertical layers. Water flowing along these contacts carries away the flysch material, widens the fissures, and simultaneously periodically or laterally deposits calcium carbonate in different ways. We can frequently observe calcite fillings of fissures that are several centimetres thick. In places, the fissures are completely filled, elsewhere up to one centimetre large scalenoedric calcite crystals were formed in the fissures, and a number of fissures are covered by a thin (a few millimetres) coat of flowstone. In marlstone with distinctly conchoidal fractures, a number of fissures have been filled with coarse-crystal calcite. It is important to emphasize that the cement is carbonate and that a number of layers can contain much more than 10% of particles of carbonate origin. Therefore, both erosion and corrosion occur when water flows through the fissures and along the faults. There is no doubt that karstification takes place to a very small extent.

Fig. 13: Entrance to flysch cave.
Sl. 13: Vhod v jamo v flišu.

Heavy weathering of the rock in the interior of the tectonically undeformed block of rock occurs along fissures and faults where the precipitation and surface water flow. Calcium carbonate (flowstone) is deposited at the majority of such contacts.

Caves were formed at the contact of marlstone and calcarenite (Fig. 13). One of the more characteristic caves of this type, measuring up to five meters in depth and width, opened to the north of the Tabor tunnel at the northwestern part of the alignment. Here are layers of dark grey to black marlstone from a few dozen centimetres to half a meter thick that due to their solidity have a clearly visible conchoidal fracture. The calcarenite is heavily fractured, so that numerous calcite veins further increase the content of carbonate. Because the layers have a dip between 70º and 90º, the water passes easily between the layers. Although the calcarenite layers are being intensely dissolved by rainwater, larger cavities or even caves are not formed due to the fractured rock.

CONCLUSIONS

The geological, geomorphological, speleological, and hydrological diversity of Slovenia's karst has been demonstrated also by the study of the karstification of breccia that formed beneath the western slopes of Mount Nanos. Water, in most cases percolating diffusely through the permeable surface of scree material or breccia to the more or less impermeable flysch bedrock, creates young karst phenomena.

Rainwater covers large rocks on the karst surface with flutes and solution pans. Fissures crossing the rock in the direction of the slope indicate tensions in the rock mass and its exposure to sliding. Breccia and scree material lie on slanting flysch, and most of the water flows along the contact causing their instability.

The percolating water is collected where the breccia is most consolidated. Earthworks have revealed the early stages in the formation of unique dolines.

Characteristic types of caves developed in the young and very porous breccia, which is consolidated only in places, lying on the more or less slanting flysch, an impermeable bedrock. The true karst caves are small and their development was influenced by the sediment that as a rule fills them. They were formed in a locally and periodically flooded zone and are often paragenetically enlarged. The largest caves were formed above the contact with the impermeable flysch bedrock, where the largest streams join. Their shape reflects the varying degrees of consolidation of the breccia. In areas where the breccia is less solid and along fissures, they rise into domes. Along the fissures that are the consequence of the breccia and scree material sliding down the slanting bedrock of frequently saturated flysch, fissure caves were formed across the slope; some of them are very long and wide enough in places to make them accessible. As a rule, their walls are covered with flowstone.

To a very small extent, karstification also takes place inside the flysch where the marlstone or sandstone contains at least calcite cement. Karstification at the contacts of marlstone and calcarenite, where caves several meters in size are formed, is more significant. In places with almost vertical layers, water quickly percolates into the underground, but the heavily fractured layers hinder the formation of larger caves.

Although the described karst is relatively young, discovered in its early development stages, it still reveals all the characteristics of the karstification of breccia in characteristic geological, geomorphological, and hydrological conditions. Learning about it expands our knowledge of Slovenia's diverse natural karst heritage and forms the basis for future planning of various spatial interventions in the environment.

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JAME V BREČI IN FLIŠU POD NANOSOM V VIPAVSKI DOLINI (SLOVENIJA)

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POVZETEK

Površje pobočja jugozahodnega dela Nanosa so oblikovali podori in mehansko razpadajoča kamnina. Pobočje so razčlenile tudi vode, ki se pretakajo nad flišem. V breči so nastale bolj ali manj navpične razpoke, ki kažejo na napetosti v pobočju. Med graditvijo avtoceste, ko se je trasa globlje zasekala v pobočje, pa je stik med gruščem, brečo in flišno podlago pokazal izredno krhko ravnotežje. Po obilnih padavinah je po stiku med flišem in brečo, ki so ga razkrili useki, na dan privrela množica manjših vodnih tokov.

Zemeljska dela med graditvijo avtoceste na odseku med Razdrtim in Vipavo so razkrila za tovrstni kras v brečah, ki leže na nagnjeni neprepustni osnovi fliša, značilne in pri nas razmeroma redke kraške pojave. Razločili smo značilne vrste jam in začetne stopnje razvoja vrtač. Največje in najbolj pogoste so jame, ki so nastale v breči nad stikom s flišem, manjše in največkrat z drobnozrnato naplavino zapolnjene so jame, ki so sredi breče, posebnega izvora pa so razpoklinske jame, prečne na padec pobočja. Sledi strnjenega navpičnega prenikanja vode so manj izrazite. Jame nastajajo tudi v flišu.

Ključne besede: krasoslovje, graditev avtocest, reliefne oblike, kraške jame, breča, fliš, Slovenija

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