The Flow Conditions in the Epikarst Zone of a Karst Aquifer. Case Study: Suva planina Mt., East Serbia

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UNESCO Chair on Karst Education
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Painting depicting the mountainous area of Custonaci with Monte Cofano in evidence, created by Samvel M. Shahinyan during his participation in Man and Karst 2022.

Back cover:
Glimpse of the coastal plain of Custonaci with the Grotta Mangiapane on the right side and Mount Cofano in the background.

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Abstract:

The epikarst as a part of the karst aquifer represents a complex point of contact and mixing of unconsolidated material from the terrain surface, carbonate rocks altered by "corrosive" water, flora and fauna (and remains of), which is partially saturated with groundwater. Significant amounts of (plant accessible) water, and other solutes and particles, can be stored in this zone for extended periods of time. Thus, attenuation or biochemical processes could start in this layer and change quality of infiltrated water. However, due to flow concentration in the epikarst, water and contaminants, as well as different types of organic and inorganic particles and colloids, can also be detached and transported downward to the active conduit network of aquifer. The nearly horizontal cave named Peč is developed in Upper Jurassic (Tithonian) limestone of Suva Planina Mt. The study of the epikarst in this area consisted of two elements: a short-term (transient) tracer experiment (artificial tracer) and a short-term experiment with "light" contaminant – manure ("natural" tracers). Tracer experiment had a twofold goal: characterizing the flow conditions in the epikarst and studying solute transport. The virtual velocity of the circulating water through the layer of epikarst and karstified limestone, was calculated: 0.0041 m/s to 0.006 m/s. Breakthrough curves of the dye tracer showed existence of three types of fissures/fractures differing in their hydrogeological function resulting mainly from the aperture width, and it is based on the different types of water flow occurring in the unsaturated (epikarst) zone: 1) large fracture – drains; 2) medium fracture; 3) small fissures.

Keywords: *epikarst, tracer test, shallow cave, Suva Planina Mt., Serbia.*

Introduction

The term epikarst, since its appearance until today, has attracted a lot of attention, and sometimes very opposing views of researchers. Numerous studies in which the authors consider the existence, influence and functions of the epikarst encounter conflicting opinions and the fact is that the scientific community has not yet fully agreed on the function of this "phenomenon" and the zone in the karst that this term defines (Petrović, 2020b). Epikarst represents the highest part of the limestone rock mass that is exposed to karstification, i.e. a layer of partially altered rock that has not yet become soil, and in which water permeability (due to fissures) and diffuse water circulation is significantly higher and more evenly distributed in space (vertically and horizontally) compared to the rest of the karstified rock mass (Klimchouk, 2000). The epikarst as a part of the karst relief (and aquifer) represents a complex point of contact and mixing of unconsolidated material from the terrain surface, carbonate rocks altered by "corrosive" water, flora and fauna (and remains of), which is partially saturated with groundwater. Recharge of karst aquifers, usually, occurs via the unsaturated zone which uppermost part could be epikarst zone. However, in most of the cases the functioning of this zone has not yet been clarified. Significant amounts of (plant accessible) water, and other solutes and particles, can be stored in this zone for extended periods of time. Thus, attenuation or biochemical processes could start in this layer and change quality of infiltrated water. However, due to flow concentration in the epikarst, water and contaminants, as well as different types of organic and inorganic particles and colloids, can also be detached and transported downward to the active conduit network of aquifer. Therefore, a tracer experiment, along with monitoring of rainfall (snowmelt) events, was used to examine circulation of solutes between the land surface and water outlets (drops and trickles) into a shallow Peč cave in the eastern part of Suva Planina Mt., in the South-eastern Serbia (Fig. 1). Mesozoic karst outcrops of Eastern Serbia cover an area of approximately 3,350 km^2 (Stevanović 1994), while Suva Planina Mt. karst area covers about 7.5% of that surface (Stevanović 1995). Suva Planina Mt. is located approximately 230 km SE from Belgrade. Studied epikarst and karst aquifer system are formed on the north-eastern slopes of the mountain that is actually part of the Carpatho-Balkanides orogenic belt and mountain chain. The research area has a moderate-continental climate with characteristically long and cold winters and relatively warm summers. Part of the area at altitudes above 800 m has the characteristics of a mountain climate.

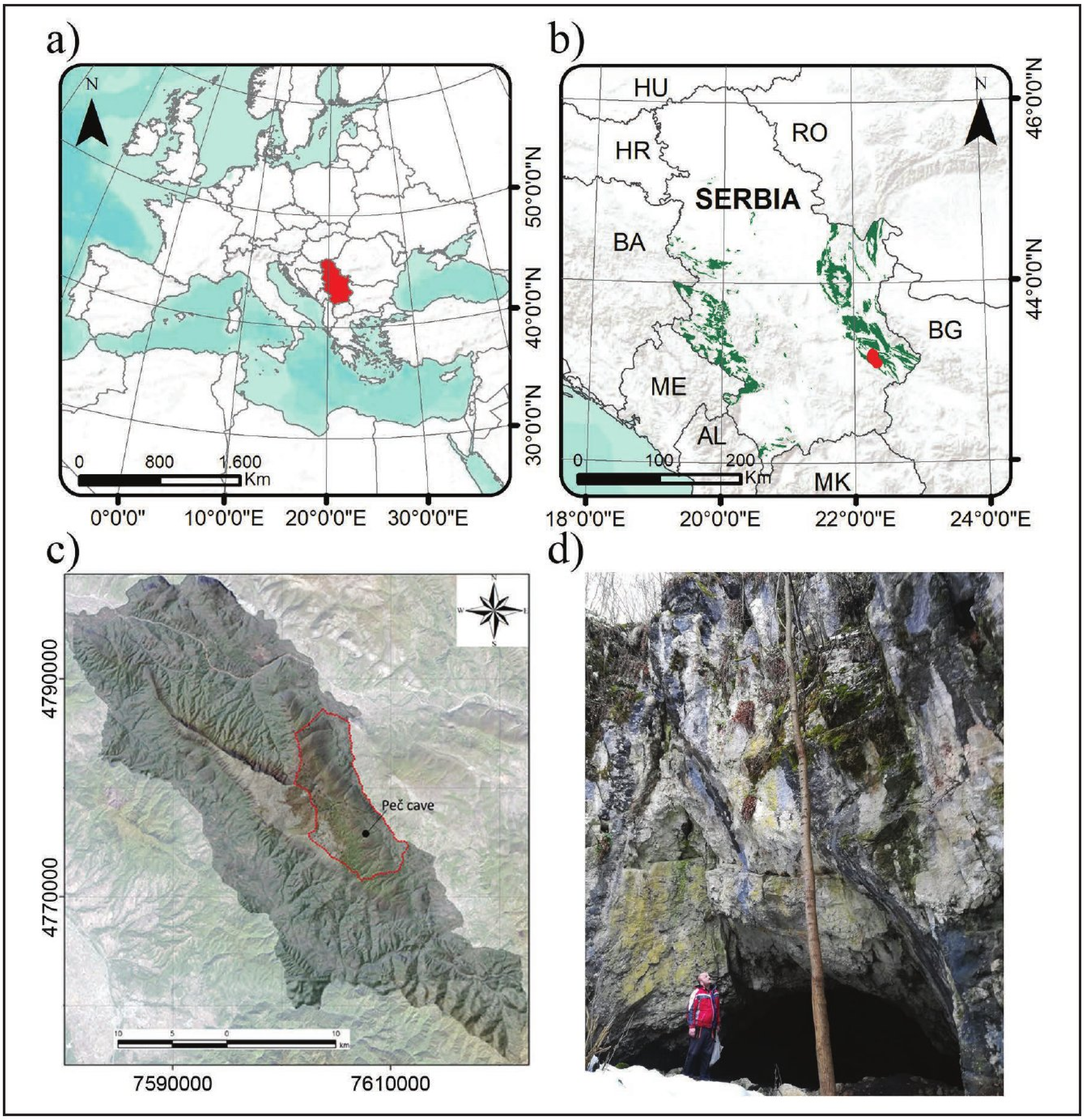

Fig. 1 a) Position of Serbia in Europe b) Location of Suva Planina Mt. in SE Serbia – red coloured area, karst areas of Serbia are in green colour, c) Suva Planina Mt. with position of Peč cave, d) entrance to Peč cave

Suva Planina Mt. is asymmetrical, normal anticline and its geological setting is very complex due to multiple thrusting and faulting that occurred during the Caledonian Orogeny, the Hercynian orogeny and finally the Alpine orogeny (Dimitrijević et al, 1980). It is actually in the form of SE plunging anticline. The process of erosion in the ascended NW part of the anticline caused destruction of limbs of anticline, that are created of Mesozoic limestone and dolomite, to the core of anticline which is mainly made up of Devonian and Permian clastic rocks (Petrović & Marinović 2022; Marinović & Petrović, 2021; Petrović 2020a; 2020b). The regional NW-SE dislocations shaped relief while local faults that are transversal caused the enhancement of the karstification process in the limestone and dolomite. Several karst aquifers have been created in faulted, fissured and karstified carbonate rocks of the Middle and Upper Jurassic and Lower Cretaceous age. The karstification of a landscape resulted in a variety of mid- or small-scale features both on the surface and beneath. On exposed surfaces all over the mountain, small features are developed and include solution flutes, runnels, some limestone pavement (clints and grikes), kamenitzas. Medium-sized features includes sinkholes/dolines while there are several caves and jamas, particularly on the western and northern slopes of the mountain, that are steeper than the one on the east and south side (Petrović 2020b). It needs to be said that mountain is covered, but unevenly, with forest vegetation (east and south part) and pastures and meadows (middle and west part). Surprisingly, one of fewer known caves is developed on the east slope. The nearly horizontal cave named Peč is developed in Upper Jurassic (Tithonian) limestone (Fig. 1c and 1d), beneath soil-mantled convex hillslope with thickets of beech and hornbeam. About 0.1 to 0.3 m of

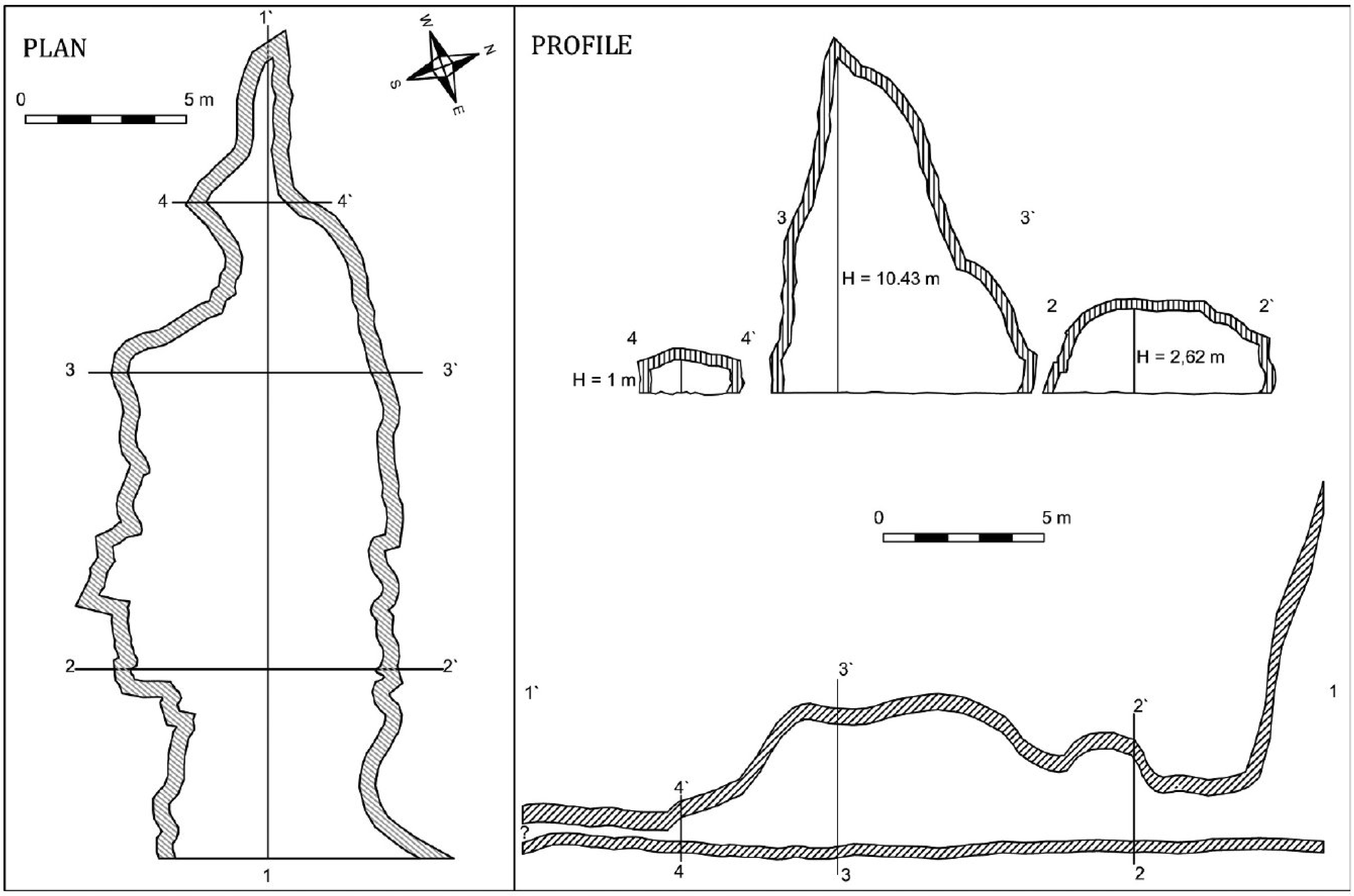

Fig. 2 Plan and cross-section of Peč cave, in the eastern slope of Suva Planina Mt.

soil and 3.5-12 m of karstified limestone (plus epikarst) overlie the 20.5 m long cave, with smaller and inaccessible 4.5 m long sub-horizontal channel in the end (Fig. 2).

Methods

The study of the epikarst (Peč cave) consisted of two main elements: a short-term (transient) tracer experiment (artificial tracer) (Fig. 3a) and a short-term experiment with "light" contaminant – manure ("natural" tracers). This paper will be focused on the artificial tracer (Uranine) experiment and its results. Several outlets from fractures at the cave roof, where water in form of drops and trickles appears were monitored and sampled (Fig. 3a and 3b). To study the response of the unsaturated zone to natural rainfall (snowmelt) events, discharge, temperature and electrical conductivity (EC) were monitored as well. Discharge was measured by collecting water from fractures in plastic pots and its summation in the selected periods of time. Temperature and EC were monitored using a conductivity probe (WTW -Cond 340i/set).

Containers for water sampling were placed at the locations where traces of dripping water were observed, inside the Peč cave on 16th February 2019. Locations for collecting of percolated water were marked with letters of the alphabet from A to M (Fig. 3a and 3b). The location closest to the entrance is location A and the location where traces of dripping water were visible and which was the farthest from the entrance of the Peč cave, is location L. Sampling of percolated water have been started few hours before pouring of tracer (Fig 3c) on the selected location - LPT on Fig. 3a, and continued with containers on 10 locations, in appropriate time periods for next 6 days (Fig 3d). Tracer experiment had a twofold goal: characterizing the flow conditions in the epikarst and studying solute transport. A quantity of 10 litre solution of 50 g of Uranine - Sodium flourescein was poured on the surface above cave - LPT, with pouring of additional 80 l of water (Petrović, 2020b). Samples were compared to previously prepared standards by using of field UV illumination set, intending to confirm presence of tracer. Afterward, all collected samples were transported and analysed in the laboratory with fluorometer: 10AU Field and Laboratory Fluorometer by Turner Design, and precise concentration of tracer were obtained.

During the monitoring, a constant decrease in the amount of percolated water was observed, so that at locations A, B, G and M, only occasional sampling of water was possible for Na-fluorescein concentration analyse, and at locations E, J and K, it was not possible to measure the specific electrical conductivity and water temperature in several time intervals. On the last day of the experiment, 23rd February 2019, the amount of water dropped drastically in all locations. Thus, the experiment had to be finished.

Results

Collecting of dripping water started a day before the tracing test itself. The tracer only needed 1 hour (probably less) to reach almost all parts of the cave (Fig. 4 and 5), because the tracer was poured at 1:00 PM on 18th February, and the first samples taken at 2:00 PM, already had significant concentration of Uranine. The tracer was de-

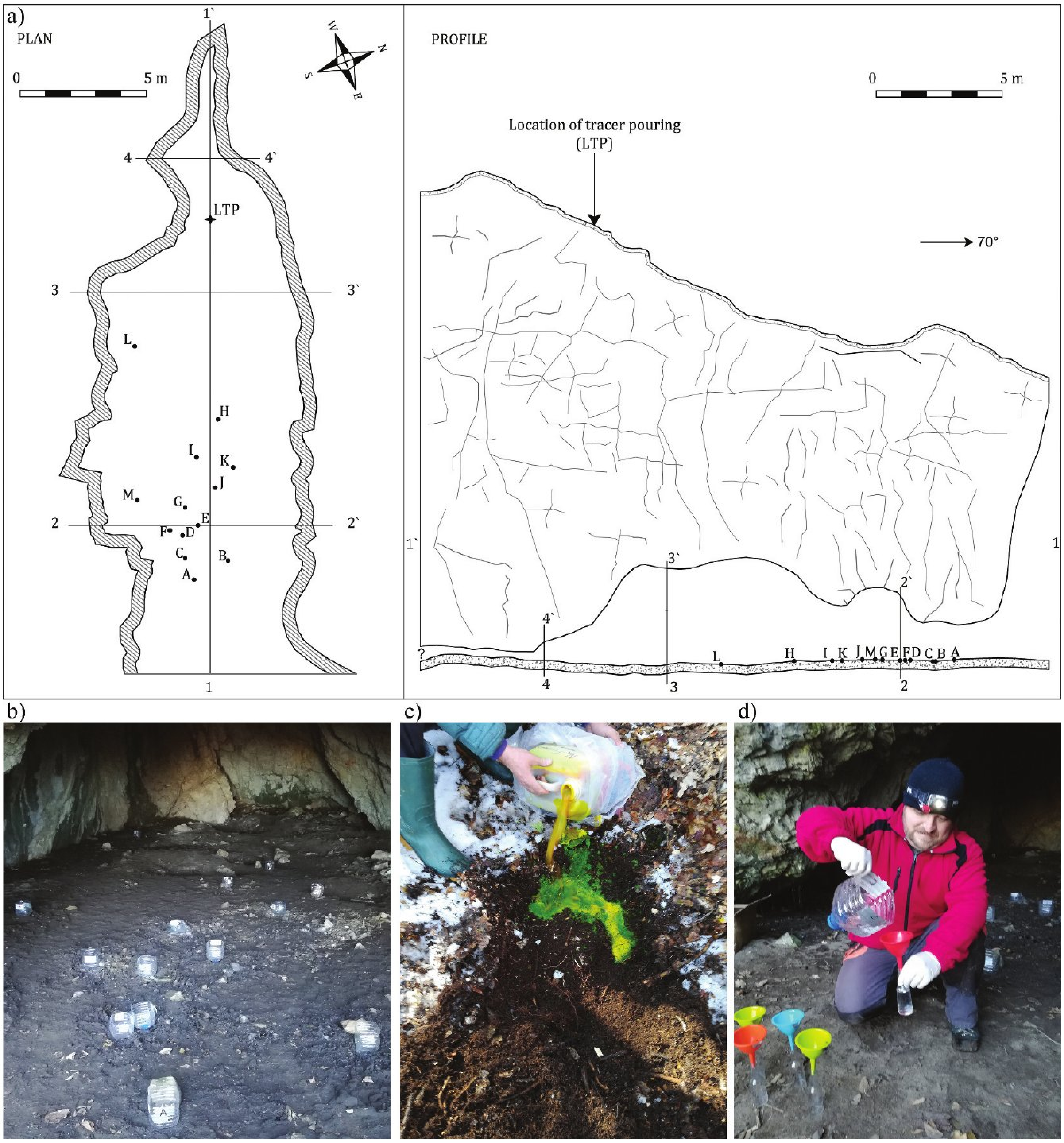

Fig. 3 *a) The LTP with locations of containers for collecting of dripping water; b) Containers on locations within cave; c) Pouring of Uranine; d) Collecting of samples*

tected in samples from locations: A, C, D, F, H, I and L, in certain concentrations, while at locations B, G and M it was not detected in any sample.

It is possible to separate three groups of locations according to the position in the cave and according to the amount of water that was dripping: the first group H, I and L; second group C, D and F; third group A, B, G and M.

At the locations of the 1st group: H, I, L, the tracer appeared in the first sample taken after pouring of tracer (Fig. 4 and 5), and the highest concentration was at location H (0.13 μg/l). The highest concentration of tracer - 0.17 μg/l, in general, during monitoring was recorded at location H at 4:00 PM on February 18, 2019, after which lower concentrations were recorded at that location until 9:00 AM on February 19, 2019 and since that moment Na-fluorescein has not been detected (Fig. 4 and 5). It is observed that the tracer at location I appears in three waves (no tracer was detected in certain samples - Fig. 4 and 5), while the peak in the second wave (0.09 μg/l) is higher than in the first wave at that location (0.08 μg/l l), and in the third wave the peak (0.14 μg/l) is even higher than in the second wave.

The last sample with dye tracer, in other locations where the tracer appeared at some point, was detected 21 hours after the tracer was poured.

The breakthrough curve at location H indicates that the groundwater to this location circulated through a dispersed system of cracks and caverns (Milanović P, 1979), the intensity curve from location I has similar characteristics, only the concentrations from wave to wave of dye tracer

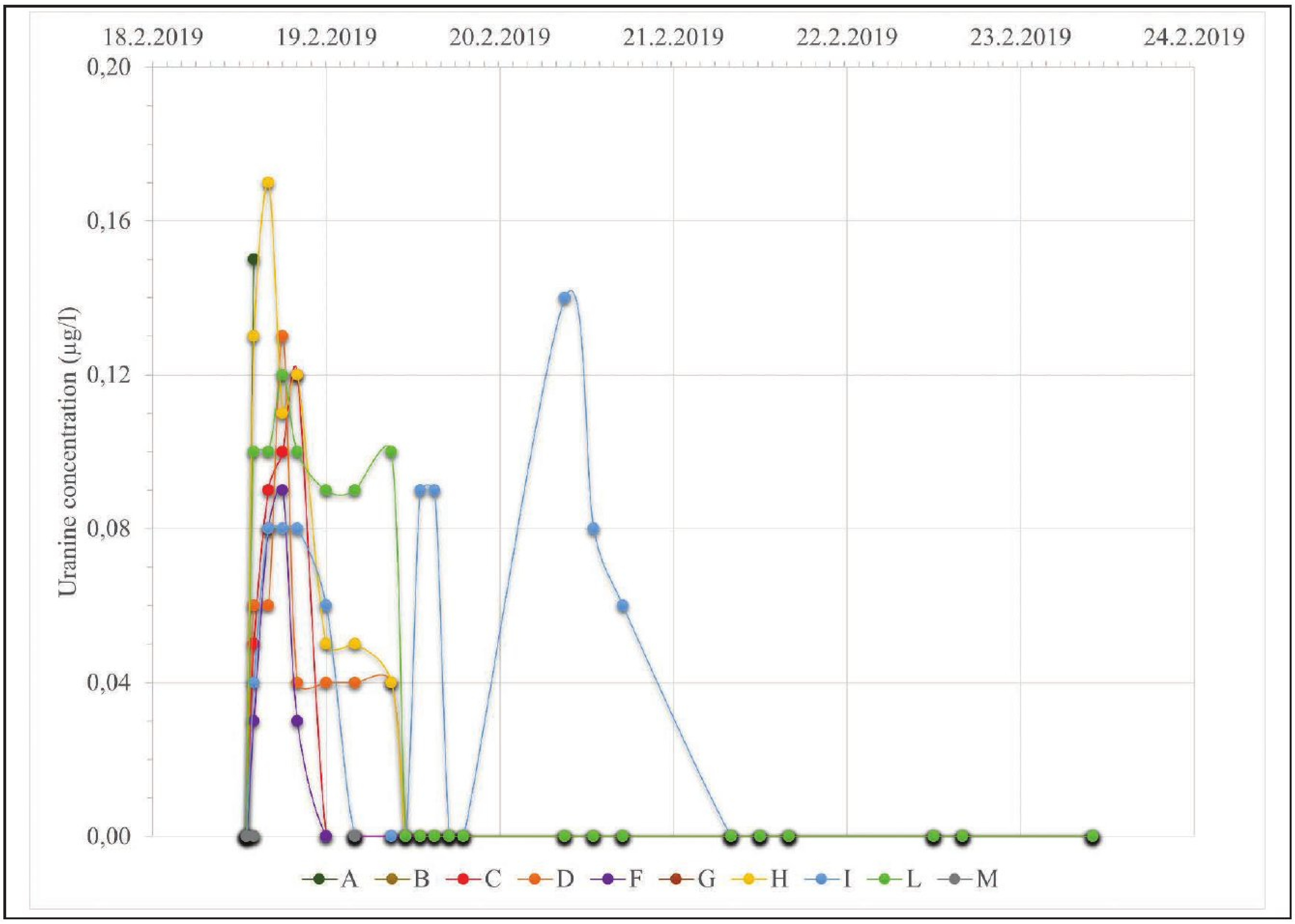

Fig. 4 *The breakthrough curves at monitoring locations*

appearance are higher, so it can be assumed that it is a consequence of flow through cavities with a higher gradient. The tracer intensity curve at location L shows a more extended wave, without a sufficiently pronounced maximum (although there is one peak), which indicates a slower flow of water towards that location, or the caverns are of smaller dimensions than those leading to location H.

The tracer was detected at the locations of groups: C, D and F (closer to the cave entrance) at the same time in the first sample after pouring the dissolved tracer, and the highest concentration was at location D (Fig. 4 and 5). At locations C and F, Na-fluorescein was no longer detected in any sample after 2/18/2019 at 8 PM, while at location D it was present in the samples until February 19, 2019 at 9 AM (Fig. 4 and 5).

The breakthrough curve of the tracer at location C indicates a wave where the concentration in each subsequent sample increases and after a pronounced maximum drops sharply (Milanović P, 1979), the breakthrough curve for location D has similar characteristics, only the drop in the concentration of the tracer is not sudden, so it can be assumed that this is a consequence of the flow through cavities of a smaller diameter than those through which the groundwater reached location C, considering that the distance from location C to location D is only 0.9 meters. The tracer intensity curve at location F has exactly the same characteristics as at location C, only the concentrations are lower, which means that the groundwater towards that location also passed through smaller caverns.

In the third group of locations: A, B, G, M, in which the least water was collected in containers, and therefore the number of samples was the smallest (Fig. 4 and 5), the tracer was detected only at location A, in the first sample, which was taken after pouring the tracer, in a concentration of 0.15 μg/l.

The fact is that the tracer travelled a straight-line distance of 17 meters in no more than 1 hour, to the point of percolation, on the ceiling above location H (where the highest concentration was recorded), and that it was also detected at location A (straight-line distance of 22 meters) and at location L (15 meters) in the same series of samples. The virtual velocity, calculated based on those data, of the circulating water through the layer of epikarst and karstified limestone, was 0.0041 m/s to 0.006 m/s.

In addition to the qualitative analysis mentioned above, a quantitative analysis of the tracing test was also performed (Milanović P, 1979), on the basis of which it was concluded that about 4% of the dye tracer flew out during the tracer test. The reason for such a small yield of dye tracer can be found in the partial adsorption of the tracer on soil particles (*terra rosa* or clay minerals) that exist in the epikarst and that are suspended in water (Milanović P, 1981) and of course due to branching of the network of channels, which have a siphonal character in certain parts, so when the tracer gets into that channel, it cannot continue moving until there is an infiltration of a larger amount of water from the surface and an increase in pressure. However, amount of percolating groundwater, as it was mentioned, has been reducing during the monitoring of tracer test in Peč cave. On the other hand, there are a lot of fissures and channels that led groundwater away from cave.

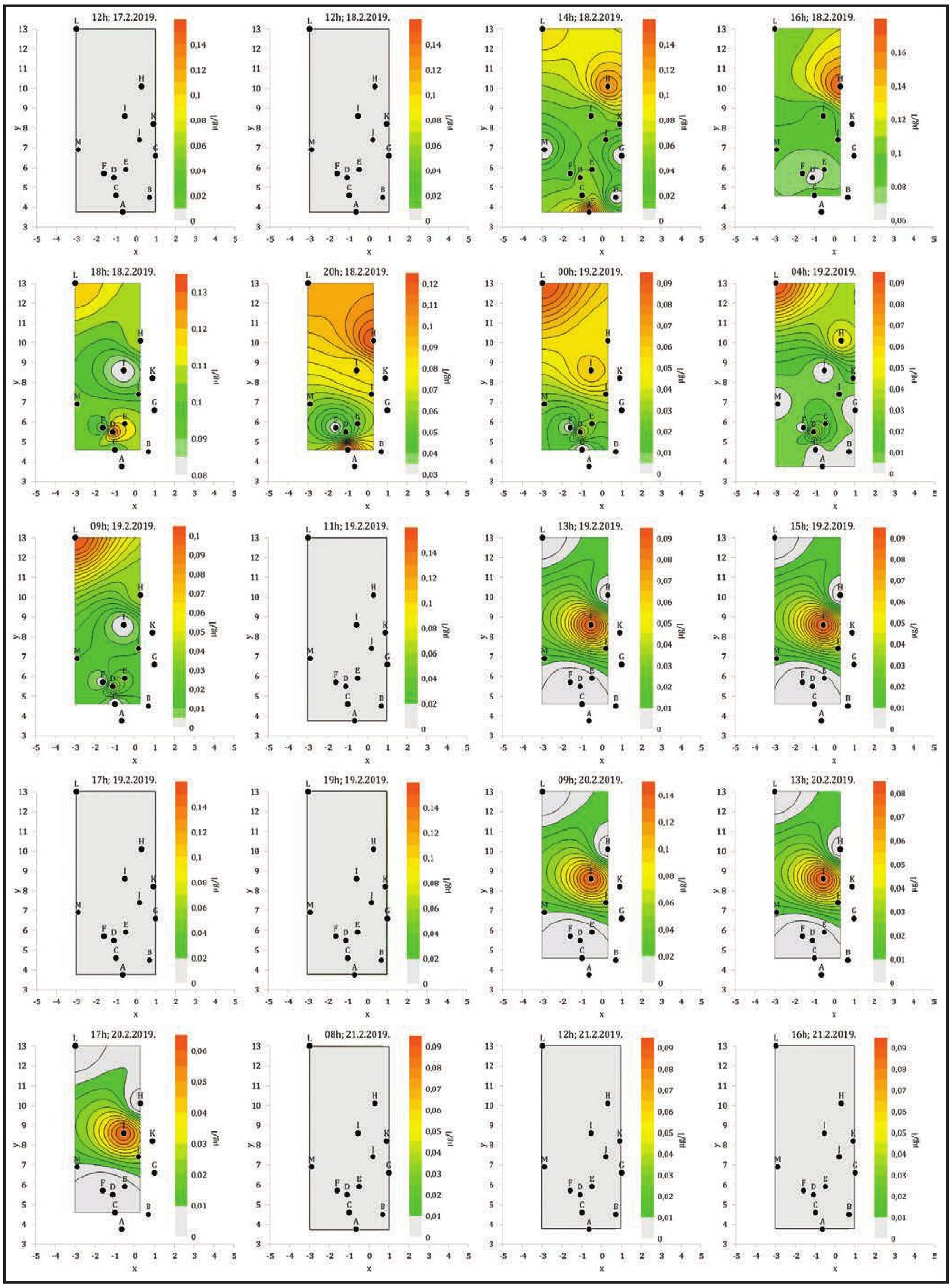

Fig. 5 Concentrations of Uranine at monitoring locations, during tracer test 18.2.2019-21.2.2019

Maps that show the change in concentration of dye tracer over time and within the space of the Pecs cave at locations A to M (Fig. 5) were made. The coordinates of the locations are shown in the local reference system in relation to the entrance to the Peč cave. Coordinates (0, 0) were assigned to entrance location for these purposes. Maps are shown for all sampling time sections until February 21, 2019 at 6 PM, the end of the monitoring.

Conclusions

The breakthrough curves of the dye tracer showed existence of three types of fissures/fractures differing in their hydrogeological function resulting mainly from fissures and channels width, and it is based on the different types of groundwater flow occurring in the unsaturated (epikarst) zone (Fig. 6): 1) large fracture – drains; 2) medium fracture; 3) small fissures. Furthermore, the result of the dye tracing experiment at Peč cave, showed that the epikarst behaves like a semipermeable membrane, which retains some water and substance, but then releases it in the next "moment". "The moment of detachment" can be immediately after arrival of the next wave of infiltrated water that is to say few hours or few days later.

The distance that the groundwater crossing from LTP to the point of percolation on the ceiling of the cave, affects the time that the water spends underground, but the permeability and size of the cavities (Fig. 6, channels (1) and (2)) through which groundwater circulates are the primary factor in this case. Finally, it should be noted that there are probably channels through which the ground-

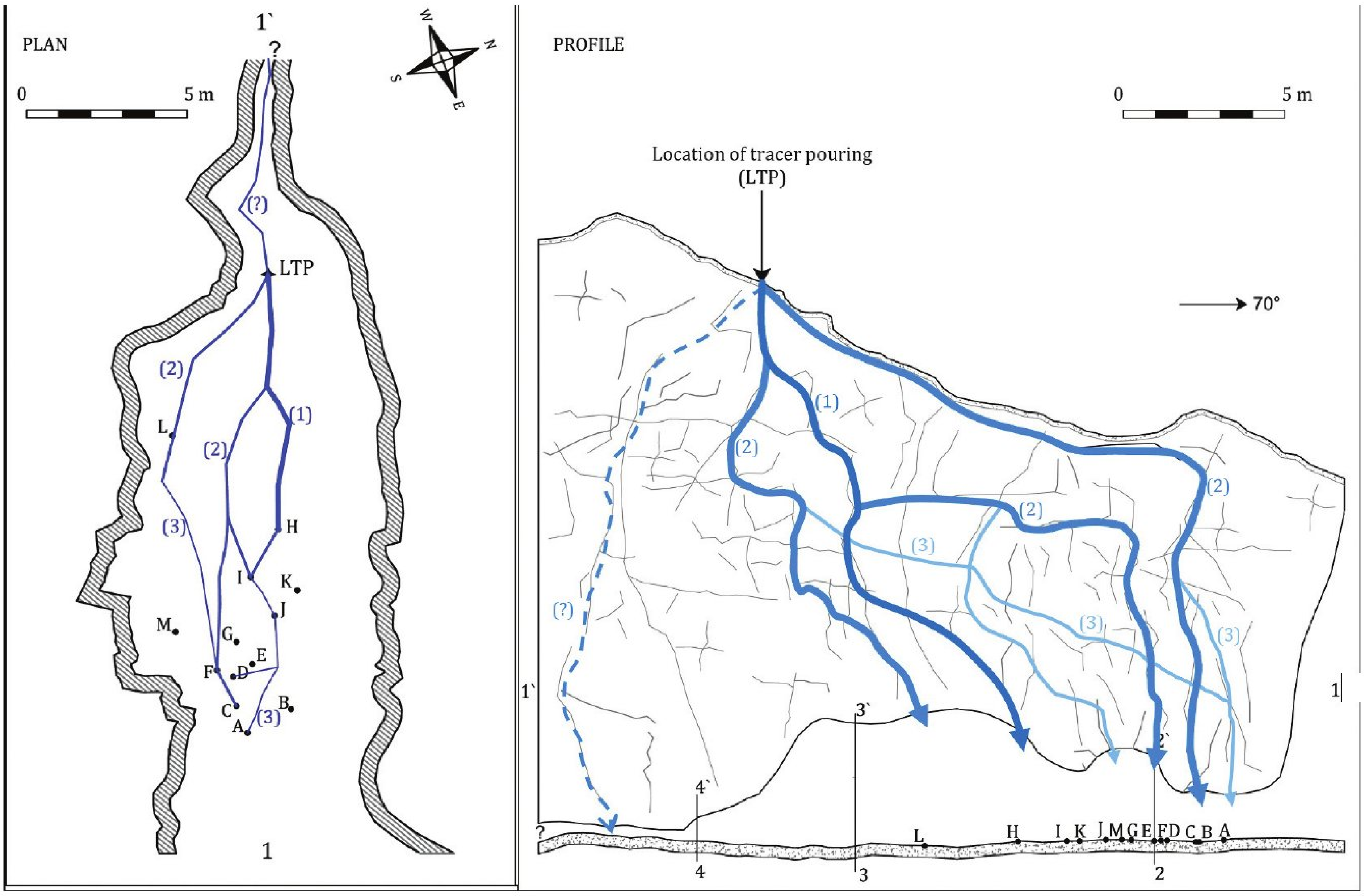

Fig. 5 Three types of fissures/fractures differing in their hydrogeological function based on the different types of groundwater flow

water flows towards the deeper parts of the cave (fissures/channels marked with (?), in Fig. 6), whose appearance in the form of drip water could not be tracked and measured due to the small dimensions of the channel that exists on at the end of the Peč cave.

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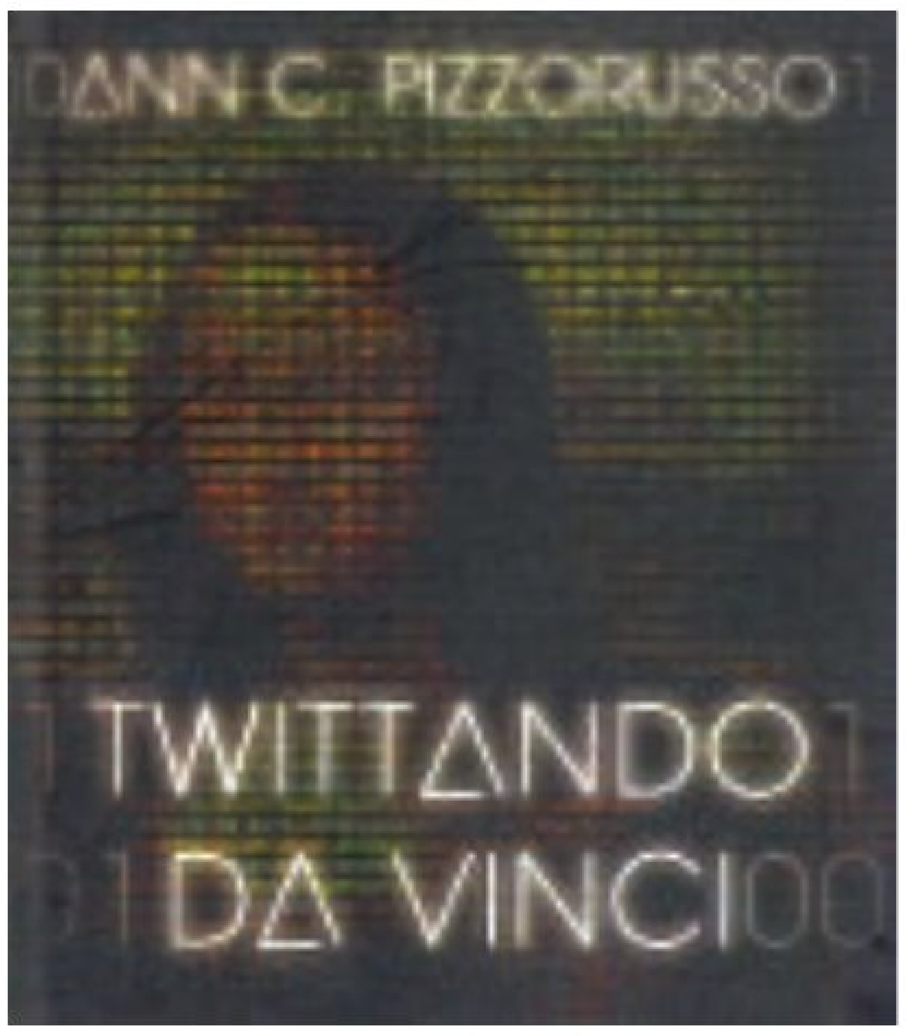

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