Projektantska skupina
2.TIR

Sofinancirano s pomočjo Instrumenta za povezovanje Evrope Evropske unije

Elea iC a member of iC group

Technical report

Second Track of Divača – Koper Railway Line, Lot 1

Study title	**Interpretation of karstological conditions for construction of tunnels T1 and T2**	
Project nr.	**190175/1**	
Study nr.	190175/1-E/01	
Stage	PZI (projekt za izvedbo)	
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Study status	Audit approved	
Revision	003	
Date	06 - 2020	

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1 UVOD

In 2017 and 2018, we continued and deepened investigations from previous years on the 2nd track Divača-Koper with additional karstic investigations. We focused on areas that would bring new insights into the karst in the areas of tunnels T1 and T2, which for the most part run through karstic rocks and areas of contact karst:

- Karstological logging (karstification) of boreholes performed in 2017-18
- Hydrogeology of Beka Ocizla cave system including surface inflows (cave stream)
- Hydrogeology of karstic springs
- Determination of nitrate concentrates in fillings of karstified areas of boreholes

Based on the new data, we re-evaluated the karst permeability in the area of tunnels T1 and T2.

1.1 Karstological borehole logging

According to the data from the boreholes, we can conclude that the underground below Veliki Gradišče, where the alignment of the T1 tunnel runs, is very karstified. Even though the drilling encountered only one larger empty cave in the hole T1-13 / 17 and sometimes with very frequent small cavities (eg. T1-14 / 17), the intensity of karstification is determined mainly by caves, cavities in centimetre and decimetre dimensions and karstic open cracks filled with karstic or cave clay. Above all, a 40-meter-high cave completely filled with cave clay at the level of the tunnel in borehole T1-13 / 17 indicates that larger cave spaces (empty and filled) are to be expected there during the construction of the tunnel. Although no major caves were directly found in other boreholes (including boreholes carried out in the 1st phase of investigations) in the T1 tunnel area, they are indicated by smaller karst cavities in the boreholes and several kilometres long caves at similar levels above the Glinščica valley. As noted above, in the vicinity of the caves, which are occasionally flooded (epiphreatic zone), cracks in their vicinity are also filled with clay. We assume that this category includes "clayey" karstic cracks in the lower part of borehole T1-12 / 17 between 185 and 231.7 meters, which are also located at the level of the tunnel, and at the same time are approximately the same level as a large filled cave in the borehole T1-13 / 14. As already mentioned, this cave is also surrounded by a several meter-thick area of "clayey" cracks. Therefore, there is a high probability that in the area of the borehole T1-12 / 17, during the construction of the tunnel, they encounter filled and possibly empty cave spaces, which is also indicated by the results of georadar measurements. A similar situation can be expected in the area of borehole T1-14 / 17, where there is a horizon of corrosion-expanded and clay-filled cracks directly above the level of the tunnel, and below is the horizon of smaller karst cavities.

Although no larger caves were found in the boreholes in the area of the T2 tunnel, the relatively good underground karstification of the karst (carbonate) part of this area is indicated mainly by corrosion widened cavities in the boreholes T2-19 / 17 and T2-20 / 17 as well as smaller open and clay ones filled corrosion cavities of centimetre and decimetre dimensions, which are more common directly below the karst surface and directly above the contact with the underlying flysch. Georadar measurements also showed a distinct underground karstification of the karst parts of the immediate vicinity of the boreholes.

The analysis of fillings in the cores of old and new boreholes for the presence of nitrates gave approximately the same values in the analysed boreholes, but the individual samples with strongly increased values deviate. The highest values were recorded for boreholes drilled in supplementary surveys. The cause of such high values is unknown, but we are proposing investigation that could give us an answer to this phenomenon.

Hydrogeology of the Beka Ocizla cave system with surface inflows

Additional investigations with expending the area of measuring points has proven that the main source of supply for Beka Ocizla cave system are cave streams. Surface measuring points gave us information on the response of surface watercourses to precipitation, where the inflow into the Ocizla Cave system works on the principle of overflow at a significant, but not at the usual amount of precipitation.

In December 2017, we managed to register a flood event with several calculated return period between 2 and 3 years at several measuring points, which caused the water to rise by about 2.5 m at the measuring point closest to the planned route of the tunnel. This indicates good flow capacity of the unknown part of the main tunnel on the other side of the siphon. In case of flood, the east doline does not play an important role, however the side inflow Zasigan rov does. With further measurements we will be able to better define background of Zasigan Rog. Floods are affected by straits, which can raise the water level by tens of meters, while the intermediate parts remain unflooded. Additional investigation has indicated the basic directions of water flow, especially in the Ocizla Cave, and shows several overflow levels through which these waters flow further into the aquifer. These levels also show the high permeability of the aquifer behind the known parts of the Beka-Ocizla Cave System. Further analyses will go mainly in the direction of estimating maximum flows, and additional conclusions are expected from the comparison of cave flow and temperature hydrographs with flow hydrograms of main surface inflows. Based on all the obtained data, we remain optimistic that by the end of the investigation we will be able to describe the entire supply system of the Beško-Ocizelj cave system with a numerical model.

1.2 Monitoring of karst springs

In order to determine the characteristics of karst springs before the start of the planned construction ("zero state") under different hydrological conditions, we continued with monitoring in Rižana and Boljunec springs, and started obtaining data from Osapska jama, which acts as a high-water overflow of Socerb karst. Similar hydrological characteristics of Rižana and Boljunec were found, and monitoring of T and SEP values showed differences in the characteristics of water flow and mass transfer in their contribution hinterland. The oscillation of the water in Osapska jama showed a relatively small overpressure at the peak of the flood event and an extremely continuous drop in the water level after it. A small fluctuation in temperature, even during overflows, indicates a predominantly autogenous aquifer supply in the hinterland of Osapska jama.

We are ready to perform a combined tracking experiment, which will further explain the directions and characteristics of water flow from the area of the T1 tunnel and more reliably confirm the position of the watershed.

1.3 Assessment of cavernousness

Tunnels T1 and T2 run for the most part through carbonate rocks, which are mostly well karstified. Due to the large karstification, the route of the T2 tunnel in the area of Ocizla jama has already been moved in the past (Figure 1). From the point of view of permeability, supplementary investigations provides a direct insight into the characteristics of the karstic part of the karst massif, insofar as deep boreholes are positioned on the karst; From this point of view, 4 boreholes were logged as part of supplementary investigations: T1-12 / 17, T1-13 / 17, T2-18 / 17 and T2-19 / 17. Particular attention should be paid to the established permeability in the borehole T1-13 / 17 or. permeability between boreholes T1-12 / 17 and T1-14 / 17, which confirmed the predicted permeability, and at T1-13 / 17 the borehole even crossed a presumably relict karst tunnel resulting from previous speleogenetic phases.

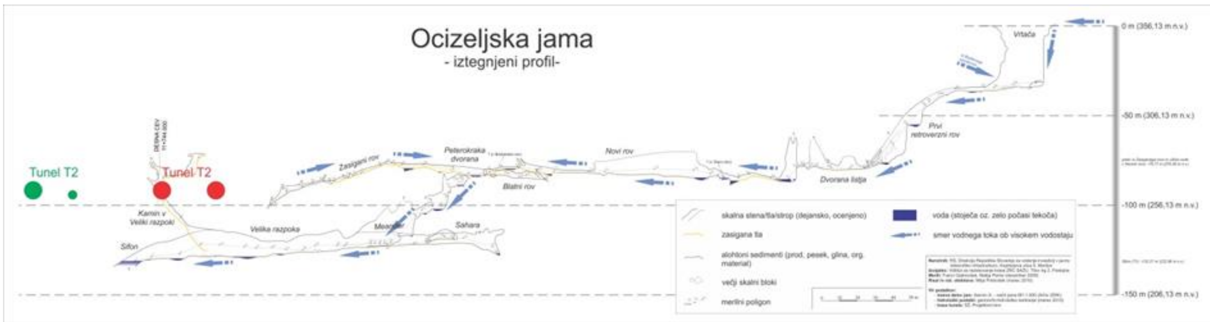


Figure 1: Initially suggested tunnel T2 alignment was shifted for 70 m already prior to Additional Investigations. This way we anticipate that tunnel will not run or breakthrough in the area.

T1-13 / 17 turned out to be the most karstified borehole. Caves occur in both the upper and lower core of the borehole, above between 32 and 34 meters and 48 and 50 meters, and corrosion-expanded cracks filled with clay are common up to 77 meters. In the lower part of the core there is an open cave with 20 cm of clay in the bottom between 205.3 and 208.5 m, and the main cave is 41 m of clay and silty clay between 234 and 275 meters. Between the mentioned caves (or the levels of the same cave?), the rock is interspersed with wide cracks filled with clay. At first glance, the cave sediment in the upper core of the borehole is slightly different from the sediment in the lower part. Above it is slightly coarser-grained, more inhomogeneous and also contains larger clusters of rock and flysch pebbles, while in the lower part the sediment is finer-grained, more homogeneous and in some places laminated (silty clay) weathered fragments of limestone. If the upper part could still be a local yield of material with local occasional flows from the flysch, the lower parts are undoubtedly larger cave spaces in which "flood clay" was deposited, probably as a by-product of a larger cave streams, which also formed this cave and carried material perhaps even from more remote areas. It is also important that in borehole T1-12 / 17 in the lower core (level approximately as the lower part of borehole T1-13 / 17) cracks are widened and heavily soiled with clay, which is assumed not to have come directly from the area above cave, but that in these cases it is also flood clay that came from below (from a nearby cave) during flood events, when the water in the karst can rise by several tens of meters. The upper core of this borehole shows a completely different picture, as there are much less widespread and clay-filled cracks. It is important that the caves or cave clay were also encountered in borehole T1-8 (only a good 500 meters from T1-13 / 17, and at a fairly similar altitude) at depths of approximately between 59 to 65, 67 to 68, 111 to 112 and 214 to 220 m. In particular, the latest data indicate that this may be a more pronounced karstic level of larger filled cave spaces and clay-filled cracks at an altitude of about 350 m. About 4 km from T1-13 / 17 and T1-8, on the northeastern edge of Glinščica, there is a several-kilometer-long cave system, which roughly corresponds to this level.

According to the data of deep boreholes, more pronounced karstification can be expected in the area between boreholes T1-12 / 17 and T1-14 / 17 (especially in the area of boreholes T1-13 / 17 and T1-8) at the level of about 350 m. Karst parts of carbonate rock can be both caves and karst cracks with or without sediments. At the level of the tunnel, the original assessment on this section of the T1 tunnel, which was given before the Supplementary Surveys were carried out, does not change, so it remains medium; however, according to borehole data T1-13 / 17, remnants of older speleogenetic phases can be expected, which, however, are practically impossible to define spatially more precisely in terms of relicenses. In the area of the T2 tunnel, on the basis of additional investigations, the rock rupture is large, but the karstification is smaller than in T1. Smaller karstic cracks and collapsed zones predominate, but the extent of the core carbonate rocks is very small, which cannot be taken as representative - the assessment of karstification given before the supplementary investigation does not change.

2 KARSTOLOGICAL REPORT FOR TUNNEL T1

2.1 Assessment of cavernousness

There are more and more useful data for estimating karst cavernousness in the alignment area. To assess the cavernousness of this part of the karst, we used the Cave cadastre, which is edited by the Cave Association of Slovenia, the results of karstological supervision of the construction of motorways on the karst and accurate measurements in the profiles of quarries. All the listed data speak of the cavernousness of the karst, especially in the epikarstic zone and the zone below it, to a depth of a few tens of meters. The assessment of cavernousness at greater depths, ie also at the depths where the tunnel line will take place, can be given on the basis of current knowledge about the development of the karst aquifer and the results of karst-geological, geomorphological, speleological and geomechanical investigations in this area. The experience gained in the construction of motorways and road tunnels on the karst is also of great help to us.

2.2 Section A (Figure 2)

Section A runs along the Cretaceous limestones and limestones of the Liburnian formation. In the cave cadastre, 11 caves were recorded in a two-kilometer strip along the route of the railway line, and 15 caves were discovered in the same rocks in the vicinity during the construction of motorways.

It is expected that 5 to 10 caves / km will be opened on this section. Cave passages (dry old ones, formed due to the former flow of water flows in a predominantly flooded zone; example: Divaška Cave) may be larger in diameter (even over 10 m), and larger predominantly horizontal epiphreatic passages may also occur. We anticipate that 50-66% of the passages will be filled with fine-grained sediments and gravel (just below the surface), and deeper also with sinter. In the meantime, (sub) recent vadose abysses may appear, the diameter of which will reach up to 5 m. Their cross-sections will be round or slit with pronounced cracks. The caves will be above the regional height of the karst groundwater, and we can expect more pronounced inflows and locally trapped water in some places.

Greater cavernousness is expected at the Cretaceous-Paleocene boundary at the transition of Section A to Section B.

5 to 10 caves / km are expected, some can be over 10 m in diameter.

2.3 Section B

Section B runs through Paleocene limestones. Knowledge of lithology and borehole data indicate a lower frequency of caves in the limestones of Paleocene and Thanetium.

No caves were recorded in the cadastre of caves in the two-kilometer strip along the route, and several smaller caves were discovered on the motorway section, most of which were filled with sediment.

We expect that most of the passages will be up to a few meters in diameter and will be filled with fine-grained sediments. We also expect vadose abysses up to a few meters in diameter and a few tens of meters deep.

The possibility of trapped water is small, but greater than in the previous section.

Greater cavernousness is expected in the fractured part around the chainage km 4,840.

Up to 5 caves / km up to 5 m in diameter are expected.

2.4 Section C

Section C passes through Eocene limestones, which are not covered with impermeable rocks on the surface. Alveolinic-numulite limestones are generally more karstified, as shown by data from the Črni Kal area. Nevertheless, there are no recorded caves in the cave cadastre in this area.

The concentration of vertical abysses will decrease towards the end of the section, as the vadose speleogenesis becomes shorter and shorter due to the synclinal geological structure.

Up to 10 caves / km with a diameter of up to 5 m are expected.

2.5 Section D

Section D runs in Eocene limestones, which, however, are covered with impermeable Eocene marls and flysch. Because carbonate rocks are covered with flysch, vadose abysses are not expected. There is a greater possibility of locally trapped water in this area. We expect passages of diameters of the order of a few meters, exceptionally up to 10 m, in the case of less expected remains of old now fossil caves.

Due to the shorter time of speleogenesis, lower cavernousness is expected, higher cavernousness is possible only on locally very limited inflows of surface waters from the flysch overburden.

Up to 5 caves / km are expected, which will have a diameter of up to 5 m.

2.6 Section E

Section E is identical to section C in terms of geological structure. We expect caves formed in the phreatic or epiphreatic hydrological zone, which passages are (sub) horizontal, and vadose abysses. The density of the abysses should increase from the beginning of the section to the end due to the length of the speleogenesis.

Given the high cavernousness of this type of limestone on the karst edge, we can expect a higher cavernousness of this area than shown by the condition of the recorded caves near the section. Namely, the karst edge was much more studied due to numerous interventions in it (quarry, construction of the motorway).

Up to 10 caves / km with a diameter of up to 5 m are expected.

2.7 Section E

Section F runs in Paleocene limestones. Lithological data and data obtained from drilling indicate a lower frequency of caves in Paleocene and Thanetium. No caves have been recorded in the cave cadastre on this section, and several caves have been discovered on the motorway section, which have been partially filled with sediments.

Most of the passages are expected to be a few meters in diameter. Some caves may also be filled with sediments. A vadose abyss up to a few meters in diameter is expected.

According to the geological profile, higher cavernousness is expected at the fault zones at the chainage km 7,100 and km 7,300 m.

Up to 5 caves / km with a diameter of up to 5 m are expected.

2.8 Section G

A short section G runs through the Cretaceous limestones of the Liburnian formation. In the cave cadastre, one cave is recorded directly along the route. In this section, sections of larger (sb) horizontal phreatic and epiphreatic caves are expected, the diameters of which can reach up to 5 meters. We also expect vadose abysses with a diameter of a few meters.

A higher density of passages is expected at the stationing of km 8,300 and km 8,440, as strong fault zones are expressed here.

In general, up to 10 caves / km with a diameter of up to 10 m are expected.

2.9 Section H

Section H runs through Paleocene limestones. No caves have been recorded in the cadastre of caves in this section, and individual caves were discovered in the motorway section, most of which were filled with sediments.

Most of the passages will be of few metres diameter. Some of the caves can be filled with sediments. Vadose abysses to few metres in diameter are expected along with vertical, narrow and long crevices generated in the areas of distinct SE-NW faults and joints. The width of 2 m and length of 10 and more metres is expected.

Higher cavernousness is expected at chainage km 8.500 where alignment is passing fault structures.

Up to 5 caves / km with a diameter of up to 5 m are expected.

2.10 Section I

Section I runs in Eocene limestones. In cave cadastre only one cave was recorded. We expect vadose abysses of few metres in diameter. Higher cavernousness is expected at the chainage km 8.930 m where alveoline nummulitic limestone and flysch transition zone meet.

Up to 10 caves / km with a diameter of up to 5 m are expected.

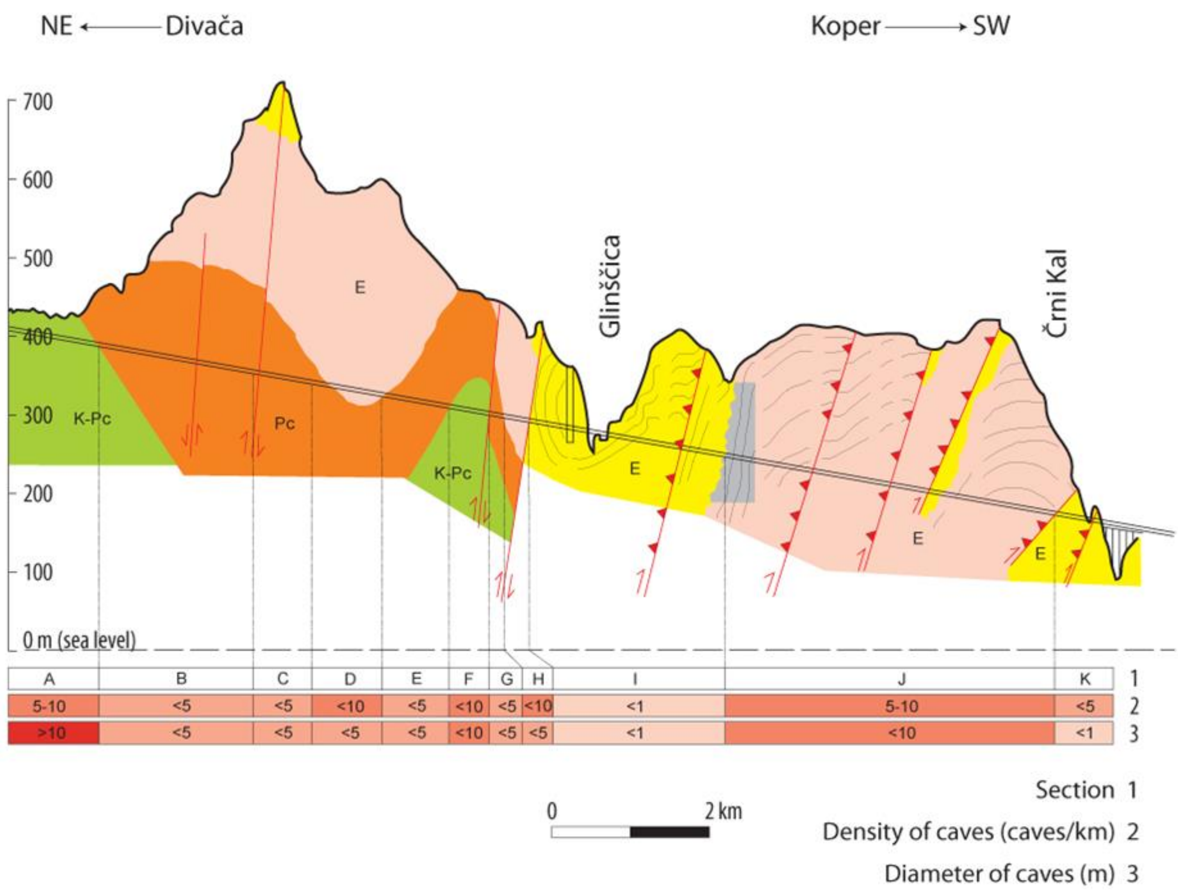


Figure 2: Assumed karstification/cavernousness along planned rail alignment.

2.11 Hydrogeological characteristics - tracking experiment

The most reliable information on the directions and characteristics of the underground flow of karst water is obtained through tracking experiments. For the northern part of the T1 tunnel, based on the results of tracking the underground flow of Reka river, we could conclude that groundwater flows through the Karst aquifer mainly towards the Timava springs, and only a small proportion of this water can occur in other springs in the Gulf of Trieste. Through the most permeable channels of the underground flow of Reka river, the apparent speed of water flow at different water levels ranges between 40 and 200 m / h. Through less permeable zones within the aquifer, these velocities are lower. Tracking in the southern part of the T1 tunnel by injection in well T1-8 also indicated the main flow direction towards the Timava springs, and only in a small proportion (approximately one tenth of the injected trail was returned) was the current towards the springs in Boljunec proven. The new tracking experiment, in which uranium was injected into the water stream in the Davorjevo abyss cave east of the T1 tunnel at the end of November 2018, confirmed the main flow direction from the T1 tunnel area towards the Rek underground stream (phenomenon followed in Cave 1 in Kanjaduce and Labodnica) and beyond against the springs of the Timava.

3 KRASOSLOVNO POROČILO ZA PREDOR T2

3.1 Hydrological conditions in Beka Ocizla cave system

The Beka Ocizla cave system was developed at the junction of Eocene flysch and alveoline nummulitic limestone. The system is a karst outflow of several permanent and occasional flysch watercourses.

The system is fed by three streams that drain an approximately 30 km2 flysch area. Two streams flow directly from the flysch into the cave stream and are active for most of the year. The third stream, which sinks into Ocizla cave, is active only during the rainy season, during major precipitation events (> 25 mm / day). It can then also represent the main inflow into the system. We tried to estimate the rough estimate of the maximum inflows into the karst with the EPA-SWMM model. The estimate is rough, as some parameters are not well known, and the total maximum inflow into the system is close to 10 m3 / s according to the model estimate.

The total length of the caves is over 3.5 km, the longest and deepest among them is Ocizla cave (length = 2750 m, depth = 157 m).

In Beka Ocizla cave system, we are performing automatic measurements of pressure (water level), temperature and specific electrical conductivity at four places with constant and occasional water flow. The measuring points in the Ocizla cave are presented in Figure 3.

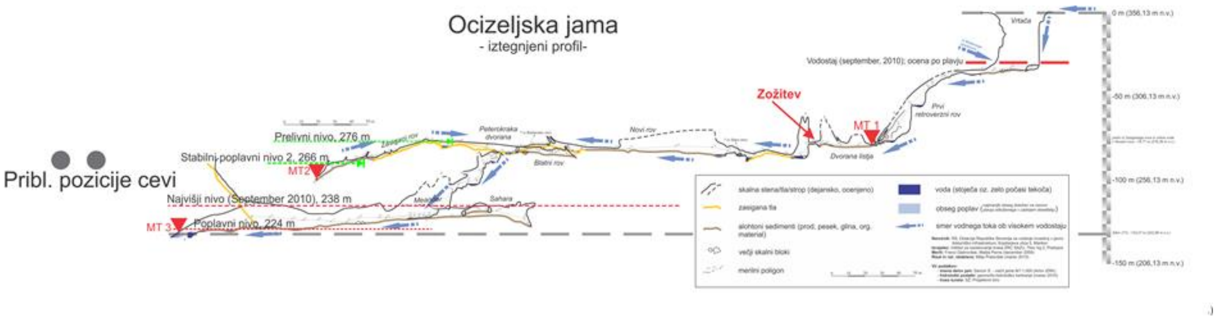


Figure 3: Ocizla cave section with measuring points 1-3 and established flood levels in the cave.

3.2 Streaming in the system

The Miškot cave is directly fed by a flysch watercourse. The flow mostly runs along the main channel, which ends at the end with a siphon that has not been explored. Undoubtedly it is hanging water, as the level is 60 m above the bottom of the Ocizla cliff. Miškot cave is also connected to Malet cave and Blaž cave.

The flow in the Ocizla Cave is extremely complex in high waters. At high flows of the sinkhole, which flows directly into the inlet landslide, the water follows a sequence of abysses and channels to the deepest point of the cave at the end of Velika razpoka (MT3). In the middle part, the flow can take place in several parallel tunnels. At exceptional flow levels in September 2010, the upper part of the cave was completely flooded (the floodplain along the perimeter of the entrance avalanche reached 5 m high), and the water level at MT3 reached 238 m; therefore, a large intermediate part of the cave was not completely flooded. Measurements and observations show that the water stagnates as it narrows in the cave. The most probable option is the passage between Dvorana listja and Staro dno, where the cross section of the tunnel is the smallest (1m x 0.5 m), and the wall facet shapes show a high flow velocity. Simple hydraulic calculations show that at a flow of 10 m^3/s the water in front of this tunnel could rise by more than 60 m, which speaks in favor of the assumption.

“Zasigani rov” above the MT2 point fills from the bottom up, as water floods back from an unknown tunnel into which we cannot physically enter. We assume (!!) that it is an inflow from the Cave with a natural bridge. “Zasigani rov” has no other outflow from the overflow at 276 m, through which water flows into the deepest part of the cave at an angle of 222 m. During the recession, the water in “Zasigani rov” stagnates at the level of 266 m, which probably represents the overflow level in the unknown inflow tunnel (or network of passages).

Despite the strong inflow, the water level at point MT3 rarely rises by more than 2 m. At a level of 224 m, there is a fairly stable level, which indicates that the water behind the siphon overflows into a sufficiently conductive tunnel, which floods only in exceptional events.

The most important flood levels are marked on the profile of Ocizla cave (Figure 1).

- Permanent siphon level (222 m) with MT3 and flood level 224 m. The lowest known outflow from the cave.
- Stable flood level 10 m above MT2, at a height of 266 m. This is water that floods “Zasigani rov” already at medium events (> = 20 mm per day). Water stays at this level for more than 50 days a year. Probably “Zasigani rov” is a water sign of the local level, held by the overflows in the lakes in inaccessible parts of the tunnel.
- Overflow level at a height of 276 m. The water in Zasigani rov rises to an overflow at an altitude of 276 m, where it overflows in the direction of “Peterokraka dvorana” and from there down towards “Velika razpoka” and point MT3. There have been 11 such events in the last year, with at least 40 mm of rain always falling per day.
- During exceptional events, water floods the entrance series of abysses and landslides. The upper part of the cave is completely flooded above the level of 275 m (narrowing in Figure 1). “Zasigani rov” is also reliably flooded up to the overflow, and the central level with “Peterokraka jama” and a series of steps to level 238 in “Meander” are only partially flooded.

Previous investigation has shown us the basic directions of water flow in the Ocizla cave and shows several overflow levels, through which these waters flow further into the aquifer. These levels also show the high permeability of the aquifer behind the known parts of the Beka Ocizla cave system.

3.3 Surface inflows into the Beško-Ocizelj cave system

Within the sinkholes that sink near T2 into the Beka Ocizla cave system, we monitor the water level and temperature of two streams, namely an occasional stream that sinks into the Ocizla cave and a practically permanent stream that sinks into the Malet cave with a waterfall. We have at our disposal a continuous data set for one year from December 2017 or January 2018.

The results show that the inflow into Ocizla cave is very rare - the riverbed is hydrologically inactive only 97% of the year. We registered 15-20 flood events per year. A comparison with precipitation shows that the riverbed becomes hydrologically active when the daily amount of precipitation exceeds 20 l/m^2 or 20 mm, and when pre-saturated, especially in winter, around 10 l/m^2 may be enough. The longest flood event (beginning of Feb. 2017) was just under 3 days, and at the highest registered water level, when the estimated peak flow was more than 1 m^3/s (December 8, 2017), the riverbed was hydrologically active only on a bad day. This indicates the distinctly torrential character of the sinkhole. The reason for the rare overflow into the Ocizla cave is the frequent subsidence of rainwater along the karstic riverbed. The water level of the watercourse that sinks into Maletova jama with a waterfall is less variable due to the catchment area on the flysch without sinking along the riverbed, which is why the water level usually responds to the daily rainfall of 10 l/m^2.

3.4 Hydrogeological characteristics - tracking experiment

The characteristics of the underground flow in the area of the northern part of the T2 tunnel were determined on the basis of a tracking experiment by injecting a trail into the Beka Ocizly cave system, from which water is proven to flow mainly towards the springs “Pri pralnici” and “Jama v Boljunec. In a follow-up experiment at relatively low water levels, apparent flow velocities between 30 and 40 m / h were detected, and over 90% of the injected tracer was recovered. With a larger time lag and a smaller share (a few%), the trace was also detected in the Rižana spring, so under conditions of higher water level, the possibility of this connection should not be neglected.

For the area of the southern part of the T2 tunnel, we have the results of two tracking experiments. Both proved the main directions of the underground flow towards the springs Osapska reka and Rižana, and also confirmed the side connection with the springs “Pri pralnici” and “Jama v Boljuncu”. At high water levels, the trail first appeared in the Osapska river (apparent speed between 25 and 35 m / h), and somewhat later and in smaller concentrations in the Rižana spring (apparent speed around 20 m / h). Given the knowledge of the situation, we can assume that as the water level decreases, the share of runoff towards Rižana increases. At low water levels, when the Osapska river dries up, the underground flow is practically entirely directed towards Rižana. The outflow through the springs “Pri pralnici” and “Jama v Boljuncu” is tied to a higher water level, speeds are relatively lower, and the share of recovered herring is only a few percent.

The existence of a wide bifurcation zone between the mentioned springs is also indicated by the results of a new tracking experiment by injecting a tracker in November 2018 into well T2-18, located between the northern and southern parts of the T2 tunnel described above. In this case, flow rates between 10 and 13 m / h were found. We can therefore conclude that the groundwater from the area of the T2 tunnel flows towards the springs in Boljunec on one side and the springs of the Osapska river and Rižana on the other. The speed and the predominant flow direction depend on the position inside the tunnel as well as on the precipitation and hydrological conditions.

3.5 Cavernousness assessment

There are more and more useful data for estimating karst permeability in the route area. To assess the permeability of this part of the karst, we used the Cave Cadastre, which is edited by the Cave Association of Slovenia, the results of karst control of the construction of motorways on the karst and accurate measurements in the profiles of quarries. All the above data speak of the permeability of the karst, especially in the epikarstic zone and the zone below it, to a depth of a few tens of meters. The assessment of permeability at greater depths, ie also at the depths where the tunnel line will take place, can be given on the basis of current knowledge about the development of the karst aquifer and the results of karst-geological, geomorphological, speleological and geomechanical research in this area. The experience gained in the construction of motorways and road tunnels on the karst is also of great help.

3.6 Section J2 (km 9,929-11,280) (Figure 4)

The characteristics of section J2 are the same as section J1 (Section J1 runs through impermeable Eocene flysch rocks and transition layers. Despite the significant carbonate binder in the flysch rocks, no greater cavernousness is expected.). There is a greater possibility of conductive channels at the chainage km 10,830, as lateral phreatic water flows independent of the locally impermeable flysch overburden can occur along the folds, which are inclined in the longitudinal direction.

In general, up to 1 cave / km up to 1 m in diameter is expected.

3.7 Section K (km 11,280-15,150)

Section K passes mainly through alveoline nummulitic limestones of Eocene age with rare but important hydrologically partially enclosing wedges of marly and flysch rocks. In the cave cadastre, 20 caves have been recorded on this section, the concentration of which is higher between chainages km 11,500 and 12,300 and between 13,500 and 14,000.

We have epiphreatic caves (trace of old water levels) in different levels, the passages have a diameter of up to 5 m and are mostly (sub) horizontal. The area is also hollowed by vadose abysses up to 5 m in diameter. This, and many of the larger caves that formed along the crevices, were revealed by karstological investigations during construction of motorways. Investigations in the Črni Kal quarry shows a 3.9% cavernousness of the upper 19 m of Eocene limestone.

The limestone is well karsified, but only in selected areas. Karstification occurs in the areas of concentrated active and fossil watercourses in contact with impermeable rocks.

Larger caves are at the outflow of water from the Eocene flysch in the area of the Beka-Ocizla cave system between chainages km 11,280 and 11,900.

Higher cavernousness is also expected at thrust faults at km 12,520 and km 13,440. Here, a lot of cavernousness with old fossil tunnels was also discovered by earthworks during the excavation of the Kastelec tunnel, where more than 500 m of cave mass opened. More than 20 other caves have opened in the tunnel. Cavernousness is expected to be high also on the railway line. The diameters of the passages will reach up to 10 m. Cavernousness with (sub) vertical vadose abysses up to 5 m in diameter will also be relatively dense.

Greater cavernousness is expected at flysch layers at chainages km 14,020 and 14,210 and at the contact of alveoline nummulitic limestones with transition layers at chainages km 15,160 and everywhere at the joints of Eocene alveoline nummulitic limestones, transition layers and flysch.

At medium to low water levels, larger amounts of trapped water are expected between chainages 11,280 and 11,900 in the area of the Beka-Ocizla system. At high water levels, water flows are active in this area above the level of the tunnel level by flooding above the narrowing of cave tunnels by a few tens of meters above the tunnel level, but there are also well-conducting cave tunnels where water does not rise to the level even after 50 years of precipitation. .

Up to 10 caves / km are expected, with a diameter of up to 10 m.

3.8 Section L (km 15,150-15,923)

Section L passes through impermeable transition layers. Due to the carbonate binder in the transition layers, only a small cavernousness is expected. As the level is less than 25 m below the thrust fault, which is at the same time the contact between the upper limestones and the lower transitional layers, karstification of the upper layer of marly layers and the intrusion of water from the upper alveoline nummulitic limestones is possible. Due to the extremely flat, also horizontal and folded thrust fault, the intrusion of locally trapped water is possible on the entire route of this section.

Up to 5 caves / km with a diameter of up to 1 m are expected.

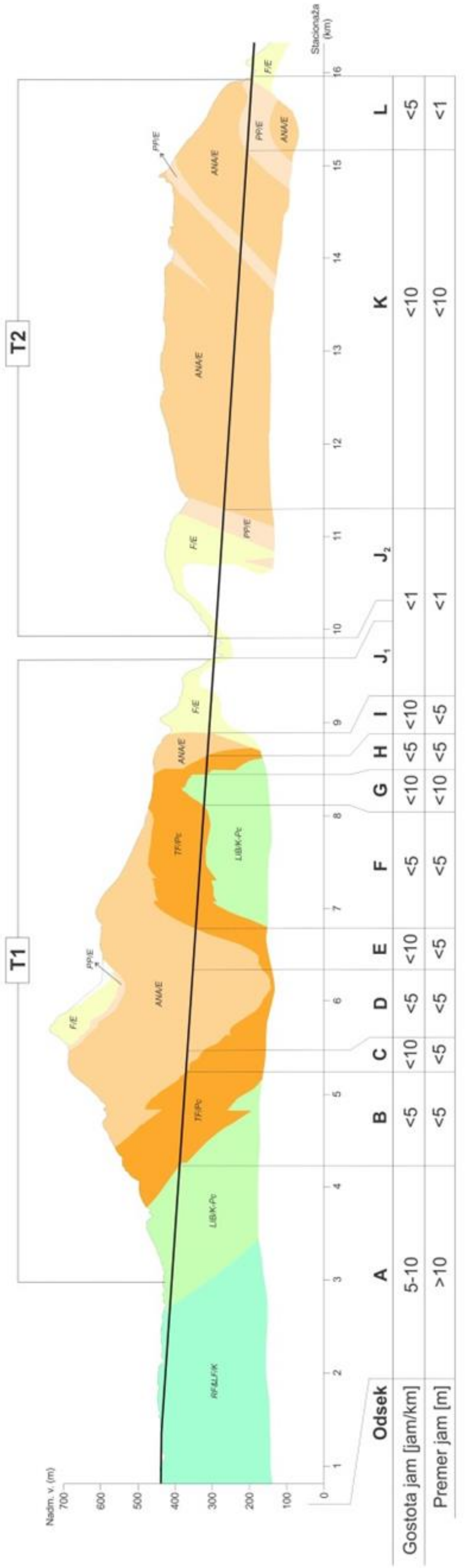


Figure 4: Assumed karstification/cavernousness along planned rail alignment.

4 TRACKING EXPERIMENT BY INJECTING IN DAVOR CHASM AND BOREHOLE T2-18

4.1 Introduction

In the area of the planned construction of a new railway line on the Črni Kal-Divača section, water flows mainly underground in a well-permeable karst aquifer and comes to the surface in karst springs at the karst contact with flysch rocks, which act as a hydrogeological barrier due to very poor permeability. The directions of groundwater flow and the position of watersheds between the catchment areas of individual springs vary depending on hydrological conditions. Their determination is therefore difficult and possible only using various hydrogeological research methods. The best results are given by follow-up experiments, in which, after the introduction of water-soluble plastic at a selected point, we monitor its transfer with water from the surface, through an underground system towards karst springs. The determined directions and speeds of water flow and the recovered amount of trace in individual springs, where the trace occurs, tell us a lot about the method of water flow in the karst in given hydrological conditions, as well as the transfer of water-soluble substances, ie the method of spreading and occurrence of possible pollution.

Tracking experiments performed in recent years have improved the understanding of the direction and characteristics of groundwater flow in the area of the planned route, but for some sections this estimate is less reliable. Therefore, as part of supplementary research, we performed additional tracking, in which two different tracks were simultaneously injected at two different points and a uniform, extended sampling network was organized in the entire area of influence of the observed section of the route. In the decision on the selection of injection sites, we cooperated with partners in charge of the hydrogeological part of the project research. In the area of the T1 tunnel, we chose the karst cave Davorjevo brezno (cat. No. 10060) with the entrance south of Kačič. The location of the cave is approximately 3 km east of the tunnel, between the Reka sinkhole into the Škocjan Caves and the T1-8 well, which were already injection points in previous tracks. The sinkhole Reka has been reliably proven to flow towards the springs in the Gulf of Trieste, especially towards the source of the Timava. One of the latter also indicated the probable direction of runoff towards the Boljunec spring, but this connection could not be reliably confirmed. By tracking in well T1-8, we proved a lateral connection with the springs of Boljunec, and a very probable main direction is towards the springs in the Gulf of Trieste. Due to the great distance and higher flows of the Timava, a significantly larger amount of tracers should be used to confirm this direction, but due to the proximity of the Boljunec spring and the danger of its contamination by the occurrence of tracers in too high concentrations. The choice of Davor's abyss as an injection point was an opportunity to obtain new information on the directions and characteristics of water flow from the T1 tunnel area and to more reliably confirm the position of the watershed among the most important springs in the area (Rižana, Boljunec, Timava). As the injection point in the area of the T2 tunnel, we chose the well T2-18, which was drilled in the zone for which the prediction of the underground flow direction was the least reliable based on previous results, but possible against all three sources (Rižana, Osapska reka, Boljunec).

As the follow-up experiment took place in the cross-border Slovenian-Italian area and its implementation was very demanding due to the large number of sampling points and difficult access to some injection and sampling points, several organizations participated in its planning and implementation. In addition to the Institute for Karst Research ZRC SAZU, there were also the Cave Association of Slovenia, the Department of Mathematics and Geosciences, the University of Trieste, the Commissione Grotte "E.Boegan" and the Società Adriatica di Speleologia from Trieste. We previously informed Rižana Vodovod Koper, the Municipality of Dolina, Servizio Geologico - Regione Autonoma FVG and Servizio gestione risorse idriche - FVG about the implementation of the follow-up experiment.

4.2 Hydrogeological characteristics

The wider area of the planned route on the Črni Kal-Divača section is characterized by a scaly thrust building. Among the carbonate rocks, mostly Upper Cretaceous and Paleocene limestones, Eocene flysch bands are formed. Surface karst phenomena and the number of registered karst caves indicate good karstification of carbonate rocks and typical characteristics of karst aquifer systems. The flysch consists of very poorly permeable marls and sandstones, and in between there are also layers of more permeable breccias and limestones. Flysch dams between karstic carbonate rocks represent local hydrogeological barriers along which water can collect and increased inflows may occur at the contact. The flysch rocks on the surface enable surface currents that sink into the underground at the contact with the karst. On the other hand, flysch also represents a hydrogeological barrier, along which groundwater karst waters flow to the surface in karst springs (Figure 5).

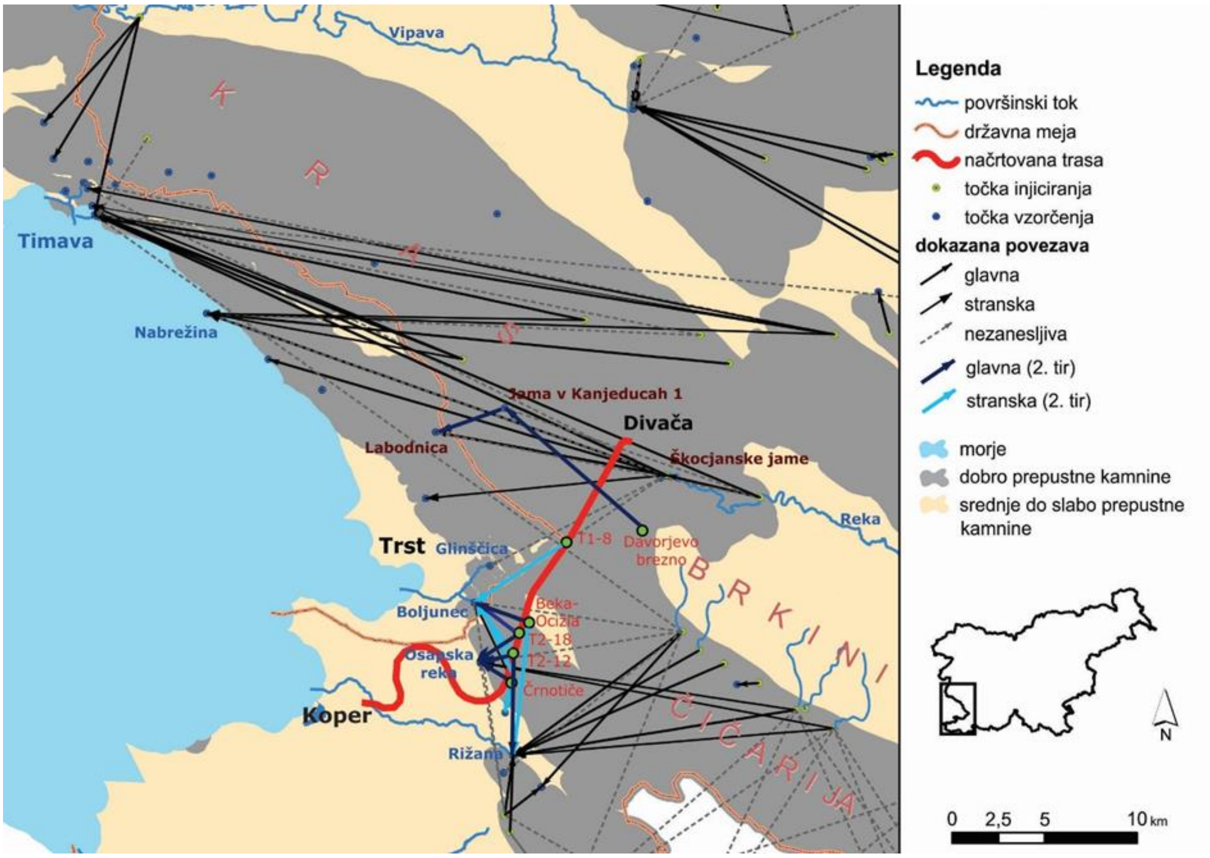


Figure 5: Hydrogeological map of a wider area of the planed railway alignment with results of previous tracking experiments in black and recent tracking experiments in blue colour.

The surface river Reka sinks into the Škocjan Caves about 3.5 km east of the railway route. In the period 1961-1990, the minimum flow of the river 0.18 m3 / s was measured at the ARSO station Cerkvenikov mlin (approximately 7 km before the sinkhole), the average flow is 8.26 m3 / s. At very high water levels, the flow can increase over 300 m3 / s. The underground flow of the river through the Karst aquifer was found in several deep caves on the Slovenian and Italian sides, among them Cave 1 in Kanjaduce and Labodnica.

Groundwater from the Karst flows to the surface in Italy in numerous springs in the Gulf of Trieste. The largest of these is the Timava spring, which has 3 main outflows. According to data for the period 1972-1983, the total flow ranges between 9.1 m3 / s and 127 m3 / s, and the average flow is 30.2 m3 / s. Many smaller springs are also deeper in the interior of the continent at altitudes between 0.4 and 12 m, and of particular interest are the submarine springs along the coast towards Trieste. The total mean flow of all these smaller springs is estimated at about 6 m^3 / s.

The source of the river Rižana is the most important karst source in the Slovenian coastline area and has been the main source for the water supply of this area since 1935. Based on basic hydrogeological research and numerous follow-up experiments, its hinterland was estimated at 247 km^2. The predominant part is karst, and the spring also receives water from sinkholes on the southern edge of the flysch Brkini. The location of the spring is connected to the contact of the carbonate aquifer with very poorly permeable flysch rocks, after which the river Rižana then flows into the Adriatic Sea. Rižana's flows range between 30 l / s and 91 m^3 / s, the average flow is 4.3 m^3 / s.

Above the village of Osp, an occasional source of the Osapska river flows from the karst cave. The entrance to the 1200 m long and 49 m deep cave is at an altitude of 105 m. In the cave, at the end of the Lower or Main Trench, there are two permanent lakes, probably suspended water basins, which lost their connection with the karst water when the water level decreased. The spring is active only after heavy rains, and flows can reach several m3 / s at high water levels. Even before the inflow of water from the cave, many springs are activated in and along the riverbed below the entrance. The springs of the Osapska river probably act as a high-water overflow of water from the hinterland of Rižana (Krivic et al., 1989). They are bound to the contact between limestone and flysch, which forms a hydrogeological barrier. Isotopic research has ruled out the possibility of tributaries from Reka, which sinks into the Škocjan Caves.

On the Italian side of the border, in the valley of Glinščica (Val Rosandra) at an altitude of about 60 m in Boljunec, there are several springs, known collectively as Boljunec. The springs Na placu and Pri pralnici are permanent, and occasionally the water flows from the karst cave as a high-water spillway Pri pralnici. We call it the source of the Caves. Spring Pri pralnici is covered for a fish farm.

Higher in the Glinščica valley, where water flows superficially in the area of contact between carbonate rocks and flysch, there are some surface tributaries (Krvavi potok, Griža) and several smaller karst springs with flows of a few liters per second (Klinšca 1, Klinšca 2, Zroček 1, Zroček 2). In the village of Dolina, there are three smaller karst springs that were in the past or are still used today as local water sources.

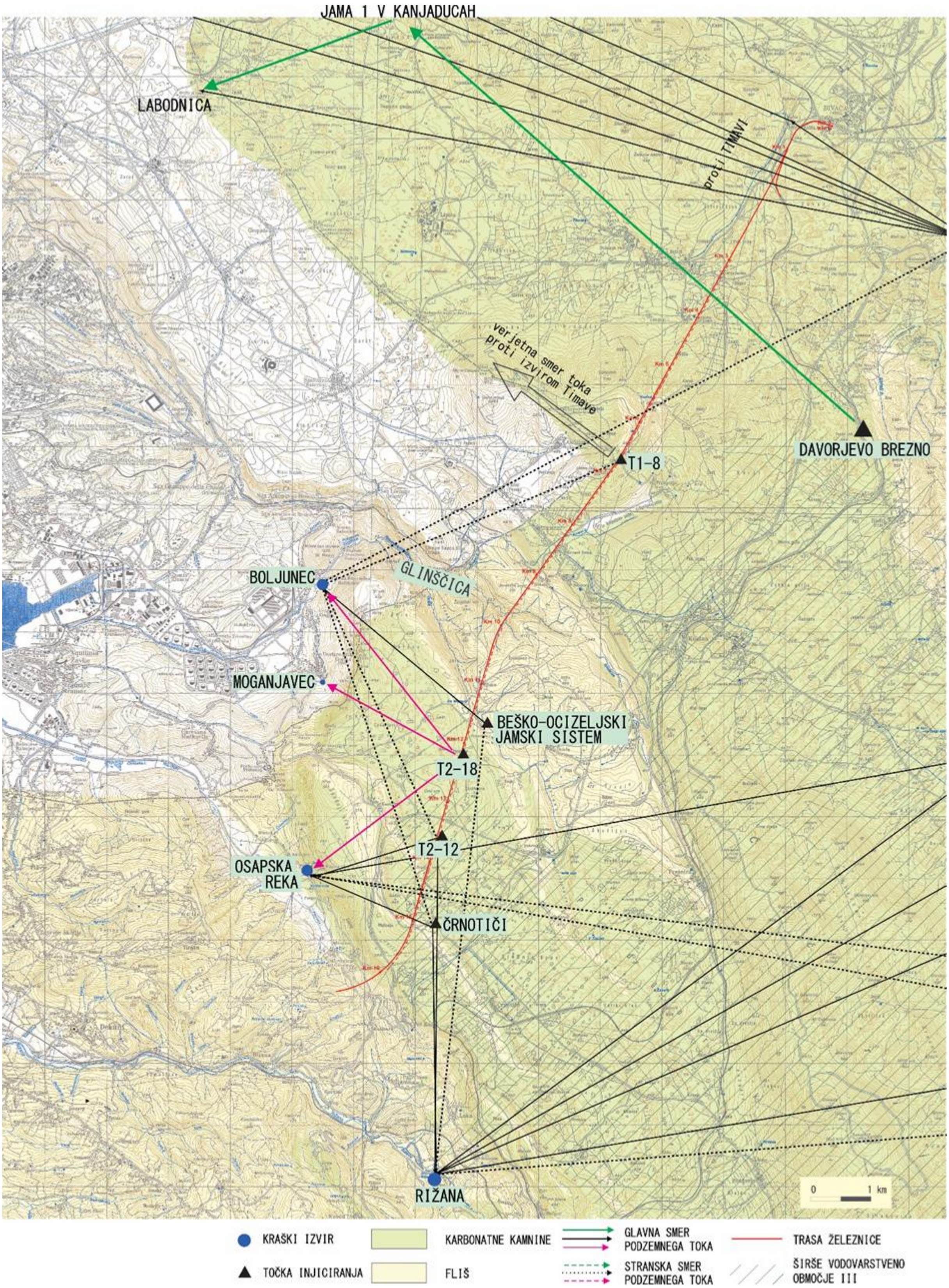
4.3 Conclusions

The results of the previous (black arrows) and new tracking by injecting uranium into Davor's abyss (green arrows) and naphthenate into borehole T2-18 (purple arrows) are shown in Figure 6.

Based on the collected older data and the results of a new tracking experiment, we can summarize the main characteristics of water flow in the area of the planned route of the railway line between Divača and Črni Kal. From the area of the T1 tunnel, the underground flow is directed through the Karst aquifer mainly towards the Timava spring in Italy, and only a small part of this water can also occur in other springs in the Gulf of Trieste. Through the most permeable channels of the underground flow of the River, the apparent speed of water flow (calculated according to the air distance) at different water levels ranges between 40 and 300 m / h. Through the less permeable zones inside the aquifer, the velocities are lower. The new tracking, in which uranium was injected into the water stream in the Davor abyss cave east of the T1 tunnel at the end of November 2018, confirmed the main flow direction from the T1 tunnel area towards Reka underground stream (trail phenomenon in Cave 1 in Kanjaduce and Labodnica) and beyond. against the springs of the Timava. We can conclude that this is the main direction of flow from Davor's abyss towards the underground flow of the river through a system of connected and well-permeable karst cracks and canals. In the conditions of medium water level, apparent flow velocities between 30 and 50 m / h were found. Only from the southern part of the T1 tunnel and under favorable hydrological conditions, according to the results of previous tracking in the T1-8 well, it is possible that a very small proportion of groundwater also flows towards the springs in Boljunec.

Using the second tracker, we tracked in November 2018 for additional information on the characteristics of the underground flow in the area of the T2 tunnel. Although the naphthenate tracer used proved to be less suitable in the study of larger karst systems, we were able to obtain new information on the position and characteristics of the wide bifurcation zone between the Rižana, Osapska reka and Boljunec springs. We confirmed that the velocity and the predominant flow direction depend both on the position inside the tunnel and on the precipitation and hydrological conditions. In the northern part, the groundwater flows mainly towards the springs Pri pralnici and Jama in Boljunec, while towards the south the share of the flow towards the springs Rižana and Osapska reka increases. The apparent flow rates determined by various follow-up experiments range between 10 and 60 m / h.

Figure 6: With previous (black arrows) and new tracking experiments (for uranin green and for naphthenate purple arrows) established underground water connections in the area of the planned railway line Divača - Koper.



5 MEASURES TAKEN WHEN ENCOUNTERING KARST PHENOMENON DURING CONSTRUCTION OF TUNNELS

Target purpose:

- definition of location, size and extent,
- assessment of hydrological function,
- definition of filling (air, water, sediments),
- interdisciplinary scientific and nature conservation inventory,
- definition of karst characteristics as one of the bases necessary for bridging.

Input data on the karst phenomenon:

- known karst phenomena (Beka-Ocizla cave system),
- expected karst phenomena during the construction of PGD / PZI,
- pre-drilling (size, type of filling),
- additional pre-drilling (all of the above + range).

Action decision-making factors:

- in the basic pre-drilling phase (Figure 7):
    - the size of the karst phenomenon determined by pre-drilling,
    - the extent of the karst phenomenon determined by additional pre-drilling (if any),
    - fullness of the karst phenomenon,
    - previous occurrence of karst phenomena (in the PGD / PZI phase, in the pre-drilling and excavation phase),
    - sedimentological characteristics of filling (sediments) of the karst phenomenon,
    - groundwater leakage,
- in the phase of access and direct investigation of the karst phenomenon:
    - all from the pre-drilling phase,
    - estimated hydrological function of the karst phenomenon (translation of vadose or (epi) phreatic water; evident from the formation of tunnels and cave sediments in it and physical-chemical analyzes of water (if water is present)),
    - stratigraphic-tectonic characteristics of walls, ceiling and floor (rock type, intrusion and layer thickness, tectonic failure),
    - connection to a wider vadose cave system (physical characteristics of the air),
    - scientific and nature conservation importance of the cave,
- in the phase of hydrological measurements (if the karst phenomenon is permanently or occasionally filled with water):
    - more detailed hydrological function (water level fluctuations, presence of major groundwater flows, origin water, assessment of hydrological function in the wider underground cave system.

Expected measures upon encountering karst phenomenon:

- in the basic pre-drilling phase:
    - karstification registration (dimension, occupancy) and communication,
    - basic hydrological measurements (if the karst phenomenon is filled with water),
    - additional fan pre drilling (if at least one karst phenomenon has been identified by pre - drilling of dimension greater than 0.5 m),
    - adaptation of blasting and excavation at the tunnel face (with the aim of reducing the collapse of walls, floors and ceilings of the karst phenomenon),
- in the phase of access and direct research of the karst phenomenon:
    - partial restriction or complete reorientation of construction works during the basic research (estimated 8-32 hours (Exceptionally, a few days as part of paleomagnetic research) (a total of 2 caves along the T1 and T2 routes). Details have already been agreed in more detail); depends on the location of the karst phenomenon (front, floor, ceiling or side of the Excavation profile), dimensions, spatial extent, scientific and nature protection characteristics and estimated hydrological functions),
    - research of the karst phenomenon:
        - safety measurements of physical characteristics of air (CO, CO2, O2), research and measurements of the spatial extent of the karst phenomenon and the implementation of scientific and nature conservation research (with the exception of paleomagnetism, presumably 100 × in caves shorter than 10 m and 10 × in caves longer than 10 m),
            - karstology-speleology,
            - sedimentology,
            - biodiversity,
            - microbiota,
            - paleomagnetism / age,
        - continuation of basic hydrological measurements (if the karst phenomenon is filled with water), assessment of mechanical characteristics of walls, floor and ceiling and sediments of karst phenomenon (rock type, intrusion and layer thickness, tectonic failure),
        - content and timing of further detailed research (if necessary),
        - in the phase of hydrological measurements (if the karst phenomenon is permanently or occasionally filled with water)

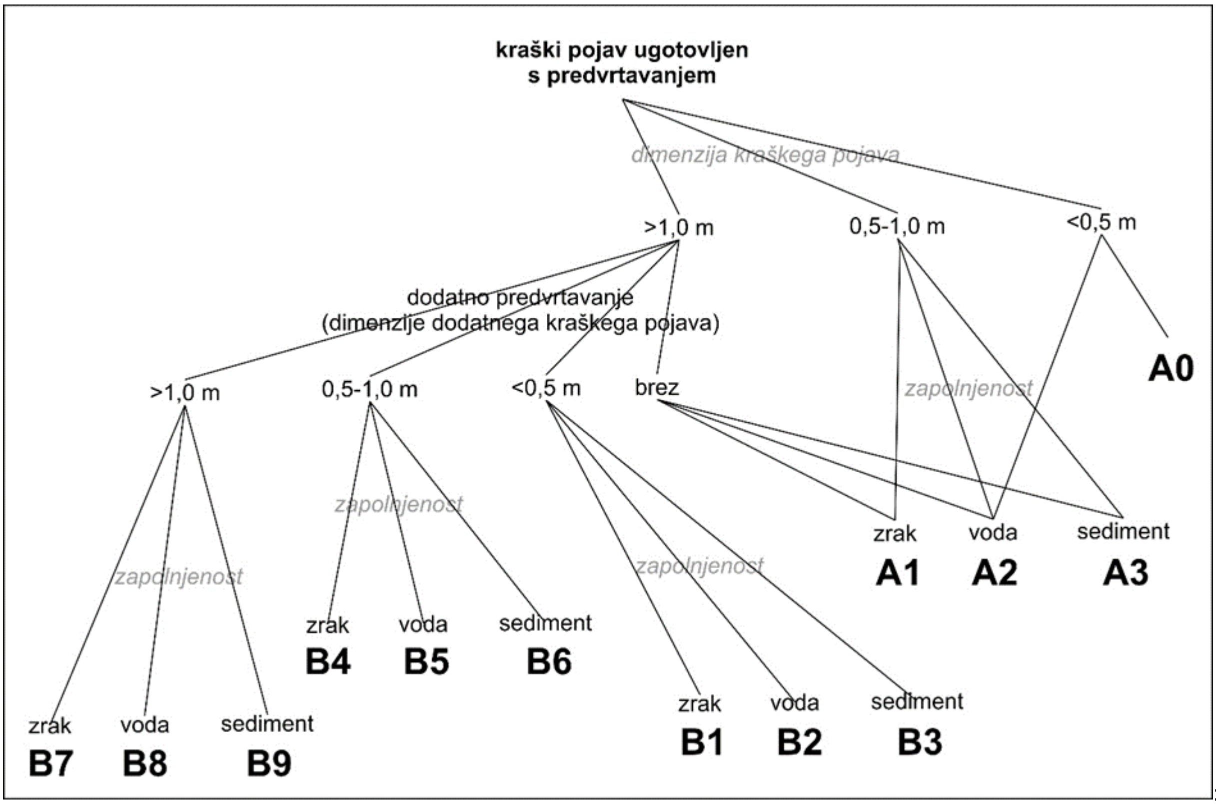


Figure 7: Algorithm for taking measures when encountering kart phenomenon with basic and additional predrilling (measures type A and B)

Technical bridging of the karst phenomenon:

- without special measures,
- construction measures,
- provision of hydrological by-pass.

6 OBLIKE IN DIMENZIJE PRESEKOV PREDORA Z ZNANIMI JAMAMI

The shapes and dimensions of the cross-sections of the cave tunnel are extremely difficult to define; cave tunnels are formed along various load-bearing structures (primarily tongues, cracks), which were transformed at the site of karstification by other factors during speleogenesis (water aggressiveness, hydrological regime, allogeneic sediments, demolition, siga deposition), which are very small, if at all, interdependencies with the geological structure and are much less known than the geological structure. Transverse, longitudinal and plan cross-sections also do not have a geometric shape conditioned solely by the geological structure - widenings / increases and narrowings / decreases of tunnels are characteristic in karst caves. Nevertheless, we estimate that some of the longer known caves, which show a broader insight into the karstification of the interior of the karst massif, well reflect at least the local laws of morphology, so they can be expected in the immediate vicinity of the tunnel. These caves include the Beško-Ocizeljski cave system, larger caves in the Kastelec / pod Škrklovico tunnel and Osapska jama; the latter indicates a general development at the thrust contact of flysch on flysch in the epiphreatic zone. The actual intersections of the tunnel with karst caves were relatively well documented during the construction of the Kastelec tunnel. When estimating the theoretical cross-section of the cave tunnels with the T2 tunnel, we took into account the general direction of the T2 tunnel on this section, ie 16-196 °.

6.1 Beka Ocizla cave system

In the area of the Beka-Ocizla Cave System, there is a significant connection between the course of the cave tunnels and the cracks (Miškotova jama) and / or cracks (Ocizeljska jama, Jurjeva jama, Miškotova jama). The tunnels are connected to the tongues and oblique fractures in the direction of 150-330 ° (Miškotova jama, Jurjeva jama) or 140-320 ° (Ocizeljska jama), the tunnels connected to the subvertical cracks are practically transverse to them, ie they have a direction of 60-240 ° (Ocizeljska jama, Miškotova jama), and the tunnels descend continuously or in steps (Figure 8). The tunnels running along the tongues and oblique fractures are subhorizontal, epiphreatic (Fig. 9B), in the vicinity of the abyss they can exceptionally form shorter oblique tunnels with vertical steps (Fig. 9D), in closed bowed parts trapped water appears in places. The average width of these tunnels is about 5 m and the height is 3 m. If they are formed at an oblique crack / fracture (Ocizeljska jama; Figure 9A), they are strongly stretched along the crack / fracture and therefore significantly longer along the longer (oblique) axis (in the Great crack-Ocizeljska jama on average 12 m), and transverse to it wide to a few meters; in the case of Ocizeljska jama, trapped water with a volume of at least 150 m3 is completed. Allogeneic material may be deposited along the bottom. Landslides are rare and do not form larger landslide halls, but local outcrops. Transverse to the tunnels along the tongues and oblique fractures are basically phreatic tunnels, which are in the zone of regular water oscillation (epiphratic zone) of the lenticular profile (Fired tunnel in Ocizelj Cave), and along the main vadose streams of submerged water down into the meander jame-

Fig. 9C and 9F, Meander in Ocizelj Cave). According to the assessment, the development of these vertical jumps is linked either to the contact of the tongue with the crack / fracture (Miškotova jama, Ocizeljska jama) and can fall both along the inflow of the layer (the joint section of Miškotova jama) and transversely to them (Meander in Ocizeljska jama). Due to their hydrological function, such meandering tunnels are narrow and high; the average width of such tunnels is 1-2 m, and the height is also more than 10 m (Fig. 9C and 9F). The quantities of trapped water in the accessible parts are usually small (Fig. 9G), but they can be completed with a siphon with more than one hundred m3 of trapped water (final part of Miškot Cave; Fig. 9E). In Jurjeva jama, in addition to the above, tunnels in the direction of 170-350 ° also stand out, and this is a local passage either from an oblique crack into the vadose abyss or a passage of a tunnel developed in the direction of 150-330 ° into the sediment-filled lower part of the tunnel. The branching of the leading hydrologically active canal is extremely small - it is formed either by local hydraulic shortcuts (by-pass; Miškotova jama), but it is by no means a branched interweaving of tunnels. In this respect, the leading structures appear to be markedly selectively karstic. Point vadose abysses are sparse and limited to cave entrances, while they are virtually absent inside the cave system.

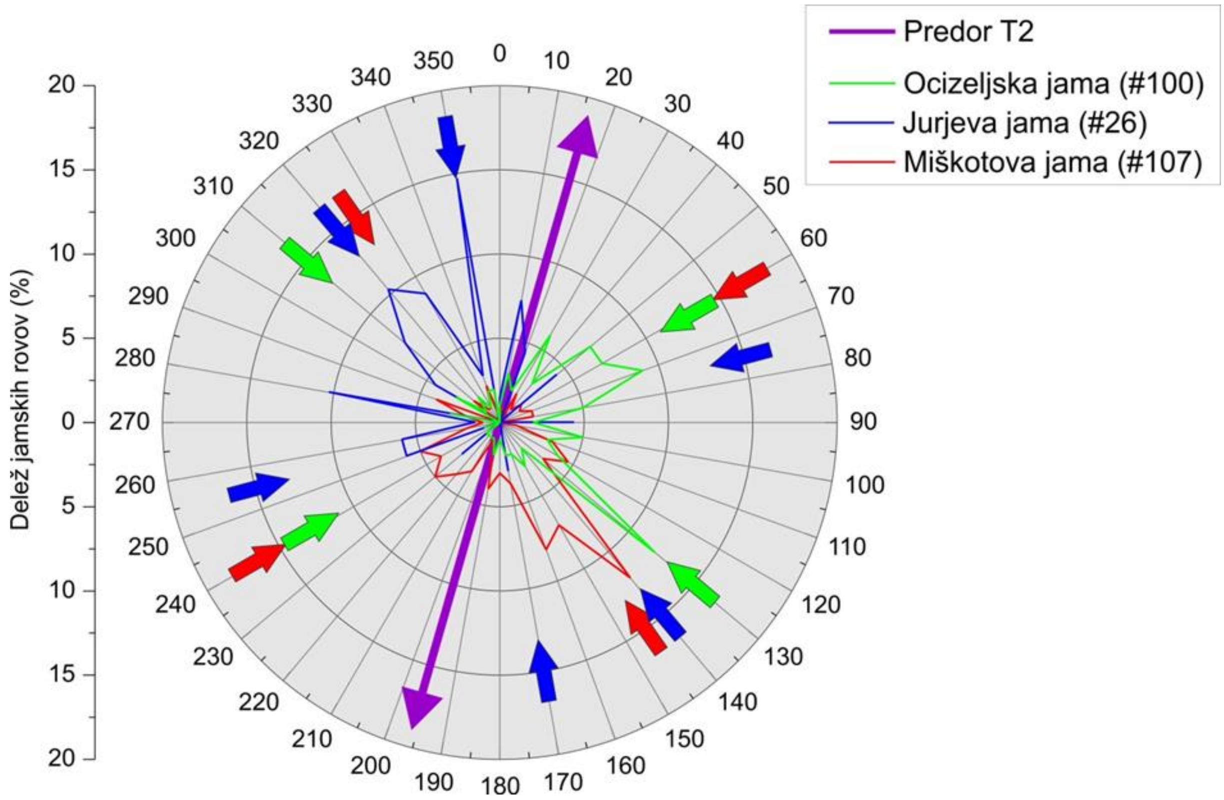


Figure 8: Ground plan directions of cave tunnels with respect to the measured polygon (2009 in October 2018) in the main caves of the Beka-Ocizla cave system. The number of measurements is indicated in the legend. The main directions are thus marked with arrows. The purple line represents the ground plan direction of tunnel T2 on the cave system.

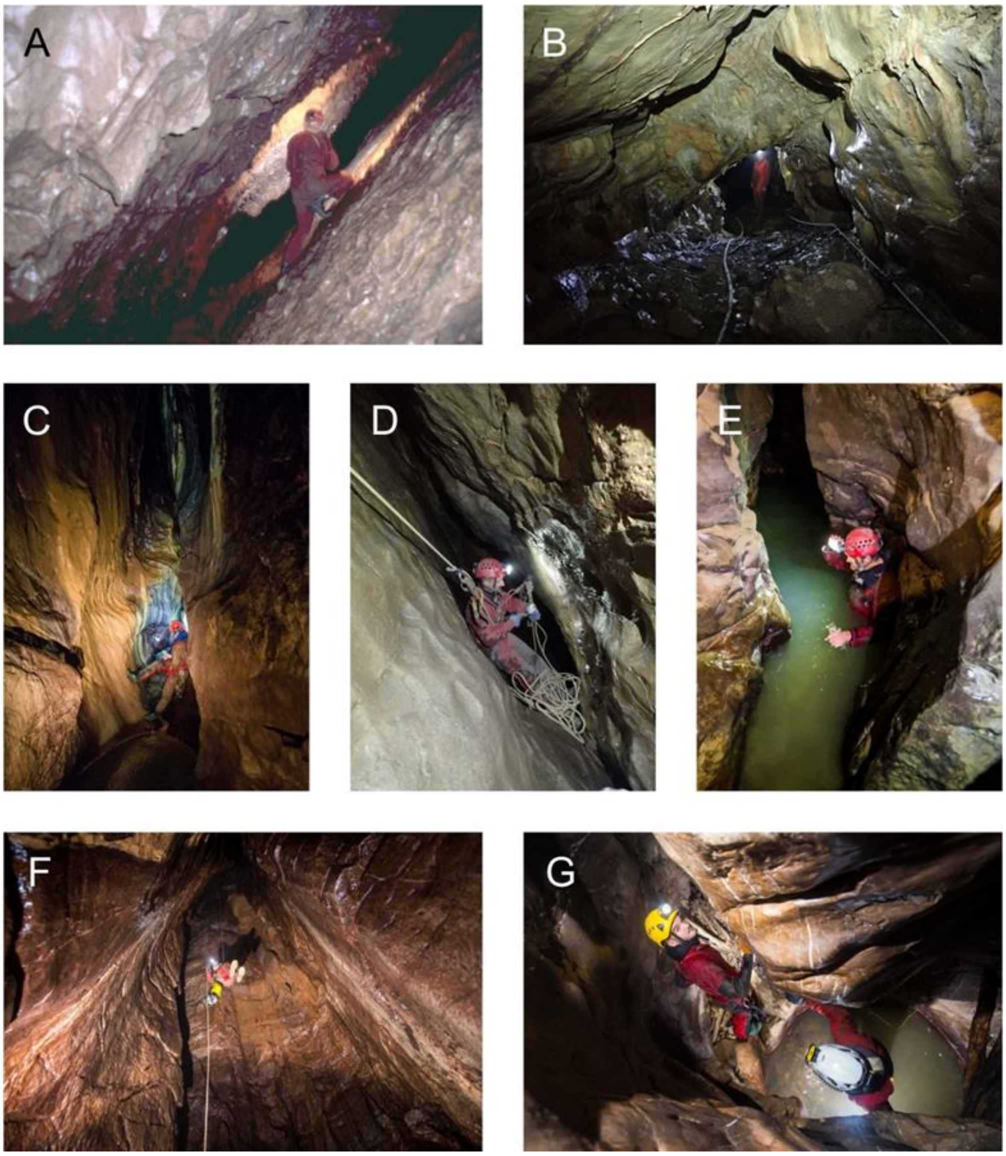


Figure 9: Examples of typical cave tunnels in Miškot Cave and Ocizelj Cave, which can be crossed by a tunnel in an unknown continuation or abandoned (relict) form. (A) The main water tunnel of the Ocizeljska Cave (Large Crack Trench) developed at the crack / fracture in the direction of 140-420 °, the continuation of which will be crossed by the T2 tunnel at the km11,690 station (photo: J. Hajna). (B) The main water tunnel of Miškot Cave with a direction of 150-330 °, which translates a few m3 / s and floods it to the ceiling in case of extraordinary floods - a similar tunnel is possible in the area of well T2-17 / 17 and between Miškot Cave and Ocizeljska cave (photo: M. Blatnik). (C) Meandrast tunnel in Miškot Cave developed at a subvertical crack / fracture in the direction of 60-240 ° (photo: M. Blatnik). (D) An example of a crack / fracture with a direction of 170-350 ° in Jurjeva jama, which translates several hundred L / s of submerged water with sediments - the course of such tunnels is unpredictable due to the uncharacteristic direction (photo: F. Drole). (E) The final siphon in Miškot Cave near well T2-17 / 17 is an example of a flooded meander with a direction of 60-240 °, which is below the flysch roof and is estimated to be only about 10 m from the contact of limestone with the transition layers; with a few hundred m3 of water, it is one of the largest quantities of trapped water in the entire Beško-Ocizeljsko system (photo: M. Blatnik). (F) Vadose abyss, developed as a vertical jump 20 m high in the direction of 60-240 ° (photo: M. Blatnik). (G) Same meander as in Figure 9C - view from above shows hollows with up to a few m3 of trapped water, sanded edges limestone protrusions indicate a strong flow of coarse-grained material along the bottom of the meander (photo: M. Blatnik).

The T2 tunnel will cross both directions in the dominant group of cave tunnels obliquely. At the km 11,690 station, the tunnel will certainly cross an oblique karst crack / fracture, along which a significant part of the Ocizla cave is formed (Rov velike razpoke, Prvi retroverzni rov, part of Novega rova) at a ground angle of 70 °, which is at T2 level in Ocizeljski jama is very differently decorated; in Meander in a width of 1-2 m and a height of 5-15 m, and in Kamin in Velika razpoka in a width of up to 14 m and a height of about 1 m (Figure 9A). The latter form of the trench seems more probable in this case. The intersection with the hydrologically active subhorizontal epiphreatic tunnel with a direction of 150-330 ° is possible in the undiscovered continuation of Miškot Cave behind the joint siphon in the area of well T2-17 / 17, as the level of trapped water is practically at the level of the tunnel level (Figure 9E). the caves on the other side of the joint siphon most likely represent a sub-horizontal tunnel. At an angle of 45 °, it is also possible to break through the hydrologically active vertically descending tunnel in the direction of 60 °, after which the cave tunnel behind the articulated siphon, which is trapped water, descends towards the groundwater level; such a tunnel will have a meander transverse profile with an average width of 1-2 m. Unexplored hydrologically active tunnels on the level of the tunnel are also very probable between Miškotova jama and Ocizeljska jama (stationing km 11,280-11,690), where a very probable inflow of water from Miškotova jama into Zasigana rov Ocizeljske jama is indicated; there flood water overflows over the elevation 262 and 266 m, which may indicate cave tunnels in the direction of 150-330 ° as well as 60-240 °, which are completely flooded at high water levels. From the point of view of the course, the relict remains of older tunnels are very unpredictable, and today they no longer perform a hydrological function and are visible in the Ocizelj Cave (Sahara, Mud Trench), and due to allogeneic sedimentation they are practically unknown, ; such tunnels can also extend outside the known area of the Beško-Ocizeljski system, ie from the stationing km 11,690 in the karst massif in the vicinity of Škrklovica, where the tunnel is already above the flood zone according to measurements in the lower part of Ocizeljska jama. . At the intersections with active water tunnels, in the case of the Beško-Ocizeljski cave system, it is necessary to ensure the transport of suspended, coarse-grained and floating material by circulations in addition to water. Given the structural-geological structure of the T2 tunnel, tunnels similar to the Beško-Ocizelj system are difficult to apply to other areas of the T2 tunnel, as they are defined by the influence of sinkholes in vadose conditions.

6.2 Large caves in the Kastelec tunnel and Brezno on Škrklovica

The large caves in the Kastelec tunnel (S 640, S 647 and S 590) and the abyss accessible from the surface in Škrklovica indicate the development of sloping tunnels in the phreatic zone (Fig. 13B), in which fine- and coarse-grained sediments were deposited and places in the vadose zone intersected by a subvertical abyss formed by infiltrated water. Sloping tunnels in all the mentioned caves are developed along (tectonic) tongues, which generally flow towards the NE; since the tunnels do not have a tendency to follow the greatest intrusion of the tongue, the orientation of the tunnels does not show the predominant direction, but theoretically encloses the entire angle of 180 ° (Fig. 10). Vadous abysses are associated with subvertical fissures / fractures. The genetic connection of the tunnels with about 100 m towards the SW located Škrkloviški thrust fault is not known; flysch pebbles over 10 cm in size found in the cave indicate a local origin, which could be formed by the now completely eroded flysch scale of the Škrkloviška thrust fault. The average width of the cave tunnels is 3.5 m and the height is 4 oz. 2 m (Fig. 13B). The intersection of the cave tunnels with the Kastelec tunnel, which at this point runs in the direction of 80-260 °, ie mainly along the cave tunnels, is extremely modest due to a web of coincidences; the cave tunnels are largely located either between the two tunnel pipes or along the side of the southern tunnel. The diametrically opposite intersection of the tunnel with the cave tunnels would be if the tunnel pipes were located 20 m to the south; in this case, the floor plan would largely overlap.

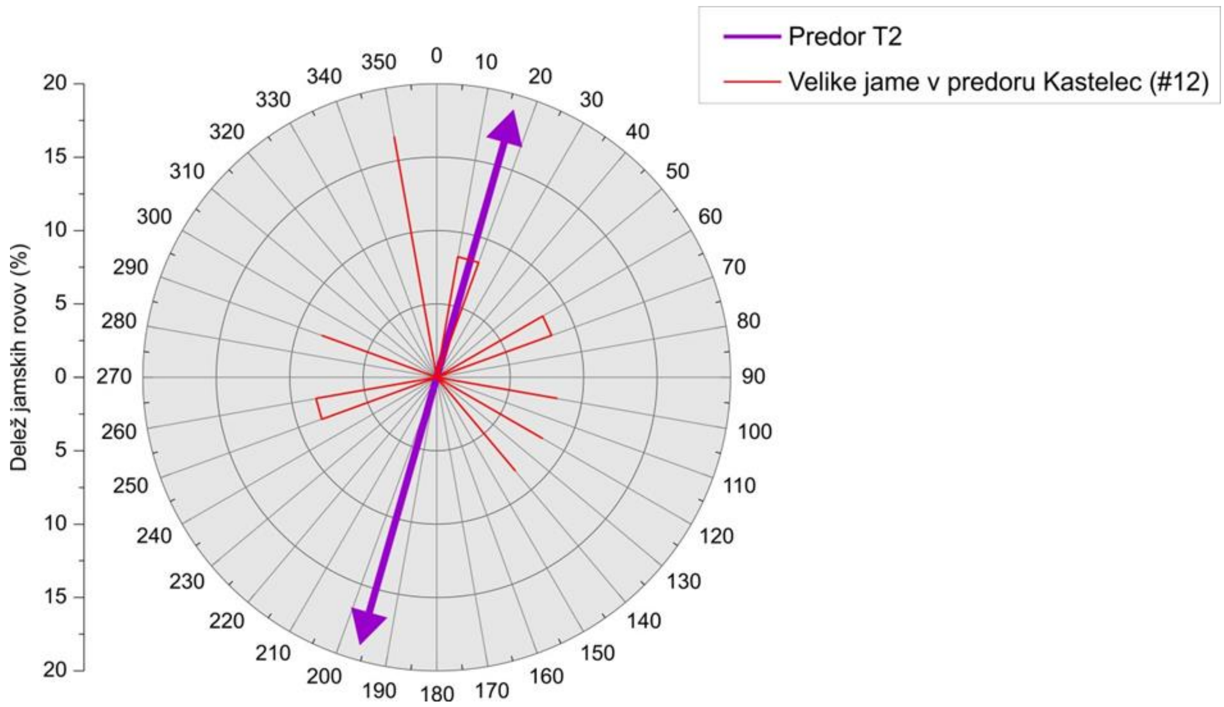


Figure 10: Ground plan directions of cave tunnels with respect to the segments of the leading polygon of larger caves (S 640, S 680 and S 600) discovered in the Kastelec tunnel. The total number of segments of the main polygon is stated in the legend. The purple line represents the floor plan direction of the T2 tunnel in the area of the cave system.

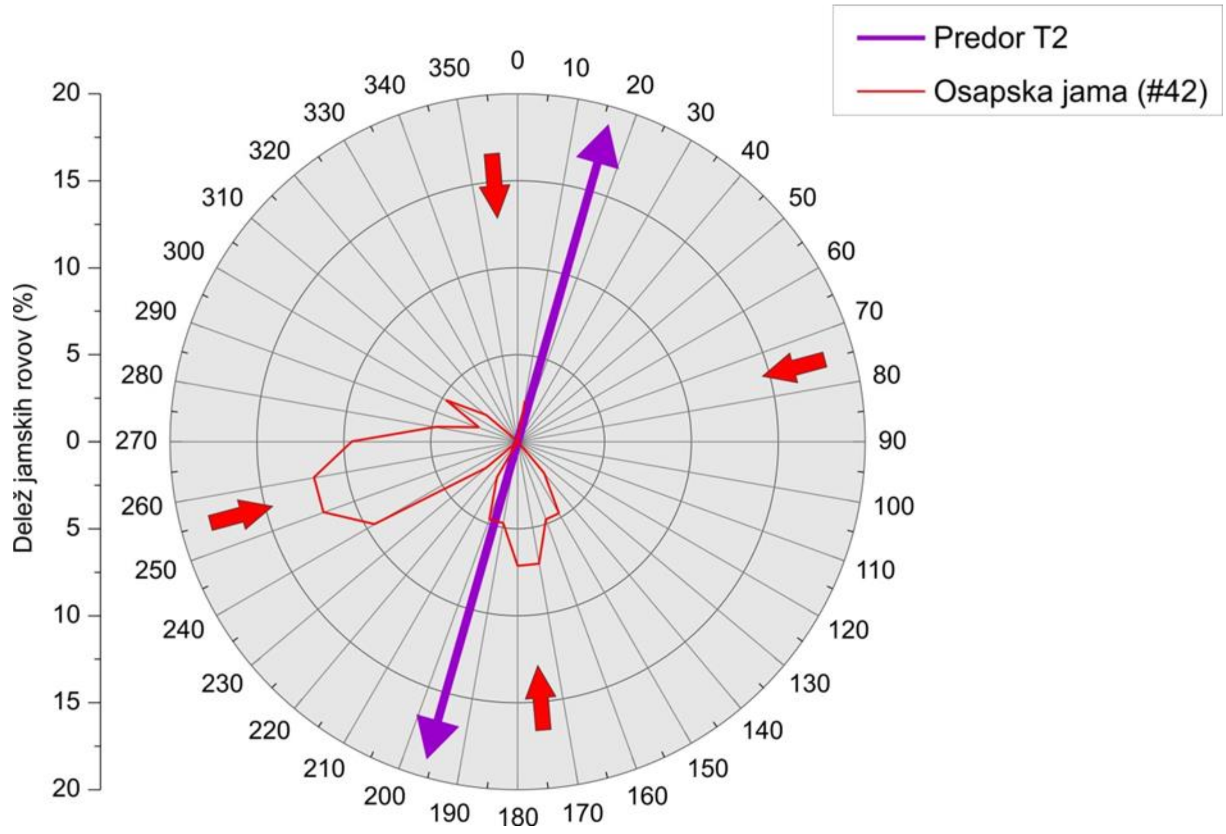
As the T2 tunnel runs at this location (stationing km 12,600-km 12,700) at a ground plan angle of 45 ° with respect to the intrusion of the foundations defining the initial development of the caves, the floor plan of the tunnel with sloping tunnels is The intersection of the tunnel with the transverse tunnels is relatively short (3.5 m) and significantly longer (24 m) with the longitudinal tunnels due to the slope of the cave. the tongue falls; in the case of a longitudinal section, it will be necessary to ensure adequate load-bearing capacity outside the intersection itself at the site of the tunnel above the tunnel ceiling.

According to the structural-geological structure of the T2 tunnel, similar oblique phreatic tunnels are expected, relict and south of the frame station km 13,000 hydrologically active, on the entire section between the station km 11,900 and km 13,900.

6.3 Osapska jama

Osapska jama is formed in the epiphreatic zone of the limestone roof, which is practically horizontally pushed to the flysch in the entrance part, and in the lower part the tunnels run just above at least two flysch scales. The majority of tunnels have a direction of 75-255 °, which corresponds to the expected intrusion of thrust surfaces with a slight decline of tunnels towards the NE, and to a lesser extent 175-355 ° (Figure 11), where subhorizontal tunnels with unidentified leading geological structure appear. The entrance part of the cave is developed exactly on the thrust surface, with a 70 m tunnel deepening into the underlying flysch by at least one meter. The tunnels are on average

7 m wide and 2-3 m high on average. The leading tunnel is followed by parallel to two parallel ones, which indicates the karstification of a wider beam, which merges upstream in the entrance hall / gabled valley.



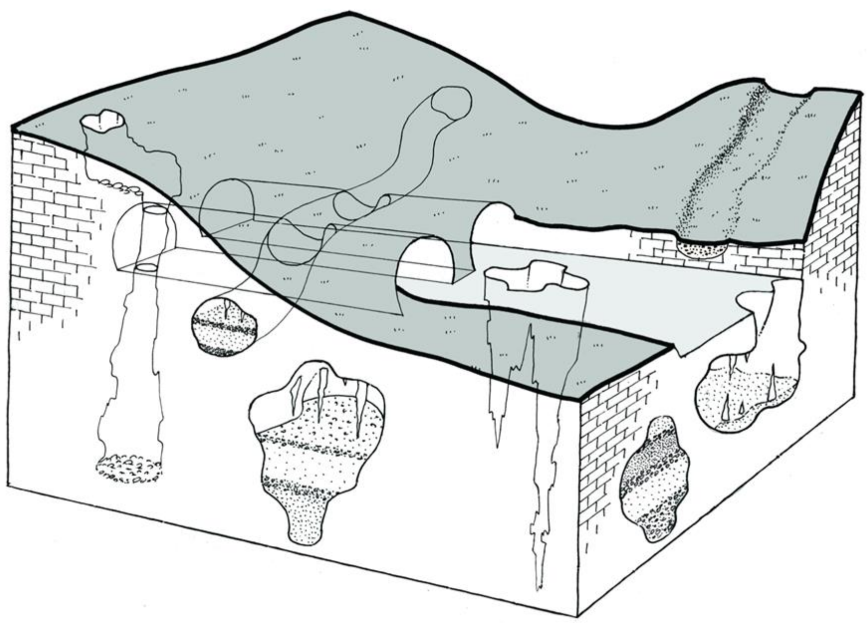
Slika 11: Ground plan directions of cave tunnels with respect to the leading polygon from the Lower Siphon to the entrance to Osapska jama. The number of measurements is stated in the legend. The main directions are marked with arrows. The purple line represents the ground plan of the T2 tunnel in the area of the scaly building at the Karst edge, where partly similar cave tunnels are expected.

Osap caves-like caves can be expected along the Kastel and Socerb thrust faults, but with a generally different direction of tunnels, as here the overflow is replaced by a lateral flow of water on a karstic thrust surface; in this respect, the direction will be closer to the sloping caves and caves along the subvertical cracks that were discovered in / near the Kastelec tunnel. The tunnels will be smaller in size, as the groundwater concentration is lower. At least in the area of the Socerbski thrust fault, there will be cave tunnels according to the established water levels in deep wells in the phreatic zone. Similar to the case of Osapska jama, a part of the cave tunnel at the contact of limestone with the transition layers can also be trapped in the underlying transition layers. Circulations will have to be provided at all major intersections, thus maintaining a predominantly lateral phreatic flow of water along the thrust structure without a marked increase in the gradient.

6.4 Caves in the Kastelec tunnel

The Kastelec tunnel (length 2.2 km) intersected genetically different types of caves, namely smaller caves of meter dimensions (fully filled, partially filled or without sediment), karstic cracks of decimeter widths, vadose abysses and longer phreatic oblique caves, which are usually partially filled with sediment (specially described as S 640, S 647 and S 590). All types of caves opened mainly along the wall (58%), vadose abysses practically only in the ceiling in the form of fireplaces (37%), only in the case of the largest abyss (5%; depth below level 45 m, cross section 3 × 7 m) can we speak of a sensu stricto intersection when the abyss opened both downwards and upwards (fireplace; Fig. 12). Only one cave opened at the front of the excavation, and also one at the bottom (S 640; southern tunnel pipe; Fig. 13A), but only in the final phase of the tunnel deepening. Only after the discovery of the S 640 did it appear that there was an intersection with the abyss / fireplace in the northern tunnel pipe (Fig. 13C), but the connection did not arouse special interest due to the abyss filling in the blasting phase, as / although the abyss was filled in height with 45 m of crushed rock. Construction technology (mining) therefore does not provide a relevant insight into the intersections of tunnel pipes with cave tunnels, as it exposes large caves above average (because crushed rock is difficult to completely cover them; Figure 12) and caves filled with sediments (because they are more stable and preserved until excavation). If the intersection is located in the ground and does not stand out in its size, the probability of detecting a larger tunnel is small. Due to the rupture of the rock, the actual intersections with the sediment-free caves are known only from the forehead of the excavation, which happens very rarely (5% of the discovered caves).

Slika 12: Scheme of typical intersections with larger cave tunnels, as found from the examples in the Kastelec road tunnel



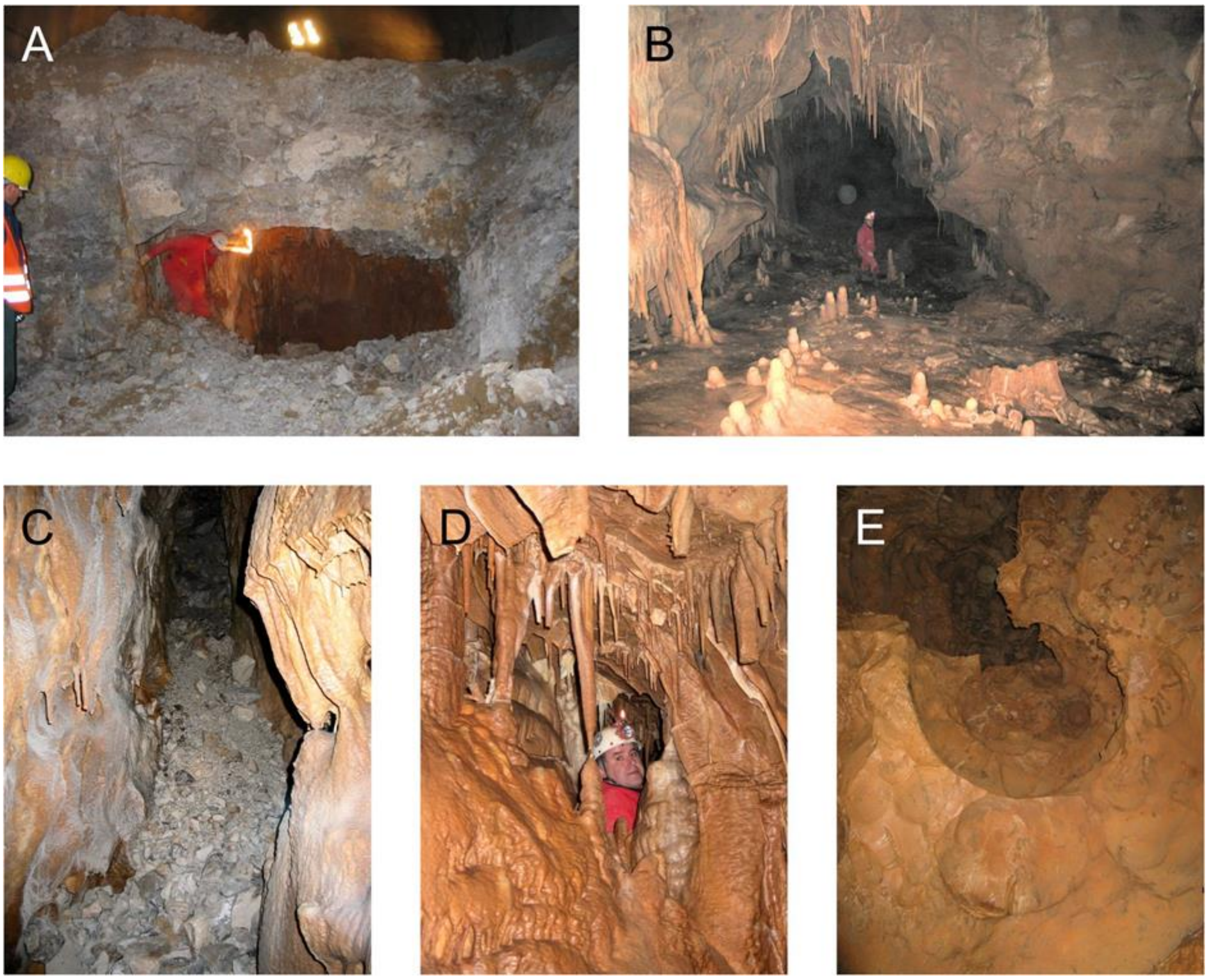


Figure 13: Typical intersections of tunnel pipes with cave tunnels. (A) Intersection of tunnel with cave S640 opened only at the front of the staircase, which is significantly more probable from the point of view of rock collapse than in the excavation phase of the dome (photo: F. Drole). (B) Cross section of a typical oblique pit of large dimensions developed in phreatic conditions along the tongue (photo: J. Hajna). (C) The outflow of crushed rock from the northern tunnel pipe to a depth of 45 m was evident only from the final naturally preserved part of cave S 640, which was more or less accidentally reached through the southern tunnel pipe (Figure 7A; photo: F. Drole) . (D) The dimensionally large S 640 cave is so narrowed in several places due to sediments in it that it does not give the impression of a more important cave (photo: J. Hajna). (E) It is difficult to determine the hydrological environment from a short section of the cave tunnel - the ceiling shapes would indicate epiphreatic conditions if the same cave did not continue into a buried tunnel with crystal sigo, which unequivocally proves a vadose hydrological zone (photo: F. Drole).

The Kastelec tunnel is an analogy to the T2 tunnel both in terms of floor plan and the expected karstification of section K at the station between km 11,900 and km 13,500, as well as in terms of excavation technique. Based on data from the Kastelec tunnel, we find that the intersections of the T2 tunnel with larger cave tunnels will generally cover a few m2, which is significantly less than the found cross section of the Beško-Ocizelj cave system, larger caves in the Kastelec tunnel or Osapska jama. Based on the method of discovering larger caves in the Kastelec tunnel, it is very likely that small intersections will most often pose a problem in the detection of larger caves, although the tunnel will partially intersect them. Complete coverage of a larger cave tunnel with an excavation profile is expected only exceptionally - as a rule, when the cave is (almost) completely filled with sediment. The problem of demolition during blasting can partially reduce pre-drilling, but the latter also has a drawback in the small intersection of the tunnel with the cave channels, insofar as it is carried out on a limited part of the excavation profile. According to data from the Kastelec tunnel, water tunnels will be largely (95%) accessible only in the wall and ceiling of the excavation, while at the bottom they will usually be completely covered with crushed rock and often recognizable only in the form of mud. To make the circulation, the crushed rock in the bottom will need to be removed as much as possible, thus ensuring the actual purpose of the circulation. Determining the hydrological zone (phreatic, epiphreatic, vadose) will be very difficult on the basis of short segments of caves (Figure 13E), and the accuracy of the assessment will be shown only in a longer (estimated several hundred meters) long section of tunnel pipe.

7 KARSTOLOGICAL MONITORING OF CONSTRUCTION OF ACCESS ROADS

Report on newly discovered cave, December 20, 2019.

Sofinancirano s pomočjo Instrumenta za povezovanje Evrope Evropske unije

ZRC SAZU Inštitut za raziskovanje krasa

2TDK Nadzor

Poročilo krasoslovne raziskave novoodkrite jame

Mesto raziskave: dostopna cesta za severni portal T1

Koordinate: Y-418.160,178; X-58.077,487; Z-414,18 (določene s strani geodetov podjetja Kolektor CPG)

Investigation description:

The entrance to the cave (s) was shown under constant surveillance on 20 December 2019. On 24 December 2019, a small unregistered cave in the immediate vicinity with a depth of -2.5 m was explored, which on 20 December 2019 had not yet been visible (the entrance was still under the gravel formed by blasting), and a partially widened entrance to the cave 2TDK-DC-001. On December 27, 2109, the entrance to Cave 2TDK-DC-001 was widened to the extent that it allowed exploration to a final access depth of -8.4 m. At that time, the surveyors of the company Kolektor CPG were also present at the site, who determined the coordinates of the entrance to the cave. On 20 December 2019, Mitja Prelovšek, the head of the access road construction project, Igor Grmek, was informed about the find by telephone, before which the current head of the specific construction site was informed of the discovery on the same day. After the New Year's holidays on 6 January 2020, Martina Stupar, a representative of the Institute of the Republic of Slovenia for Nature Protection of the Nova Gorica Nature Protection, was also informed by telephone about the discovery of the caves.

In the area with a diameter of about 7 m around the pit 2TDK-DC-001, several holes were visible in the ground, among which several were partially or completely filled with gravel formed by blasting. The entrance to one of the caves was 30 cm wide, but at a depth of 2.5 m it ended in gravel, which entered the cave while removing the mined material. All walls were covered with a layer of whitefish up to 15 cm thick. Due to the small depth and backfill, the cave was not registered, and research was focused on a cave named 2TDK-DC-001.

Geologically, this area intersects several parallel fracture structures with a subhorizontal direction of movement. In the fracture structures, cave sediment of probably flysch origin of a fraction of fine sand, silt, clay and small pebbles was observed in several places, which could have been deposited in the crack in situ or moved along the tectonic shift. A sediment sample was taken for further sedimentological and granulometric analyzes. This sediment was not observed in the pit due to corrosion wear and leaching. In several places, up to 15 cm thick whitefish crust could be traced, which could cover the sediment. According to the verticality, the conditionality of the formation on subvertical fracture structures and wall forms, in all cases there are abysses, most likely formed in vadose conditions. The relation of cave formation with sediment of supposed flysch origin is not known.

The otherwise uniform pit 2TDK-DC-001 had three smaller entrances on the surface at a distance of up to 1 m, the widest of which had a width of 20 cm with a visible depth of 2 m. With the stone, it was heard to continue obliquely at least another 2 m deeper into a slightly larger space. After removing the material at the entrance, it was possible to descend to a depth of -8.4 m, where the cave was naturally filled with rock fragments of blocks mostly from a few cm to 1 m; from the outside, only one block measuring up to 30 cm fell to the bottom between the larger pieces. The walls of the 2TDK-DC-001 pit were mostly corroded, there were very few whitefish - to a lesser extent stalactites up to 10 cm in length were present.

During all three inspections, at outdoor temperatures around 5 ° C, there was no draft at the entrance to the 2TDK-DC-001 cave, and there was no draft during the survey of the cave bottom. There was no draft at the other partially blocked entrances.

Schematic drwaing:

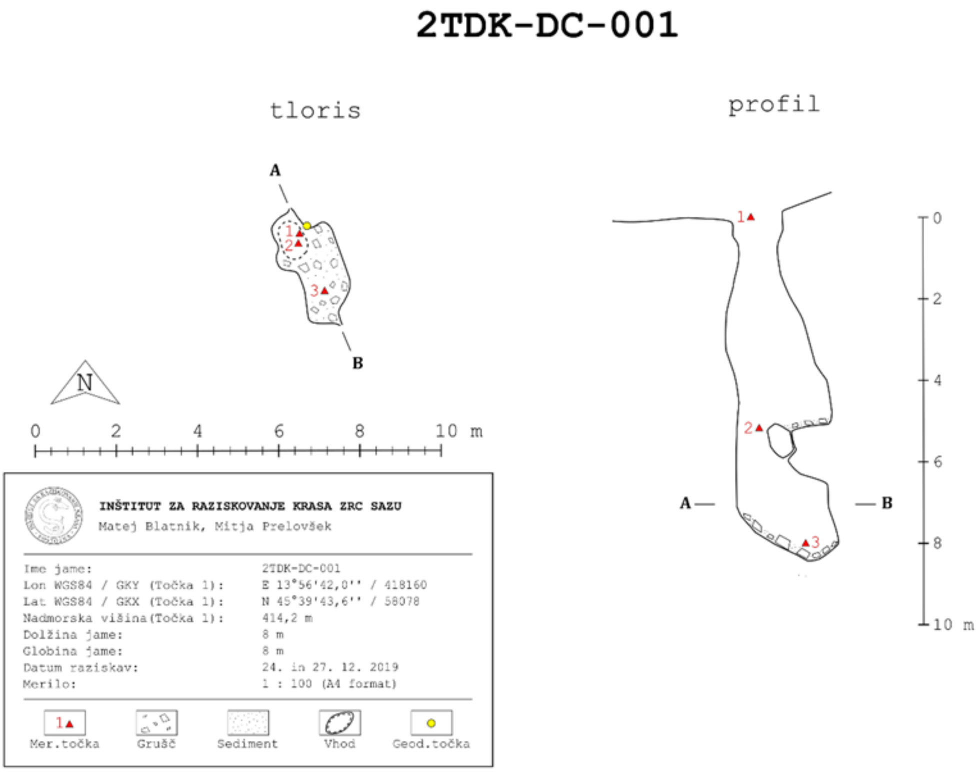


Photo:

Entrance to the cave 2TDK-DC-001 at the beginning of the removal of the demolished part of the rock and before the removal of the collapse blocks just below the entrance (photo: M. Blatnik, IZRK ZRC SAZU).

Situation of the entrance to the cave 2TDK-DC-001 after the removal of the rock just below the entrance during the exploration of the bottom of the cave; view to the northeast (photo: M. Prelovšek, IZRK ZRC SAZU). More photos can be found in the folders.