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Engineering-geological, geotechnical and hydrogeological parameters of the Soroška tunnel rock sequences

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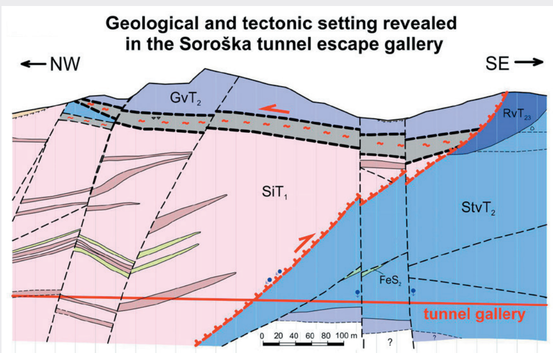
Abstract: The detailed stage of engineering-geological and hydrogeological survey for the motorway R2 Rožňava – Jablonov nad Turňou assessed engineering-geological, geotechnical and hydrogeological conditions along the Soroška tunnel route. The roles of the geological survey consisted of the verification of geology, partitioning and characteristics of the rock massif. The tunnel tubes were divided into quasihomogeneous blocks, carried out together with categorization of the rock mass in the RMR (Rock Mass Rating) and QTS (Classification of rock and semi-rock formations for underground constructions) classification systems.

Geological survey has contributed to the geological knowledge by the finding that the Szin Beds manifest metamorphic overprint typical for Turnaicum, as well as strong tectonic overprint. Over the Szin Beds in the length 1.725-2.3 km of the tunnel route (from the western portal) the bed of Gutenstein limestones/dolomites of Silicicum was north-vergently tectonically displaced. Moreover, the Szin Beds along the Soroška tunnel route are tectonically reduced along an E-W to ESE-WNW trending fault zone with steep dip to N, displacing the Szin Beds with Gutenstein limestones/dolomites in their tectonic overlier on the Steinalm and Wetterstein limestone massif, as well as smaller body of Reifling/pseudoreifling limestones, all belonging to Silicicum.

Results of communication tracking tests showed common direction of the groundwater currents in karstic-fissure environment towards the Eveteš groundwater source and the Hrušovská jaskyňa cave at the Hrušov village, as well as connections of the tunnel section with the springs in the Krásnohorska Dlhá Lúka area.

Key words: Soroška tunnel, engineering-geological survey, RMR - Rock Mass Rating, communication tracking test, hydrogeological structure, Slovak karst.

Graphical abstract



Highlights

- The Szin Beds along the tunnel route manifest metamorphic overprint typical for Turnaicum
- The Gutenstein limestones/dolomites of Silicicum are displaced north-vergently over the Szin Beds belonging probably to Turnaicum
- The Szin Beds with the Gutenstein limestones/dolomites in tectonic overlier are tectonically reduced along a E-W to ESE-WNW trending overthrust zone with steep dip to N, displacing both sequences over the Steinalm and Wetterstein limestone massif of Silicicum

Introduction

The Soroška tunnel is a part of 14.1 km long motorway R2 Rožňava-Jablonov nad Turňou. Based on STN 737507 norm, the tunnel is designed to belong to 2T-8.0 category with temporary two-way traffic, using northern tunnel tube (NTT). As a part of the project design there are two tunnel tubes marked as the Soroška tunnel (northern tunnel tube; NTT) and an escape gallery (southern tunnel tube; STT). The total length of the Soroška tunnel (the northern tunnel tube) is 4264.3 m, tunnel section is of 0.5287–4.793 km. Based on the terrain evaluation the Soroška tunnel was designed as declining from the western towards the eastern side of the tunnel mouth into the valley of the Turňa stream with longitudinal tilt of 1.7 % along its profile and the thickness of the roof rock up to 282.00 m. The Soroška tunnel which is parallel to the Jablonov railway tunnel has an elevation approximately 50 m lower than the Jablonov tunnel.

The Soroška tunnel geology and tectonics; general overview

The Soroška tunnel passes through the territory, which geomorphologically belongs to the Inner Western Carpathian Subprovince, the Slovak Ore Mountains area and the Slovak Karst unit with subunits of the Silica Plain and the Horný vrch Plain. Geological-tectonic structure of the rock massif is complicated, manifesting a distinctive karstification. The Slovak Karst has a typical karst relief with flat plains divided by deep gorges with hollows, lapies, abysses and caves. The rock environment of the tunnel consists of Early-Middle Triassic rocks of the Silica and Horný vrch Plain of the Silica Nappe and of Quaternary deluvial-proluvial sediments.

Engineering-geological, geotechnical and hydrogeological conditions of the tunnel area were investigated by horizontal and vertical wire-line boreholes of a total length 5519.2 m.

During engineering-geological investigation of the tunnel area the Quaternary deluvial and proluvial complexes of the western and eastern tunnel mouth as well as the Early-Middle Triassic complex of the Silica Nappe were evaluated (cf. Kozur & Mock, 1973a, b; Mello et al., 1996).

The oldest dated rocks, present in the explored area belong to the Bódvaszilas Beds (cf. Kovács et al., 1989), formed of the differently weathered variegated argillaceous schists and fine-grained sandstones.

The Szin Beds, developed in the overlier of the Bódvaszilas Beds (l.c.), are formed of alternating laminae and interbeds of argillaceous schists, fine-grained calcareous sandstones, marlstones and calcareous marlstones.

The Middle Triassic carbonate platform facies are formed of the dark-grey well-bedded and tabular limestones, dolomites, breccias and rauchwackes of the Gutenstein Formation.

The beds of light-coloured massive organogenic Steinalm and Wetterstein limestones, sometimes with karst breccia, are developed in the overlier of the Gutenstein Formation (cf. Schréter, 1935; Balogh, 1940; Pia, 1940; Bystrický, 1964).

Both, geological and tectonic setting in the investigated area are very complex. The most distinct fault-systems in the tunnel area are those of NE-SW and E-W as well as ESE-WNW direction dipping to the NW and N, fault-systems of NW-SE direction dipping to the NE and fault-systems of N-S direction dipping to the W and also to the E (Fig. 1). The direction of the tracer currents carried away by the groundwater currents from the exploration borings towards the Eveteš groundwater source and springs in the Krásnohorska Dlha Lúka locality, present along the tunnel route, was caused by the NW-SE and E-W as well as ESE-WNW trending faults. Faults with general trend NNW-SSE and NW-SE are present in the Hrušovská jaskyňa cave (Vlček, 2008).

Another important type of faults present are the dominant left-lateral (sinistral) or right-lateral (dextral) faults of NW-SE direction. Also faults trending NE-SW are present. The overthrust zone along which the Lower Triassic - Werfenian rocks (Szin Beds) were shifted over the Middle Triassic limestone massif shows predominant tectonic structures (faults) of NE-SW direction dipping to the NW, based on obtained data from the oriented core in 2.1-2.2 km of the northern tunnel tube in interval 160-190 m (Fig. 3c).

Geological setting along the Soroška tunnel route

Based on the Soroška tunnel geology, represented by the Quaternary sediments and Lower-Middle Triassic rocks, several types of rock sequences were selected in relation to engineering-geological and geotechnical investigation. Fig. 6. shows longitudinal engineering-geological profile along the southern tunnel tube.

<u>Quaternary</u>

Deluvial complex was revealed in all boreholes drilled in the area of western and eastern portal of the Soroška tunnel. Deluvial sediments are represented by clay and silt of various degree of plasticity and consistency, rock-clay and clay-rock debris, sliding deluvia, formed of clay, debris and completely or highly weathered Triassic rocks. Sediments overlaying limestone massif are formed mostly of silt and gravelly debris in the bed thick up to 2 m.

<u>Mesozoic sequences</u>

The **Bódvaszilas Beds** (Griesbachian-Nammalian) occur within 4.525-4.725 km of the Soroška tunnel route. They are represented by variegated shales and fine-grained sandstones of different weathering grades. Their strength degree is medium strong (R3) in unweathered and slightly weathered shales and very strong to strong in sandstones (R1-R2). The measured planar structures in outcrops have demonstrated the general dip 50-60° of these beds towards the north.

The **Szin Beds** (Nammalian-Spathian) are present in the overlier of the Bódvaszilas Beds in segments of 0.5-1.725 km and 4.2-4.525 km (counting from the western portal; Fig. 1) within the Soroška tunnel route. The Szin Beds are built of shales, fine-grained calcareous sandstones, marlites and marly limestones. Petrographic analyses have revealed their low-grade metamorphic overprint (typical for the Turnaicum). The marlite beds were locally classified as slates (Soták in Grenčíková et

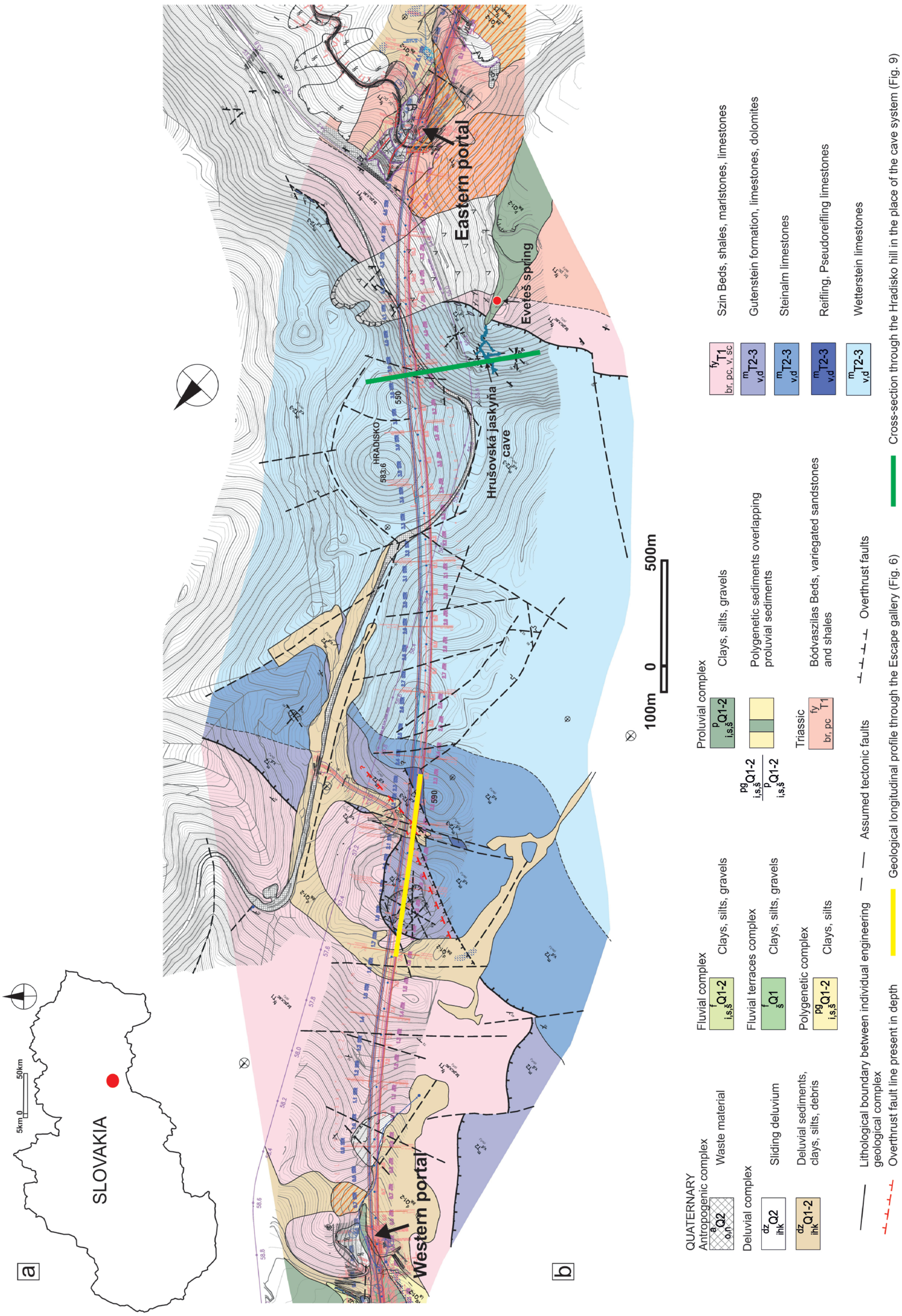


Fig. 1. Engineering-geological map along the Soroška tunnel route (Szabó in Grenčíková et al., 2018).

al., 2018). The planar structures in outcrops as well as in boreholes in the Szin Beds indicate their prevailing southern dip 40-50° (0.5-1.7 km), as well as northern dip 45-70° (4.2-4.525 km). The detail tectonic research of rocks in the segment 0.5-1.1 km along the route has revealed the rock distinctive folding, brecciation and reverse fault structures (Fig. 2).

Carbonate laminae in Szin Beds are in some places overfolded in the centimetre-scale and form systems of disharmonic, isoclinal, or ptygmatic folds, being penetrated and reduced by steep dip-slip discontinuities. Also boudinage was revealed in some thin carbonatic beds, occurring in the plastic environment of marlites. Generally, the Szin Beds are penetrated also by faults, oriented correspondingly with bedding and being filled by tectonic breccia.

In addition to above described deformations also steep planar structures were discovered in boreholes using geophysical methods, as well as when penetrating the crushed rock and rock debris by boreholes. The steep planar structures are trending mostly perpendicularly to the tunnel tube. Towards the Soroška saddle (length interval 1.1-1.7 km; in the Lipovnik quarry surrounding), the Szin Beds are massive and slightly faulted. In this interval also ductilely deformed beds of dark calcareous claystone occur. Their boudins consist of carbonate tectonoclasts, positioned correspondingly with bedding.

In a distance of 2.1 km from the Soroška tunnel western portal, the Szin Beds are tectonically reduced along a steep overthrust zone trending **E-W to ESE-WNW** and **dipping to the N** on which the Lower Triassic - Werfenian rocks (Szin Beds) were displaced over the Middle Triassic limestone massif (Figs. 1, 3 and 6). This overthrust zone (detected by two boreholes) is permeable and filled with water. It is penetrated with younger subvertical to vertical fault trending NE-SW, on which the dominant cave systems were developed with caverns up to 13-20 m high, being revealed by boreholes (Szabó in Grenčíková et al., 2018). Structural analysis of the oriented rock core from a location with tectonically reduced Szin Beds (interval 160-190 m) has revealed a NE-SW trending preferred orientation of microstructures (faults) with a dip to NW (Fig. 3c). Based on evaluation of oriented structures from boreholes, geological cross-sections, geophysical data (Komoň in Grenčíková et al., 2018; Záhorec in Grenčíková et al., 2018) and earlier data from the Jablonovský tunnel excavation (Registration No. 430), deciphering boundaries of limestone massif and the Werfenian rocks (Szin Beds) in the area, we found out that the trend of a distinctive overthrust zone is E-W to ESE-WNW. In this distinctive tectonic dislocation, water-bearing brecciated marlite layers and marly limestone occur, being moderately to slightly weathered, weak to very weak (R4-R5) and in some places filled with yellowish brown tectonic clay. In the interval 185.5-186 m these rocks are hematitized.

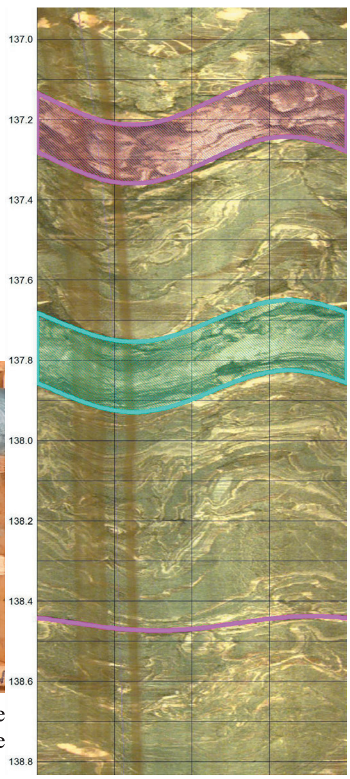


Fig. 2. Detailed folded carbonate laminae in marly sequence of the Szin Beds (photo Szabó). a - structure on the borehole walls at the same interval (Holeša in Grenčíková et al., 2018).

Due to varied lithology we have selected in the Szin Beds several lithological types:

Breccias, unweathered, very weak to weak (R5-R4), in some places, where they are filled with clay, they are extremely weak (R6). Breccias contain angular clasts of quartz, carbonate, claystone and sandstone of 0.5-3 cm grain-size. Boudinaged carbonate laminae were found there, as well as frequent transitions between unweathered compact breccias and breccias filled with clay.

Dark calcareous claystone (shale), unweathered, medium strong (R3), ductilely deformed, with carbonate boudinage to lenses. This layer, which we consider as a "lithological horizon marker", probably represents stratigraphically older levels of the Lower Triassic sequence.

Zones with majority of very strong to medium strong (R2-R3) limestones in contrast to the slates.

Zones with majority of weak to medium strong (R4-R3) slates in contrast to the limestones.

Zones with layers of fine-grained calcareous sandstones and marlites (marl slate), medium strong to weak (R3-R4).

Due to lithology of the Szin Beds, as well as overfolding of the

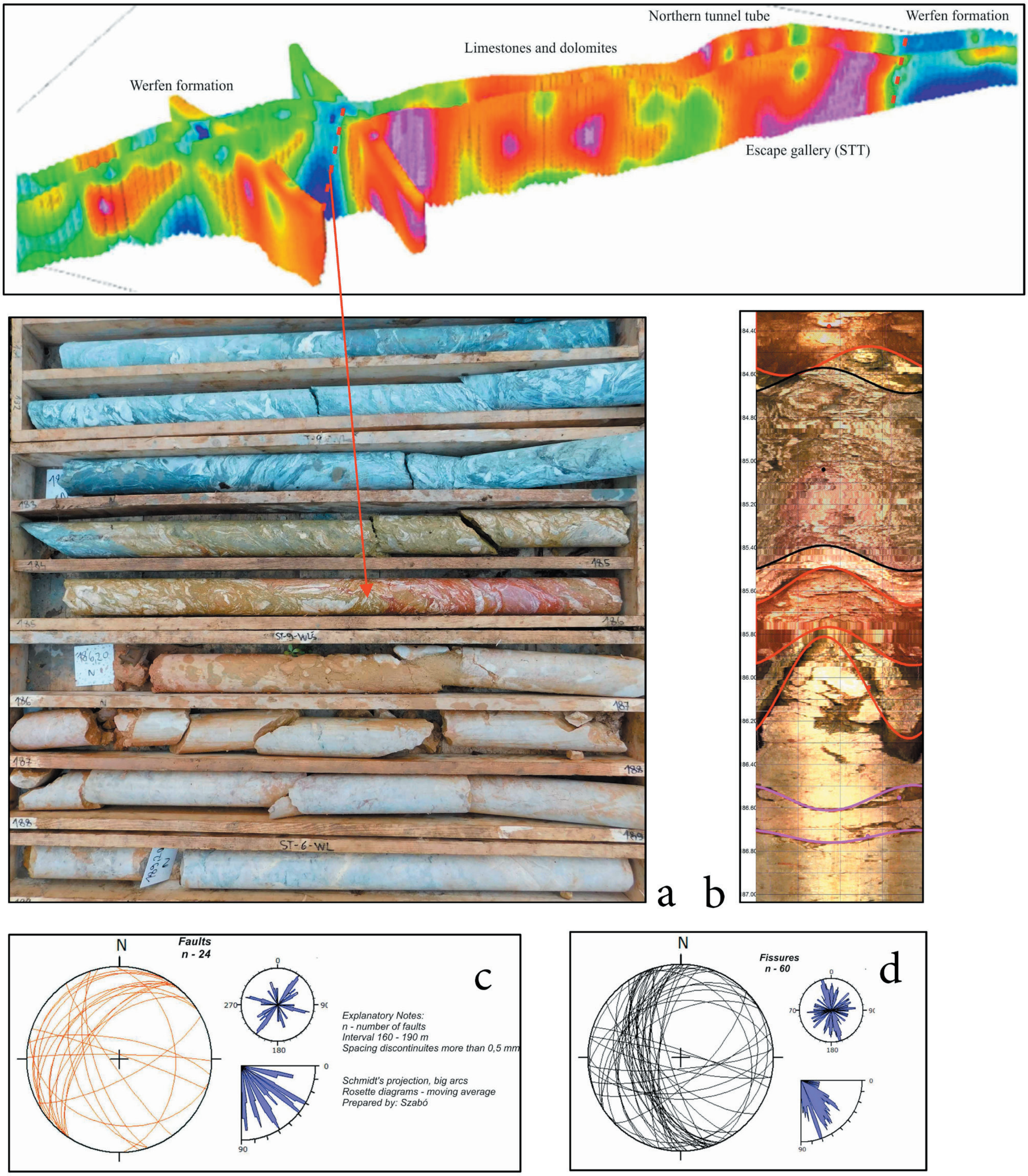


Fig. 3. Depicted 3D resistance model of the tunnel tubes using CSAMT (Controlled Source Audio-frequency Magnetotellurics) data along the Soroška tunnel route (Komoň in Grenčíková et al., 2018). In this model, the low resistance indicates the mutual contact zones of the limestone massif and the Werfenian rocks (Szin Beds; blue colour) in the western and eastern part of the route, as well as the zones with tectonic discontinuities, lithological boundaries and karstification. a - tectonic contact, in overlying Szin Beds and carbonate facies (both the Wetterstein and Steinalm Limestone) in the footwall (photo Szabó), b - structures on borehole walls in the same interval (Holeša in Grenčíková et al., 2018), c - orientation of tectonic dislocations in the interval 160–190 m, d -orientation of fissures in the interval 160–190 m (Szabó in Grenčíková et al. 2018).

massif and frequent alternation of lithotypes (limestones, marlites, slates, sandstones), we have selected above stated three zones, based only on predominant lithotype in relevant section (borehole profile). We have marked them by an appropriate index.

Also the *Szinpetri Formation* (Upper Spathian) was discovered in a segment of 1.3-2.1 km along the Soroška tunnel route, overlying the Szin Beds with majority of limestone occurrences. These were selected by petrographic analysis and being formed by shaly limestones and phyllite breccias. Based on the data from boreholes also tectonites of the Szinpetri Formation with interbed of gypsum were described, which can represent a sign of an overthrust plane existence (Soták in Grenčíková et al., 2018).

The **Gutenstein Formation** (Lower Anisian) is formed by the Gutenstein limestone and dolomites, which occur in interval of 1.725-2.3 km along the Soroška tunnel route. They are formed by the dark-grey well-bedded and tabular limestones and dolomites, breccias and rauchwackes containing calcite veinlets of several generations. Limestones are very strong (R2), locally medium strong (R3). The Lipovník quarry is built of the Gutenstein limestone and dolomites (second horizon of the Gutenstein and Steinalm limestones), best describing the character of their deposition and tectonic overprint. In the northern part of the quarry in the dark-grey Gutenstein limestone, the thin calcite veinlets (maximum 3 cm in thickness) occur with sporadic cubic fluorite crystals. Fluorite in calcite veins in Mesozoic limestones was described by Števko et al. (2010). The body of Gutenstein limestone, deposited in shallow sedimentary conditions, is 60 m thick, having general moderate dip 20-45° to S or SW. Contact of the Szin beds in the footwall and Gutenstein Formation in the hanging wall, detected by boreholes (Fig. 6), is represented by an important up to 20 m thick subhorizontal tectonic zone in the tunnel tube area, trending NW-SE, dipping to SW. In the surrounding area it is trending NW-SE, but also E-W (Szabó in Grenčíková et al., 2018; Fig. 1). These findings show that there must have been a movement between sedimentation of each formation. In this tectonic dislocation, weathered even disintegrated medium strong to very weak (R3-R5) limestones with more compact layers of brecciated limestones were formed. In some places limestones are crushed and cataclastic, being covered with sandy clay. It this tectonic dislocation there occur also interbeds of marl slate and sandy shale with yellowish rust, dark-grey and reddish brown colour, covered and partially filled with tectonic clay, similar to tectonic breccia. The whole tectonic dislocation is water-bearing. In an interval 1.9-2.1 km along the Soroška tunnel route the Gutenstein limestone and dolomite beds were discovered in boreholes also located under vertical alignment of the tunnel tube (Fig. 6).

The **Steinalm** (Anisian, Bithynian-Illyrian) **and Wetterstein limestones and dolomites** (Ladinian-Lower Carnian) occur in interval 2.350-4.2 km along the Soroška tunnel route. It was possible to distinguish them only determining the fossils, found during drilling, that is why they are marked in the geological map and cross-section only based on petrographical analysis of samples from the boreholes and from the surface. Their boundary is indicated with a dashed line. Steinalm and Wetterstein limestones, very strong (R2), and dolomites medium to very strong (R3-R2), locally weak (R4), are light, massive, organogenic, in some places brecciated (porous to cavernous) due to karstification. They are generally trending to S and SW with a dip 20-45°. Layers of *Reifling* and *Pseudoreifling* (Upper Anisian-Ladinian) fine laminated limestones and layers of the *Dachstein* and *Schreyeralm* limestones, which belong to slope and basinal facies of carbonate platform, were discovered in boreholes, as well as on the surface (Soták in Grenčíková et al., 2018). Their determination is based on a similar litofacial character, because the microfossils were not foud. Reifling and Pseudoreifling limestones were detected also in the contact zone of Lower and Middle Triassic sediments, on the eastern edge of the explored area, in the shape of lenses several meters long. In some places in these layers also intraformational breccias (up to 20 cm thick) occur, which are tectonically disconected by steep tectonic displacements.

Mostly steep tectonic dislocations were detected in the massif, some water-bearing, trending NE-SW, N-S and E-W. These dislocations are locally karstified with the occurrence of caves and faults trending NE-SW and NW-SE with sinistral and dextral dispacements. Subhorizontal faults were also discovered in boreholes with tectonic clay fill, containing the sulphide mineralization (FeS_2) with cubic pyrite crystals of 0.5 cm size. In the distance 3.250 km of the Soroška tunnel route, in 30 m depth, the karst void trending NE-SW (*part of a cave system with a minimum length of 150 m*) was discovered (Szabó in Grenčíková et al. 2018; Fig. 4). Based on the borehole records we can state that in the Soroška tunnel area four different horizons of karst voids occur: in the depth intervals of 30–45 m, 50–80 m, 90–110 m and 240 m.

Fig. 4. Cave discovered during exploration work (photo Szabó).

Lithology and stratigraphy of Triassic Formations of Silicic and Turnaic units in Soroška area

The **Bódvaszilas Formation** (ST-H1 – Soroška tunnel, horizontal borehole)

The grey fine-grained micaceous sandstones of basal Bódvaszilas Fm. (Lower Triassic – Induan; Soták in Grenčíková et al., 2018) are characteristic with parallel and wavy lamination up to lenticular bedding. Detritic material of sandstones is siliciclastic and phyllosilicate, consisting of angular quartz grains and mica flakes. Monocrystalline quartz grains predominate. Micas are mostly chloritized or baueritized and separated by cleavage foliation to microlithons. There are rarely present the small-sized meandrospiroid foraminifers of a species *Meandrospira cheni* (HO) and *M. iulia* (Premoli Silva).

The **Szin Formation** (ST-2 WLP, wireline borehole with installed piezometer)

The Szin Fm. consists of marly facies and metapelitic lithologies. This formation is composed mostly of the greenish-grey shales with distinct schistosity. They display a microfoliation S_1 segmented into transpositional zones with oscillatory zoning of phyllosilicates. The microfoliation S_1 is overprinted by the crenulation cleavage S_2 mostly in axial zones of asymmetric and kink folds. Sandstone and carbonate interbeds display a lower grade of metamorphic alteration and brittle-ductile deformation. They are flattened or dismembered into boudins and folded. In spite of a strong recrystallization of carbonates, they still preserve a numerous foraminifers with dark microgranular walls. They belong to species *Meandrospira pusilla* (HO), *Meandrospira iulia* (Premoli Silva), *M. cheni* (HO), *Postcladella kahlori* (Broennimann et al.), *Arenovidalina chialingchiangensis* HO, *Ammodiscus parapriscus* HO, *Hoyenella sinensis* HO, etc. Meandrospiroid and ammodiscid foraminifres are common constituents of the Lower Triassic microfauna, which appeared since the biotic crisis at the end of Permian. Their stratigraphic range corresponds to Nammalian–Spathian stages. Marly sediments manifest a facies features of the Szin Fm. of Silicicum (*cf.* Kronome & Boorová, 2016), while the metapelitic rocks exibit a structural features and metamorphic overprint of the Szin Fm. of Turnaicum (Soták in Grenčíková et al., 2018).

The **Szinpetri Formation** (ST-6 WLŠ, wireline inclined borehole)

In several drills, the shaly formation upwardly passes to carbonate sediments of the Szinpetri Fm. They are dark-grey biodetrital limestones with crinoid ossicles and ooids doplnenie (Fig. 5d). Microfacial types of these limestones correspond to biosparites and biooosparites. The recrystallization and alteration of Szinpetri Fm. graded up in sparitic limestones with intensive pressure solution (stylolitization) and formation of authigenic minerals (e.g. quartz). Hovewer, recrystalized limestones still contain tests of foraminifers like *Meandrospira cheni* HO a *Meandrospira insolita* (HO). The presence of these meandrospiroid species is used for differentiation between the Szinteri limestones from Gutenstein limestones from indicates the Upper Spathian age of Szinpetri limestones (Soták in Grenčíková et al., 2018).

Limestones of Gutenstein Fm. and Annaberg Fm. (ST-3 WLP, ST-7 WL)

The Gutenstein Fm, consists of a brownish grey granular limestone with network of white calcite veins and fissures. Sometimes the limestones are brecciated, indicating the dissolution and pressure solution. Gutenstein limestones exhibit mostly pelitomorphic structure with rare particles of pseudoooids, intraclasts and spotty recrystallization of micriric and microsparitic matrix. (Fig. 5c) Hypersaline conditions, which are typical for Gutenstein Fm., are also indicated in these limestones by a presence of degenerative forms of meandrospiroid foraminifers (*Meandrospira deformata*) Salaj and gypsum pseudomorphs in a shape of lath-like aggregates.

Similar organodetrital limestones belong to Annaberg Fm. (DB-157 and DB-200). They have a biosparitic microfacies with grainstone–rudstone structure. Skeletal grains are formed of crinoidal particles and bivalve shells. Unlike of Gutenstein limestones, these limestones contain also a more abundant microfauna of ammodiscid and archaeodiscid foraminifers (e.g. *Ammodiscus multivolutus* Reitlinger, *A. parapriscus* HO, *Arenovidalina chialingchiangensis* HO, *Glomospirella facilis* HO, *G. tenuifistula* HO). The age of both the Gutenstein and Annaberg limestone is dated to early Middle Triassic (Anisian, Aegean – Bithynian; Soták in Grenčíková et al., 2018).

Limestones and dolomites of the Steinalm Formation (ST-9 WLŠ)

In the Soroška area, the Steinalm limestones are commonly present in the carbonate formations of Silicicum. The limestones are of light-grey to greyish-white colour, manifesting biogenic and void structures. These limestones provide a various stage of dolomitization from selective displacement of original components (e.g. calcareous sponges, algae), up to complete recrystallization by dolosparite (crystalline dolomite). Organogenic and organodetrital limestones were a primary type of the Steinalm limestone. They have a biosparitic and biointrasparitic structure of the bindstone-type Bindstone-type limestones with overgrown skeletal components or their particles in a grainstone–rudstone limestone types. The most common biogenic components are represented by calcareous sponges Sphinctozoa, algal nodules and encrustations, microproblematics (*(Aeolisacus sp., Microtubus sp., Plexoramea sp.)*, *Microtubus, Plexoramea*), dasycladalean algae (*Diplopora*) and foraminifers. Stratigraphic classification of these limestones is based on foraminiferal species *Endothyranella lombardi* Zaninetti et Broennimann, *E. robusta* (Mckay & Green), *Endotriadella wirtzi* (Koehn-Zaninetti), *Meandrospira dinarica* Kochansky-Devidé et Pantić, *Pilamminella cf. gemerica* (Salaj), *Earlandinita grandis* Salaj, *Trochammina almtalensis* Koehn-Zaninetti, etc. These foraminifers belong to guide fossils of Steinalm limestone, differentiating them from Ladinian limestones of Wetterstein Fm. Considering that, the Steinalm limestone could be assigned to Anisian, more precisely to Pelsonian – Illyrian (Soták in Grenčíková et al., 2018).

Pelagic limestones of Silicica Unit - Reifling, Raming, Schreyeralm? Lms. (ST-10 WLŠ, ST-9 WLŠ, DB-14)

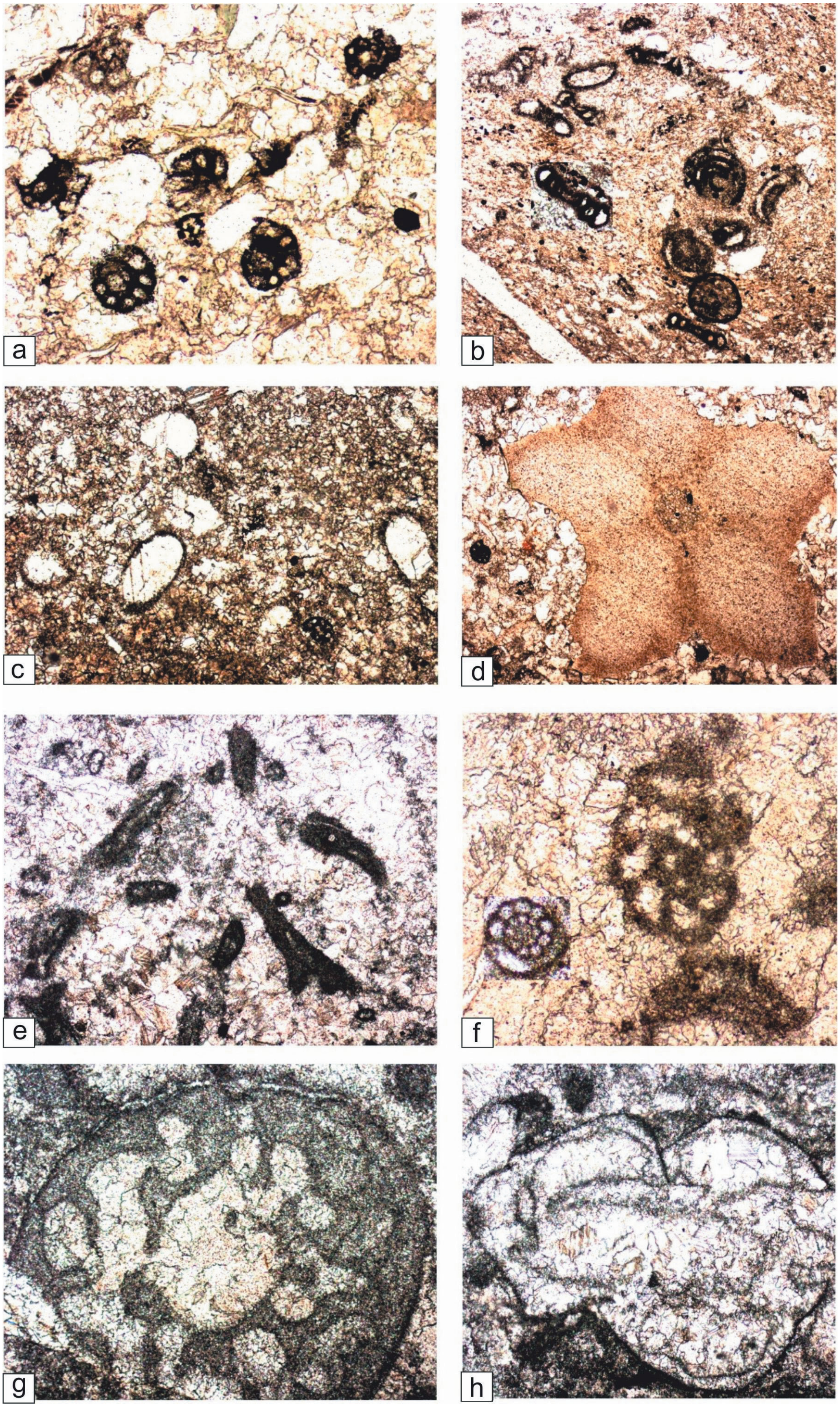
These limestones were recognized as a grey and variegated muddy limestone with features of pelagic and condensed sedimentation. They occur between limestones of both the Steinalm and Wetterstein Formations. Pelagic facies are well developed in the Reifling limestone (ST-10 WLŠ, ST-HG3, DB-14). In outcrops, they are light-grey platy limestones with lamination and redish stylolitic fissures. They are biomicritic limestones with weakly and densely packed bioclasts (wackestone – packstone). The concentration of juvenile thin-walled lamellibranchs form a so-called "filamentous" microfacies, which is typical for Reifling limestone. The other planktonic elements are represented by zoospores *Globochaete* and crinoid ossicles of *Osteocrinus*. Planktonic microfossils are completed by benthic foraminifers (*Pilammina densa* Pantić, *Arenovidalina*, *Planiinvoluta sp.*), algal tubes (*Microtubus sp.*) and ostracods. Reifling-type limestones are sometimes recrystallized and dolomitized (ST-9 WLŠ). Besides of typical facies of the Reifling limestones, there are also pelagic limestones with reefal detritus, which remind the Raming limestone. In borehole ST-9 WLŠ, there are also redish limestones with features of recrystallization and condensation. Their muddy matrix is neomorphosed to sparry aggregates and red-stained by Fe-oxides. Condensation and pressure solution is expressed by stylolites filled by red residual clays. These facial features and stratigraphic position allow to correlate red limestones with the Schreyearalm limestone.

Described pelagic-type of limestones belong to Reifling, Raming and Schreyearalm? formations of Silicicum (Late Anisian, Pelsonian – Illyrian); (Soták in Grenčíková et al., 2018).

Limestones of the Wetterstein Formation (ST-10 WLŠ, ST-13 WLŠ, ST-16 WL, ST-17 WLŠ, DB-13)

Limestones of the Wetterstein Formation exhibit a typical features of the Middle Triassic reef complex. This is manifested by the presence of skeletal, encrustation and void structures of reefal limestones. Reefal cavities are filled with radiaxial and blocky calcite, sometimes forming "evinospongies" with multiple generations of isopachous calcite cements. Principal structural components of these limestones comprise of calcareous sponges *Sphinctozoa*, corals, algal encrustations, sessile foraminifers, thalli of dasycladalean algae, crinoidal stems, serpulide worms, etc. Limestones with corals, sponge skeletons and algal tubes belong to boundstone–framestone facies, those with algal overgrowths belong to bindstone facies and reefal biodetrital limestones to rudstone–floatstone facies. Wetterstein limestones contain such organisms as skeletal parts of organisms like sponges *Solenolmia sp., Colospongia sp., Vesicocaulis sp., Celyphia sp.* and *Uvanella sp.,* cyanophycean algae *(Tubiphytes sp., Crescentiella sp., Baccanella sp.)*, dasycladacean algae *(Macroporella sp.)*, microproblematics (*Plexoramea, Microtubus*), etc. Frequent microfossils of these limestones are also foraminifers like *Duostommina alta* Kristan-Tollmann, *Diplotremmina altoconica* Kristan-Tollmann, *Endothyra keupperi* Oberhauser, *Endothyranella bicamerata* Salaj, etc. Present sponges, algae and foraminifers are considered as typical components of Ladinian biohermal limestones of the Wetterstein Formation. Some of them like alga *Plexoramea cerebriformis* Mello, has been established

Fig. 5. Representative microphotographs of principal lithologies present along the Soroška tunnel route. **a** - Calcareous sandstones of the Szin Formation with abundant microfauna of meandrospiroid foraminifer. Their association consists of species *Meandrospira cheni* a *Meandrospira pusilla*. borehole ST-2 WP, depth 61.3 m, Nammalian - Spathian, magn. 90x. **b** - Shaly marlstones of the Szin Formation with foraminifers *Postcladella kahlori* and *Arenovidalina chialingchiangensis*. Borehole ST-8 WL, depth 172.35 m, Nammalian – Spathian, magn. 90x. **c** - Sandy crinoidal limestone of the Szinpetri Formation with large pentagonal crinoid ossicle (columnalium) and small tests of foraminifers *Meandrospira iulia* (left side). Borehole ST-HG1, depth 53.7 m, Late Spathian, magn.35x. **d** - Oolitic limestone of the Gutenstein Formation with oomicrosparitic structure. Ooids are outlined by dark micritic rims and selective dissolved and replaced by pure sparite. Foraminifers *Meandrospira deformata* (right lower sector) are rarely also present, being specific for hypersaline facies of Gutenstain limestones, Early Anisian (Egean – Bithynian), magn. 50x. Borehole ST-3 WLP, depth 129.0 – 129.2 m. **e** - Limestone of the Steinalm Formation with structure of bindstone. Limestone components are formed by algal tubes and nodules of *Tubiphytes*, which were important reef-forming organisms of Middle Triassic carbonates. Soroška, site BD-14-03, magn. 42x. **f** - Steinalm limestone with foraminifers *Endothyranella lombardi* and *Meandrospira dinarica*. This is a typical association of species from the Steinalm limestone belonging to foraminiferal zone of *Meandrospira dinarica* (late Anisian – Pelsonian *sensu* Salaj et al. 1983). Borehole ST-9 WLŠ, depth 245.5 – 245.7 m, magn. 110x. **g-h** - Wetterstein limestones with skeletons of calcareous sponges *Sphinctozoa*, which form growth components of biohermal limestones (boundstone – framestone). Moniform sponges resemble genus *Vesicocaulis* (8) and polyglomerate sponges reveal a generic features of *Solenolmia* (7). Calcareous sponges *Sphinctozoa* were a typical reef-forming organisms of Wetterstein limestones. Ladinian to Early Carnian, boreholes ST-16 WL, depth 36.6 – 36.8 m (7), ST-17 WLŠ, depth 240.9 – 241.3 m (8), magn. 80x. (Soták in Grenčíková et al., 2018).


a
b
c
d
e
f
g
h

from Wetterstein limestones of Silicicum (Mello, 1977). Younger stratigraphic age of Wetterstein limestones could be indicated occasionally by the presence of foraminiferal species *Paleolituonella meridionalis* (Luperto), which is mentioned mostly from the late Ladinian and early Carnian. This younger age could by proposed in limestones from uppermost part of Wetterstein Formation, which already reveal lagunal facies with mud mound structures (fenestral pores, stromatactis, etc.; Soták in Grenčíková et al., 2018).

Engineering-geological a geotechnical conditions

Based on the drilled engineering-geological boreholes and geophysics, in the northern tunnel tube area the rock massif was divided into 22 quasihomogeneous sections (Tab. 1), with similar engineering geological and geotechnical characteristics of the rock massif, which were defined based on the existence of lithological types, degree of rock strength, weathering, tectonic overprint, bedding, spacing of discontinuities and their filling, number of joints, as well as the RQD (the Rock Quality Designation) and the RMR (the Rock Mass Rating) classifications (Bieniawski, 1989) and the QTS classification (Classification of rock and semi-rock formations for underground constructions; Tesař, 1989), and the presence of the groundwater. These characteristics have the bigger influence on the type of drilling, length of individual runs and stability of the massif. In the case of Soroška tunnel, the assumed mining direction was from the western tunnel mouth downslope and from the eastern tunnel mouth upward.

Based on geotechnical classifications, the quality of rock massif in the portal sections is very weak, categorized as class V. Regarding the presence of deluvial sediments in the first drilled meters, as well as weathering zone and tectonicaly disturbed rocks in the western tunnel mouth, we can expect instability of the tunnel face, side walls

Tab. 1
Quasihomogeneous blocks selected in the northern tunnel tube (NTT)

Quasihomogeneous blocks	Chainage		Section	Hanging wall height	RMR (Rock environment quality)	QTS	Rock mass class	corresponding NATM excavation support class
	From [km]	To [km]	length [m]	from vertical alignment [m]				
1	0.528	0.558	30	1-4				
2	0.558	0.739	180	4-24	20 (very poor)	30	V	5a
3	0.739	1.006	267	24-87	32 (poor)	48	IV	4
4	1.006	1.243	237	87-156	42 (fair)	61	III	3
5	1.243	1.375	132	156-196	38 (poor)	52	IV	4
6	1.375	1.633	258	196-220	28 (poor)	46	IV	4
7	1.633	2.009	376	220-282	41 (fair)	56	III	3-4
8	2.009	2.059	50	228-245	23 (poor)	44	IV	4
9	2.059	2.285	226	226-252	34 (poor)	48	IV	4
10	2.285	2.381	96	249-255	46 (fair)	65	III	3
11	2.381	2.638	257	249-275	20 (very poor)	35	V	5a
12	2.638	2.850	212	248-259	52 (fair)	61	III	3
13	2.850	2.925	75	250-255	23 (poor)	39	IV	4
14	2.925	3.275	350	192-250	52 (fair)	61	III	3
15	3.275	3.350	75	192-213	23 (poor)	39	IV	4
16	3.350	4.140	790	116-246	55 (fair)	62	V	5
17	4.140	4.190	50	103-116	25 (poor)	38	IV	4
18	4.190	4.471	281	58-103	37 (poor)	49	IV	4
19	4.471	4.508	37	54-58	27 (poor)	36	IV	4
20	4.508	4.700	192	20-54	31 (poor)	39	IV	4
21	4.700	4.765	65	10-28	17 (very poor)	14	V	5a
22	4.765	4.793	28	5-10				

and a roof rubble and overprofile area with a presence of the groundwater. Stabilized failure body at the eastern tunnel mouth is detected. During the boring of the tunnel, mostly in the weathered and tectonicaly disturbed rocks with thin hanging wall and sliding plane of a deluvium, the roof scree, tunnel face and the side walls will be very unstable, with falling rock fragments from the roof and overprofile area with a presence of the groundwater.

Along the Soroška tunnel route, based on geotechnical classifications, the worst evaluated quasihomogeneous blocks are 8, 17 (9, 20 in the STT - southern tunnel tube), blocks 11 (12 in STT), blocks 13,15 (14, 18 in STT).

In quasihomogeneous blocks 8, 17 (9, 20 in STT) the quality of rock massif is very poor, categorized as class IV. In these sections the Wetterstein limestones and the Szin Beds occur, that is why we expect a distinct irregularity in presence of different lithological types of rocks (transition from limestone massif to the Szin Beds, Fig. 6) and different geotechnical properties as well as excavation of rocks. The rock massif is moderately to highly weathered.

In this section the steep overthrust zone trending E-W to ESE-WNW and dipping to N occurs. The tectonic structure is permeable and filled with water. That is why it is assumed that on the litotypes contact the massif will be distinctively tectonically faulted with instabilities at the tunnel boring and a roof scree as well as the overprofile area formation with a presence of the groundwater.

In quasihomogeneous block 11 (12 in STT) at the tunnel level the karst voids were discovered. Based on geotechnical classifications the quality of rock massif in the borehole KHB-11 is very poor, categorized as class V. In this section the Steinalm and Wetterstein limestones and dolomites occur. The massif is unweathered, with the presence of steep faults trending N-S, NE-SW, as well as subhorizontal faults filled with tectonic clay. Due to a presence of caverns at the tunnel level and also thin hanging wall of the tunnel, as well as embedding of the massif by steep and subhorizontal tectonic dislocations, it is assumed that the massif will be distinctivelly faulted, with the instability of the tunnel face and a roof scree, locally also side walls with forming of an overprofile area and the groundwater inflow.

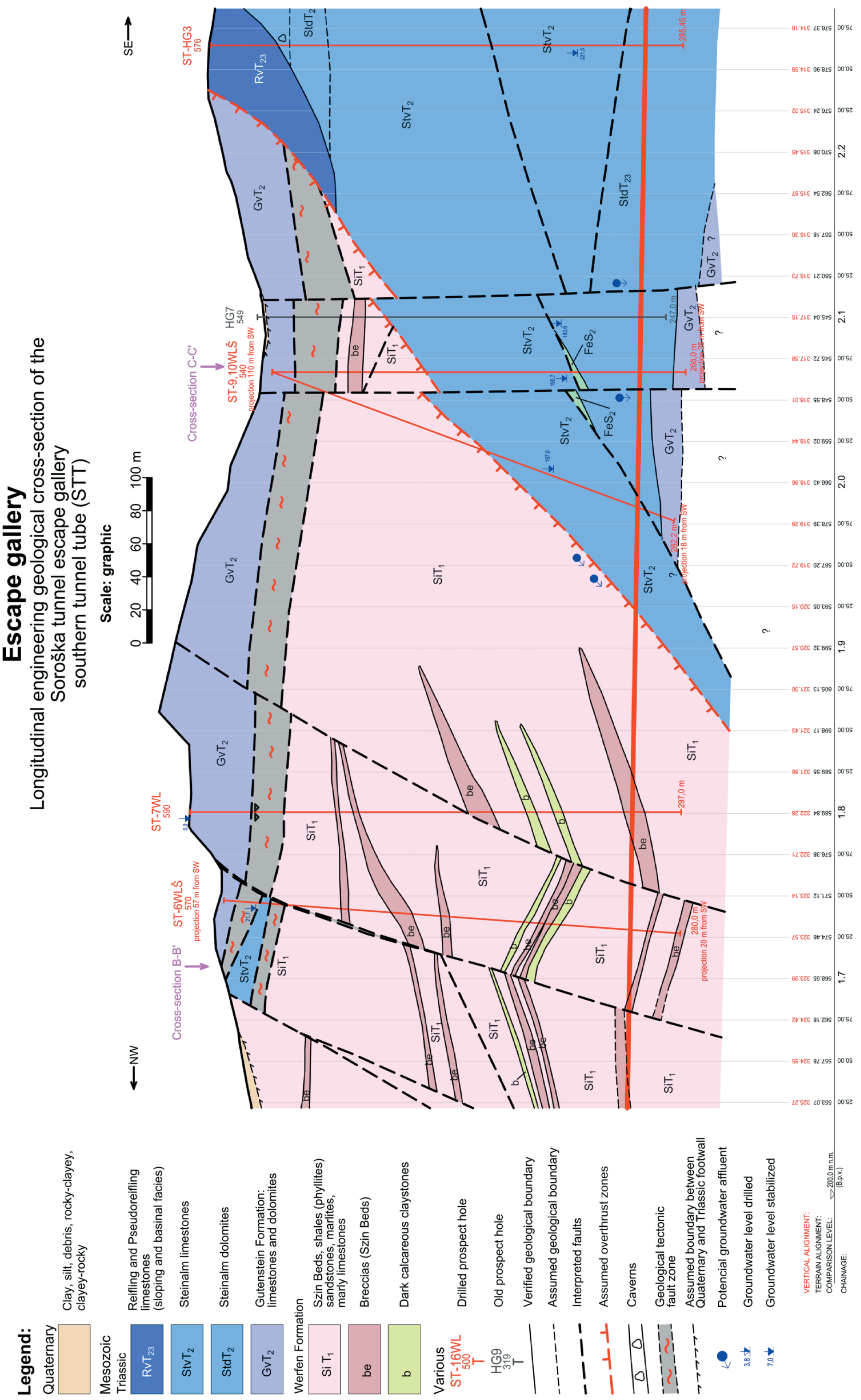
In quasihomogeneous blocks 13, 15 (14, 18 in STT) the quality of rock massif is very poor, categorized as class IV. Based on the geophysical profile (Komoň in Grenčíková et al., 2018) the massif is faulted by steep faults and fissures which can be open, karstic or filled with clay. Due to low failure stability in this section which reflects karstification in the Wetterstein limestones it is assumed that the massif will be distinctivelly faulted, with the occurrence of karst voids and fissures and with high instability of the tunnel face and a roof scree, forming an overprofile area and the groundwater inflow.

In the southern tunnel tube area, the massif was divided into 25 sections based on the information from the drilled structural engineering-geological boreholes and geophysical methods – quasihomogeneous sections with similar engineering-geological and geotechnical characteristics of the rock massif.

Hydrogeological conditions

The hydrogeological conditions in the territory of the Soroška tunnel are dependent on the geological structure of the area, the tectonic overprint, the geomorphological, hydrological and climatic conditions of the area. According to hydrogeological zoning of Slovakia (Šuba et al., 1984), the route of the expressway tunnel section passes through the hydrogeological region MQ 129 Mesozoic of the central and eastern part of the Slovak Karst and the subzones of the SA 50 – Silická planina, Horný vrch, Zádielská planina, Jasovská planina and Dolný vrch karst plains. With respect to classification of the groundwater bodies, it is the pre-Quaternary formation SK200480KF with dominant karst-fissure groundwaters of the Slovak Karst of the Hron and Hornád rivers catchment area (Kullman et al., 2005). Regarding to the division of Slovak Karst into hydrogeological structures according to Šuba et al. (1979) in Mello et al. (1997), the tunnel route passes through a Silica–Turňa hydrogeological structure. The hydrogeological structure is drained by 3 springs (Pod kameňolomom, Buzgo, Pri Kaplnke) in its northern part, as well as occasional springs in the Krásnohorská Dlhá Lúka area, and it is drained by the springs Mezeš, Sväta Anna and Eveteš in the south-western part. Division of surface water between basins of the Slaná and Turňa rivers passes along the Silická planina plain and the Horný vrch plain. The groundwater division has not been yet defined by the tracing tests. Due to its lithological composition, the complex of Middle and Late Triassic carbonates with prevalence of limestones forms a system of karstic planes with well developed surface and underground karst (Šalagová et al., 1997), having karst-fissure and karst groundwater regime. The hydrological systems of the Hrušovská jaskyňa cave and the Krásnohorská jaskyňa cave with active subterranean stream are known in the northern and northeastern part of the Silická planina plain. The Hrušovská jaskyňa and Krásnohorská jaskyňa caves are included by UNESCO to the World Natural Heritage List. Hydrogeological system of the Hrušovská jaskyňa and Krásnohorská jaskyňa caves was partially investigated during the phase of detailed survey (tracing tests).

Complex of limestone and dolomite synclinals of the hydrogeological structure is broken by longitudinal and transversal tectonic lines. The longitudinal lines have a overthrust-fault character. Alongside longitudinal lines, the Lower Triasic beds were stretched-out, allowing the Mesozoic to be subdivided into partial tectonic units. An extent of tectonic disruption, geomorphology of the area


Escape gallery
Longitudinal engineering geological cross-section of the Soroška tunnel escape gallery southern tunnel tube (STT)
Scale: graphic
0 20 40 60 80 100 m
NW
SE
Cross-section B-B'
Cross-section C-C'
ST-6WLŠ
570
projection 57 m from SW
ST-7WL
590
ST-9,10WLŠ
540
projection 110 m from SW
HG7
549
ST-HG3
576
280,0 m
projection 20 m from SW
297,0 m
262,2 m
projection 18 m from SW
266,0 m
247,0 m
285,45 m
Legend:
Quaternary
Clay, silt, debris, rocky-clayey, clayey-rocky
Mesozoic
Triassic
RvT23
Reifling and Pseudoreifling limestones (sloping and basinal facies)
StvT2
Steinalm limestones
StdT2
Steinalm dolomites
GvT2
Gutenstein Formation: limestones and dolomites
Werfen Formation
Si T1
Szin Beds, shales (phyllites) sandstones, marlites, marly limestones
be
Breccias (Szin Beds)
b
Dark calcareous claystones
Various
ST-16WL
500
Drilled prospect hole
HG9
319
Old prospect hole
Verified geological boundary
Assumed geological boundary
Interpreted faults
Assumed overthrust zones
Caverns
Geological tectonic fault zone
Assumed boundary between Quaternary and Triassic footwall
Potencial groundwater affluent
Groundwater level drilled
Groundwater level stabilized
VERTICAL ALIGNMENT:
TERRAIN ALIGNMENT:
COMPARISON LEVEL: 200,0 m n.m. (B.p.v.)
CHAINAGE:
1.7
1.8
1.9
2.0
2.1
2.2
FeS2

Group	Parameter	Unit				
GEOMETRY	Dimensions of the tunnel	[m]				
	Chainage of the tunnel	[km]	1,895	1,945		2,125
	Azimut of the tunnel	[°]	147 147	146	146 145	144
	Marking of the selected quasihomogeneous sections	[č.]	**8**	**9**	**10**	**11**
	Length of the selected section	[m]	300	50	180	208
	Hanging wall height	[m]	224-287	268-280	233-268	233-264
GEOLOGY	Geological age - tectonic unit					
	Lithostratigraphic classification		Szin Beds - shales, sandstones, marlites, marly limestones with breccia layers	Szin Beds / Steinalm limestones	Steinalm limestones	Steinalm limestones and dolomites
	Engineering geological rock type		SiT_1, v>b, ±be, (SiT_{1tp})	SiT_{1tp}, v>b/$StvT_{2tp}$	$StvT_2$, $StvT_{2tp}$	$StdT_2$, ($StdT_{2tp}$), $STvT_2$ ($StvT_{2tp}$)
	Degree of weathering		unweathered (0)	medium to highly weathered (2-3)	slightly weathered to unweathered (1-0)	unweathered (0)
	Size/Type of blocks		small to medium / Ta, Po	very small to small / Po, Ta, Eq	medium to small / Eq, Po	medium to small / Rh, Eq, Po
	Parallel tectonic disturbance					
	Transverse tectonic disturbance					
	Discontinuity diagram of points and intersections in relationship to the direction of the tunnel boring (bedding / foliation; schistosity; joints; tectonic dislocations)		ST-6WLŠ, ST-7WL		ST-9, ST-10WLŠ	ST-HG3
GT RATE	Unit Weight (ρ)	[g.cm-3]	2,700	2,546	2,715	2,693
	Modulus of deformation (Edef)	[MPa]	4700	50	3500	2000
	Poisson's ratio (ν)		0,24	0,30	0,18	0,17
	Abrasion (Fv)	[mg.m-1]	0,1875	-	0,2482	0,4156
ROCK MASS CHARACTERISTCS (after Z. T. Bieniawskeho, 1989) – Rock strength	Uniaxial compressive strength (c) σ	[MPa]	40	≤ 5	57	70
	Rating RMR	[points]	4	1	7	7
RQD Index	Rock mass quality index (from drilled rock)	[%]	85	73	77	74
	Rating RMR	[points]	17	13	17	13
Characteristics of discontinuities	Density-distance of discontinuities	[mm]	60-600	60 - 200	60 - 600	60-600
	Rating RMR	[points]	9	8	9	9
	Persistance, opening, roughness, weathering and fill of discontinuities		continuous, 0,1-1,0 mm, slightly rough - smooth, unweathered, with soft fill	continuous, >5 mm, rough - slightly rough, highly to medium weathered, with soft fill	continuous, > 5 mm, rough, slightly weathered to unweathered, with soft fill	continuous, < 5 mm, rough, unweathered, with soft/hard fill
	Rating RMR	[points]	14	6	10	15
Underground water	Inflows 10,0 m of the tunnel tube length	[l/min]	10-25	>125	>125	25 - 125
	General character of the section		wet	running water	running water	dripping water
	Rating RMR	[points]	7	0	0	4
Influence of the orientation, direction and dip of the discontinuities (bedding) in relationship to the tunnel axis and boring direct.	Orientation of discontinuities (bedding) in relationship to the tunnel axis		diagonal	perpendicular	perpendicular	diagonal
Dip of the discontinuities (bedding) in direction of the tunnel tube boring	Antithetic: a) 90-45°; b) 45-20° rating	[°]	30-85	40-60	30-80	
	Rating	[points]	-5	-5	-5	
	Arbitrary, slight ± 20° rating	[°]				
	Rating	[points]				
	Conformable: a) 90-45°; b) 45-20° rating	[°]				20 - 80
	Rating	[points]				-2
GT CLASSIFICATIONS – RMR (Z. T. Bieniawski, 1976, 1989)	Total Rock Mass Rating /sum	[points]	46	23	38	46
	Quality of Rock Mass	[quality]	fair	poor	poor	fair
RMC	Rock Mass Class for tunnel boring	[class]	III	IV	IV	III
QTS (Tesař 1979)	QTS sum	[points]	58	44	49	65
ÖNORM B 2203	Corresponding type of the rock environment according to ÖNORM B 2203/94	[type]	B2	C2	B3 - B2	B1
NRTM	Corresponding technological class NRTM	[tech. class]	3	4	4	3
GEOLOGICAL RISKS	Predisposition of the front wall instability (blow down in ceiling)	big / medium / small	medium	big	medium	medium
	Predisposition of the wall instability (blow down in side walls)	big / medium / small	small	big	medium	small
	Predisposition of the invert instability (expansion)	big / medium / small	small	medium	small	small
	Predisposition of the concentrated water inflows	big / medium / small	small	big	big	medium

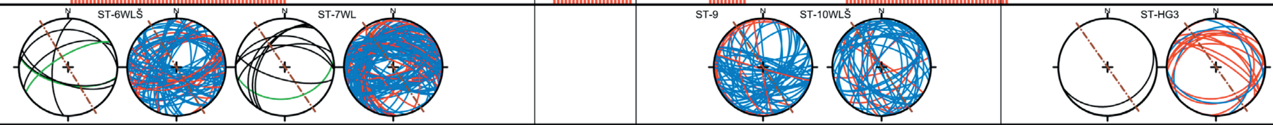


Fig. 6. Longitudinal engineering-geological cross-section along selected principal segment of the southern tunnel tube (Escape gallery; Szabó in Grenčíková et al., 2018) and its engineering-geological a geotechnical parameters.

blue rings - detection sites in 11 monitored locations around the route, red rings - tracking application in 3 tunnel boreholes

blue rings - places for positive tracking detection (Eveteš spring, Hrušovská jaskyňa cave, Pri kaplnke, Pod kameňolomom springs in Krásnohorská Dlhá Lúka)

Photo: Tracing test in Eveteš spring (photo Copláková, 8/2017)

Photo: Tracking test in Hrušovská jaskyňa cave (photo Szabó, 9/2017)

Fig. 7. Situation of monitoring sites and sites with positive detection of tracers

and karstification of carbonates is related to fault tectonics. The basic feature of the tectonic structure is the system of anticlinal and synclinal stratification of carbonates on the low-permeable or impermeable sediments of the Lower Triassic. The nature of the carbonates disruption of the Silica Nappe formed an important factor in the formation of endokarst (i.e. caves). Transversal fracture systems have the overthrust-fault character, subsidence and directional shifts and these systems have affected the hydrogeological conditions of the area.

From the groundwater point of view the Slovak Karst National Park presents a unique natural complex, which is characterized by the extreme richness of the water, being significant also from the water-management point of view. For this reason, a part of the National Park and its protection zone were declared as a protected area of the groundwater sources. Middle Triassic carbonates build the important hydrogeological structures in the areas called the Veľká skala and Horný vrch, while the area of the Soroška passage represents an assumed area of their hydrogeological distribution. Part of the Soroška tunnel route reaches the CHVO (Protected water area) Horný vrch and part of the route goes through the declared Second degree of external protection of the Eveteš groundwater source, supplying the inhabitants of the Jablonov nad Turňou village with drinking water. The hydrogeological conditions within and around the Soroška tunnel were evaluated applying the quasi-homogeneous blocks. Using the geological works allocated in the portals and the tunnel itself, it was found that the Soroška tunnel would be excavated in two lithologically different environments.

The western portal of the tunnel is located in the inhomogeneous environment of slopes built by Quaternary deluvial and proluvial sediments. Groundwater is accumulated inside the Quaternary deluvial clays and debris, as well as proluvial clays, which hydrogeologically represent a collector with accumulation of the groundwater with intergranular permeability and uplift effect. During the construction of the western portal, they will represent a negative factor because of the groundwater drainage from a rock massif to the tunnel tube and so the demand to drain it out. The Quaternary soil bedrock is built by the highly weathered shales, claystones and Lower Triassic limestones.

The eastern portal of the tunnel is located on the slopes built of Quaternary deluvial sediments and landslide deluvial sediments. From the hydrogeological point of view, the Bódvaszilas Beds and the Szin Beds, with predominant fissure permeability, represent the hydrogeological isolators without significant drainage or significant groundwater accumulations. However, the groundwater may accumulate within their contact zone within the near-surface weathered zone. Groundwater can also be bound to tectonically faulted zones, where it can also descend into deeper levels.

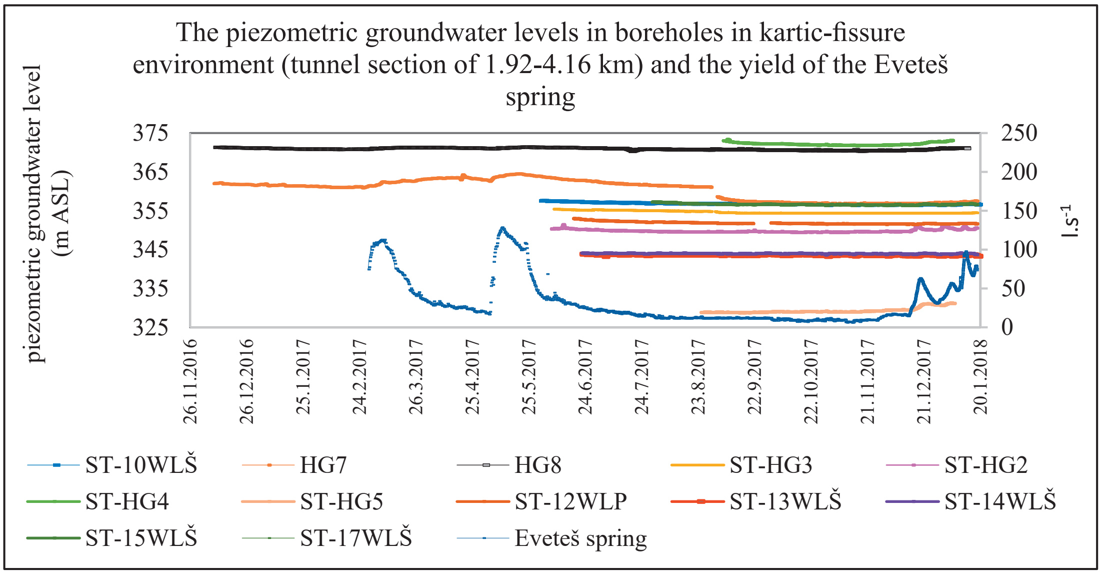
The tunnel section will be excavated in the rock environment of the Szin Beds (Nammalian - Spathian) and the Bódvaszilas Beds of Werfenian (Griensbachian – Lower Nammalian) with fissure and intergranular permeability and will also be excavated in the environment of Mesozoic carbonates of the Silica Nappe (Lower Anisian – Lower Carnian) with karst and fissure permeability.

To investigate the groundwater regime of the part of the Soroška tunnel within the Lower Triassic rock massif (the Szin Beds) during in the stage of orientation and detailed engineering geological and hydrogeological survey (Mašlárová et al., 2012, Grenčíková et al., 2018), three vertical boreholes with open level measurement system and 2 oblique observation boreholes were built. In vertical boreholes, the groundwater level fluctuated in the weathered and decomposed rock zone up to max. 15 m (477.22 m ASL). In oblique boreholes, sensors with a closed measuring system were built, primarily to measure the values of the porous (fissure) pressures. Stabilization of pore pressure values in such a low-permeable environment and at great depths was very slow with a settle time of few months.

The permeability of the Szin Beds was tested by water-pumping tests, in which the permeability was tested within 15 sections of the 3 boreholes at depths of 36-176 m. According to the results, the values of the permeability coefficient $k_f = 6{,}317.10^{-8}$-$1{,}544.10^{-6}$ m.s^{-1} with the geometric mean G (k_f) = $4{,}71.10^{-7}$ and the median M (k_f) = $6{,}07.10^{-7}$ m.s^{-1} (Coplák et al., in Grenčíková et al., 2018). According to the classification of the permeability of the rocks (Jetel, 1982), there is a low-permeable environment with the permeability class varying from class V to class VII. From the results of the rock massif hydraulic parameters and the water-pumping tests, the size of the instantaneous inflows of the groundwater to the tunnel tubes was estimated. In the sections where the tunnel will be excavated in the environment of deluvial-proluvial sediments and in the environment of predominantly tectonic disturbed Szin Beds and Bódvaszilas Beds, the assumption of instantaneous total inflow of the groundwaters from both tunnel tubes was estimated to be about 4 l.s^{-1}.

By the means of hydrogeology, the most interesting section of the tunnel – and at the same time the most risky one in terms of influencing the natural groundwater regime in the area – is the tunnel section in 2.2-4.2 km, which will be excavated in Triassic Steinalm and Wetterstein limestones and dolomites of the Silica Nappe. Middle Triassic carbonates of the Silica Nappe show the varying degree of tectonic faulting. Generally, in this environment, the tectonically induced fractures act as a drainage of the water circulating due to fissure-karstic permeability, unless filled with impermeable material. Replenishment of the groundwater reserves in this environment proceedes by the infiltration of precipitation water through the ruptured epikarstic surface or through abbyss and, in some cases, through the swallow holes into the system of ruptures and karst channels. Local permeating precipitation water penetrates into the deep underground phreatic zones of the cave systems down to the erosion base. The vertical movement of the precipitation water passing through the karstic-fissure environment is complicated and depends to a large extent on the disruption degree of the rock environment. These fractures and cavities of the endokarstic zone are transiently or permanently filled with water. The tectonic discontinuities disrupt the integrity of the limestone rock massif. Significant movement along these faults is documented by the presence of tectonic striations on the fault planes.

For the purpose of assessing the groundwater regime in a part of the tunnel, driven in karstic-fissure environment, of predominantly limestones collector, 7 vertical and 5 inclined boreholes were drilled during the phase of orientation and detailed engineering-geological and hydrogeological survey (Mašlárová et al., 2012, Grenčíková et al., 2018), verifying almost 290 m thick layer of the vadose zone. From the results of the level regime observation in the built-in wells there can be derived that the fluctuations of the groundwater levels in the fissure-karstic environment showed a certain hydrodynamic retardation due to the damping capacity of the unsaturated vadose zone of relatively great thickness that equalized the uneven inflow of precipitation water from the surface and a relatively high hydraulic diffusivity of the karstic environment as well. Through the interpretation of piezometric level´s and water temperature regime measurements in the boreholes in karst-fissure environment, it was found that the groundwater level is sunken within the contact zone of Middle Triassic carbonates more than 100 m lower. Altitudes of the groundwater levels in built-in wells in 2.2–4.2 km in tunnel section, driven in the Middle Triassic carbonates were found from 330 m to 365 m a.s.l. The height of the water column in the observation boreholes reached above the projected tunnel tubes level, ranging in average about 40 m (from 33 to 74 m). The level of the projected Soroška road tunnel will the decrease from the northwest (from the western portal), from about 341 m a.s.l. to the southeast (to the eastern portal) to the altitude of about 272 m a.s.l., which represents the altitude difference of 69 m. It follows that the standing groundwater levels in the piezometric wells, built in the karst-fissure environment, oscillates above the projected tunnel level and the tunnel would act as a significant drainage element of the groundwater. The piezometric groundwater levels for the tunnel section of



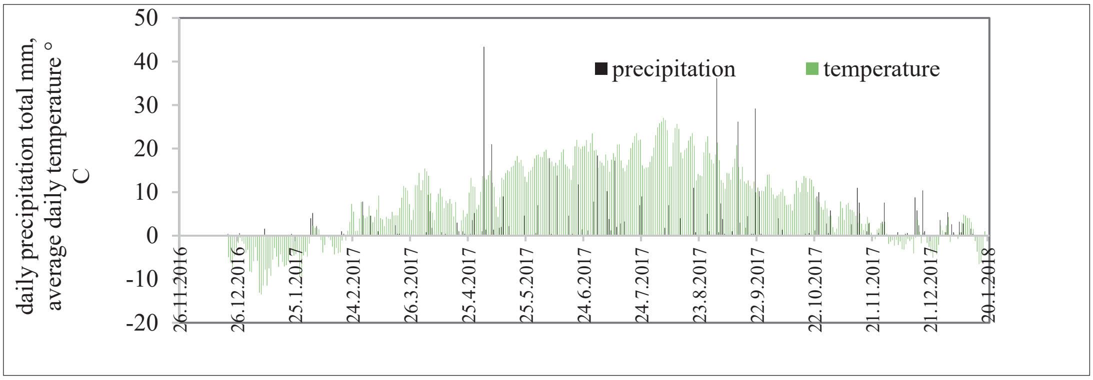


Fig. 8. Piezometric height of steady groundwater levels in the wells and the yield of the Eveteš spring and climatic and precipitation data from the temporary meteorological station at Soroška saddle (Copláková in Grenčíková et al., 2018)

1.92-4.16 km driven in the abovementioned carbonates with karstic-fissure permeability and the yield of the Eveteš spring draining a part of hydrogeological structure are presented in Fig. 8.

Fluctuations of groundwater levels in boreholes, being dependent on the magnitude of effective precipitations additional to the quantities of groundwaters in the karstic-fissure environment are not uniform in the investigated area, but there are significant fluctuations in the preferred sections. The highest variation was found in the vicinity of archive borehole HG7, in km 2.1 of the tunnel section, with a 3.5 m variation of the groundwater levels over the 13-month observation period. Analysing the precipitation and climatic characteristics from the temporarily installed weather station, based directly on the surface of the Soroška pass, increased observed groundwater levels in the HG7 borehole were bound especially to the period between the end of February and the beginning of March 2017, related to melting of the snow cover due to the air temperature increase. The response of the Eveteš spring, as well as the outflow from the Hrušovská jaskyňa cave to the precipitation indicates the dependency on the saturation of the massive groundwater with a certain time delay. The highest observed groundwater levels were found in May 2017 when 95.8 mm of precipitation fell down on the Silica Plain. With the time delay, the highest flow rates of Eveteš spring and Hrušov stream were recorded in March 2017 and especially in May 2017, when spring yield of Eveteš was 128 $l.s^{-1}$ and the flow at Hrušov stream (SHMÚ object No. 2031) was 248 $l.s^{-1}$. From this period until November 2017, the gradual decrease of the groundwater levels in structure was observed and, at the same time, the depression in the yields of the Eveteš spring was recorded.

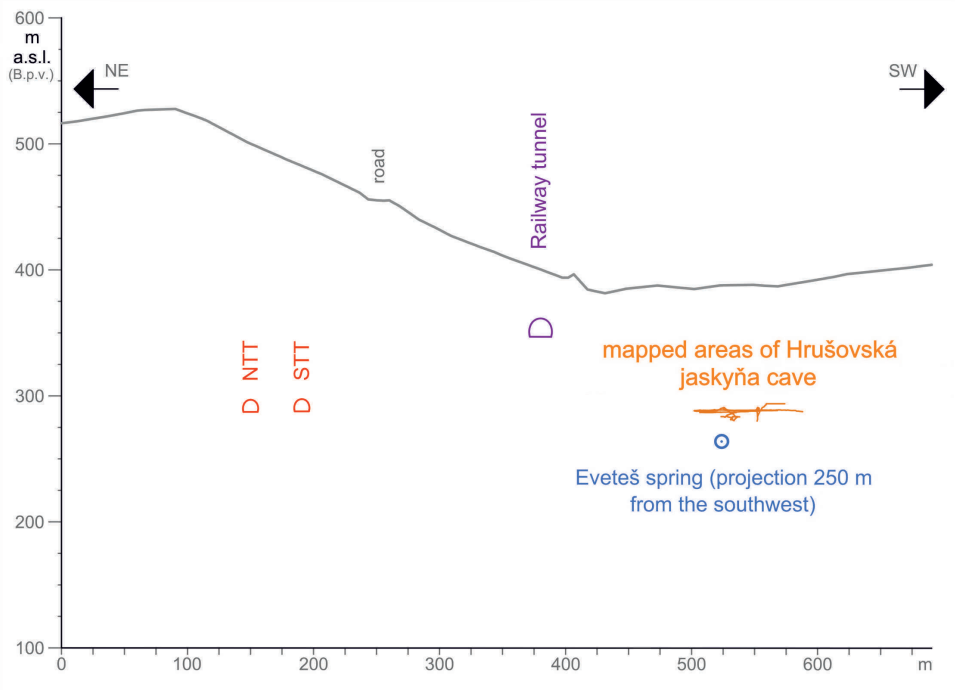
Borehole HG7 is located in the environment of tectonic contact of the Szin Beds with overhanging Middle Triassic carbonates of the Silica Nappe. In the HG7 borehole at a depth of 120 m, a steep overthrust zone trending E-W to ESE-WNW and dipping to N was detected, on which the rocks of Szin Beds were shifted over limestone massif. This thrustline was also captured by the ST-9 WLŠ borehole at a depth of 185 m with repetition of layers in tectonic blocks. The tectonic zone is permeable and filled with water. The thrustline was penetrated by the younger subvertical to vertical structure trending NE-SW on which the dominant cave systems (caverns of size varying from 13 to 20 m) were found and which were permeable and filled with groundwater. These tectonic fractures greatly direct the flow of groundwater quantities in this area. In this contact zone, the highest instantaneous groundwater inflows into each of the tunnel tubes were estimated to approximately 30-35 $l.s^{-1}$ (Szabó in Grenčíková et al., 2018). The rock massif is penetrated by a system of steep faults and fractures as well as karstic cavities, which can be accompanied by increased inflows of karst groundwater and the occurrence of increased amount of clay minerals present as the fill of caverns.

The water-pumping tests were conducted inside the boreholes for evaluation of hydraulic parameters of karstic limestone rock massif. The permeability of Middle Triassic carbonates was verified by the water pumping tests, where the limestones (without detailed lithostratigraphic resolution) were tested in 3 boreholes - totally in 19 sections - at depths varying from 62.1 to 266.15 m. According to the results, the values of the permeability coefficient k_f = $6{,}155.10^{-8}$-$1{,}039.10^{-4}$ $m.s^{-1}$ with geometric mean G (k_f) = $2{,}557.10^{-6}$ and median M (k_f) = $3{,}315.10^{-6}$ $m.s^{-1}$ (Coplák et al., in Grenčíková et al., 2018). The results of water pumping tests have demonstrated high variability in permeability for this kind of rock environment. According to the classification of the rocks permeability (Jetel, 1982), it is varying from a rather highly permeable environment with the class III permeability to a very poorly permeable environment with the permeability class VII.

The existence of tectonic fault zones, abyss caves and sinkholes supports the fast infiltration of precipitations into massif. Greatest inflows to the tunnel tubes level can be expected in the different lithology contact zones, tectonically disintegrated zones, tectonic faults crossings and inside sections, where cavern appearance which were documented in superjacent tunnel overburden and in tunnel level itself. The total outflow from the tunnel may vary over time, depending largely on the state of rock saturation with the groundwater and the effective precipitation that significantly affects it. The existence of karstic zones and tectonically ruptured sections was confirmed by geophysical resistance cross-sections, where they appeared as areas with low resistances and with occurrence of karstic phenomena directly in the tunnel tubes route, or with the reach even below the tunnel tubes respectivelly. Therefore, a tunnel without compensatory (insulation) measures represents a line drainage element and as such may affect the status of the groundwater body.

The Soroška tunnel has to be connected with the NPR (National nature reservation) Hrušovská jaskyňa cave and the Eveteš spring, because part of the water of the underground stream flowing through the cave is used as the only source of drinking water for the inhabitants of the Jablonov nad Turňou municipality. The Soroška tunnel will be driven in the same hydrogeological structure. From the background of structural and geological measurements in the Hrušovská jaskyňa cave (Boroš & Ščuka, 1984; Vlček, 2007, 2008), a new speleological survey was carried out (Komoň & Bašista, 2012). Within the frame of this new speleological survey, as well as structural and tectonic measurements, a 3D model view of the cave was constructed. The model 3D view shows that up-to-date mapped spaces of the Hrušovská jaskyňa cave are sufficiently distant from the projected tunnel, while the closest perpendicular distance is 305 m and the cave itself should not be jeopardized by the tunnel construction works. As important finding there came the knowledge that the measured height of the cave bottom is approximately the same as the height of the tunnel tube´s level. Erosion base level respectivelly the overflowing height of the springs draining the Hrušovská jaskyňa cave as well as the inflow zone of the Eveteš spring used as a water supply source, are located at an altitude of 275 m a.s.l., that is under vertical alignment of the tunnel tube. Fig. 9 shows a cross-section through the area of the cave system - the altitude of the projected tunnel pipes of the Soroška road tunnel and the existing Jablonov tunnel and the catchment of the Eveteš spring.

During the survey, the issue was not only the assessment of the impact of the hydrogeological conditions on the excavation of the Soroška tunnel, but also the impact of the tunnel on the quantity and quality of the drinking water sources in affected municipalities, the sources of the individual well-water supply, and the problem of the drainage impact of the tunnel to the quantity and quality of surface flows in the area. For this purpose, tracing tests were carried out to verify mutual groundwater communication between individual parts of the hydrogeological structure. Three indicators (sulforodamine B, tinopal, uranine) were used. The principle of the tests requires to feed a solution of each of the tracers diluted with drinking water with a volume of 10 cubic meters into the sinking part of the saturated collector (Máša et al. in Grenčíková et al., 2018), representing perforated sections in 3 boreholes built-in to the axis of the projected tunnel. Time schedule of tracking tests was based on the assumption of the tracer´s delay in the rock environment for 3 months. Their discovery was monitored at 11 checkpoints (the Hrušovská jaskyňa cave, drinking water sources Eveteš, Mezeš, Studená studňa, Záhradský potok, three springs in the Krásnohorská Dlhá Lúka municipality, two side tributaries to the main stream



NTT – northern tunnel tube, STT – southern tunnel tube

Fig. 9. Cross-section through the massif in the place of the Hrušovská jaskyňa cave system (compiled from the documents of Boroš & Ščuka, 1984, and Komoň & Bašista, 2012).

in NPR Krásnohorská jaskyňa cave and in the well in the village of Jablonov nad Turňou). Fig. 7 shows an overview of the places where trackers were applied, as well as the places where the trackers have been positively detected. In the past, authors Boroš and Ščuka (1984) reported a positive fluorescein tracing test that was applied to the bottom of the Jablonov abyss cave (Veľký Lipovnícky Zombor) with a cave depth of 42 m. The discovery of the fluorescein tracer in the underground water of the Eveteš spring took a place 48 days after its application, with an air line representing the tracer passing distance of approximately 2.1 km. The cave is located northeast of the Hradisko hill, east of the Soroška saddle.

Tracking tests have shown interconnection and directions of the groundwater flow, groundwater flow rate, rock massif´s groundwater retention time and, in particular, hydrological groundwater connections in the tunnel stationing in kilometres 2.13, 2.3 and 3.24 with the Eveteš spring. The calculated speeds (Tab. 2) indicate the range of the phreatic zone as the tracers moved from the places of their application to the source of the Eveteš karst spring. Tracing tests during a detailed survey also showed that the hydrogeological structure, in part of which the Soroška tunnel will be driven, is partially a catching area of the underground water for the water sources at Kaplnka and Pod Kameňolomom in the Krásnohorská Dlha Lúka area. The catch area of these strands has been traced in the past by tracking tests in the central part of the Silica Plain (Roda et al., 1986; Erdös, 1995), but the tracing tests of our own we have shown that the reception area of these strands is extended to the Jablonov saddle, where the hydrological border of the structure of the Veľká skala and Horný vrch is assumed.

The presence of rhodamine B tracer applied to the HG7 well in the contact zone of karstic and non-karstic rocks, which was detected in the Hrušovská jaskyňa cave, points to the possible underground connection, respectively to the possible continuation of other yet undiscovered underground spaces of the Hrušovská jaskyňa cave. It should be noted that the tracking tests were carried out during the low groundwater saturation stage of the rock massif, when the groundwater circulation in certain parts of the massif could be impaired and due to the longer transport time, the tracers did not have to be detected at some points during the 3-month tracking test (Tab. 2).

The basic prerequisite for assessing of the impact of tunnel excavation, but also the tunnel operation on the drainage conditions of the territory, was the separation of the infiltration area of the Eveteš spring draining the Silica and the Horný vrch plains. The groundwater balance analysis confirmed the planned drainage of the hydrogeological structure by the tunnel. For the area delineation of the potential infiltration area of karstic groundwaters, respectively of the catchment area affected by the drainage effect due to the tunnel construction, the hydrological balance of the area depicted in Fig. 10, has been compiled

Tab. 2
The results of the tracking tests.

The results of the positive trace test with a continuous fluorimeter with a recording frequency of 15 minutes									
Place of detection	**Traceable substance**	**The date of the tracking application**	**The date of the traveler's arrival**	**Peak of detection**	**Date of tracking**	**Approximate air distance (m) from application**	**Calculated flow rate (m/h)**	**The max. concentration (ppb)**	**Duration of tracer's arrival (days)**
Eveteš spring	Uranine into ST-HG4	28.8.2017 (11:55-14:09)	17.9.2017 16:30	26.9.2017 18:00	17.10.2017	900	1,86	0,45	20,19
	Sulforh.B into HG7	29.8.2017 (11:35-12:00)	18.9.2017 15:00	26.9.2017 21:00	2.10.2017	2000	4,14	0,09	20,15
	Tinopal into ST-HG3	28.8.2017 (7:50-8:10)	17.9.2017 8:00	22.9.2017 17:30	31.10.2017	1700	2,79	6,68	25,40
Mezeš, Studená studňa, Buzgó, the tributaries of the Abonyi and the Heliktite Dome in the Krásnohorská jaskyňa cave	Uranine into ST-HG4	negative							
	Sulforh.B into HG7								
	Tinopal into ST-HG3								

Place of detection	Results of the tracking test using plastic capsules																										
	measurement dates																										
	6.9.2017			13.9.2017			20.9.2017			27.9.2017			12.10.2017			26.10.2017			2.11.2017			9.11.2017			1.12.2017		
Pod Kameňolomom spring		S						S																U		S	
Pri Kaplnke spring															U											S	
Well in the village Jablonov nad Turňou	negative																										
Záhradský potok																											
Hrušovská jaskyňa cave																				S						S	

Explanatory notes: S-sulforhodamine B, U-Uranine

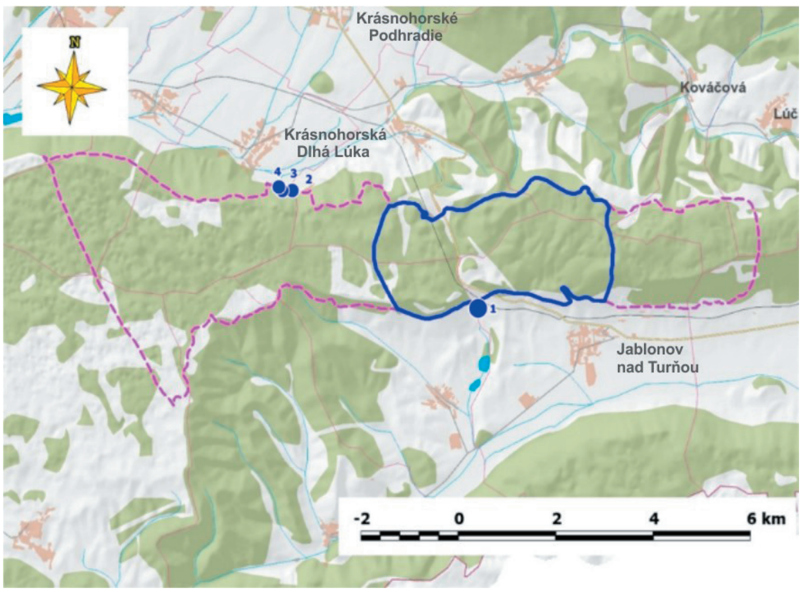


Fig. 10. Probable infiltration area of groundwater drained by the Soroška tunnel (red) and the Eveteš spring (1) infiltration area (blue). Springs Pod Kameňolomom (2), Buzgó (3) and Pri Kaplnke (4) are located at the Krásnohorská Dlhá Lúka municipality.

(Malík et al., 2017). The red line indicates a probable infiltration area of groundwater that can be drained by the Soroška tunnel on an area of 31.792 km^2, including the springs Pod Kameňolomom[2], Buzgó[3], Pri Kaplnke[4] at the Krásnohorská Dlhá Lúka municipality (cf. Fig. 10).

The blue line indicates the probable infiltration area of the Eveteš[1] spring with an area of 9,50 km^2, which is most likely to be drained by the Soroška tunnel. In the processed balance, attention was focused on identifying the magnitude of the Eveteš karst spring infiltration area, where the highest probability of impact was demonstrated. By interpreting the results it can be stated that in the area of the Soroška tunnel it is possible to expect average effective precipitation of 162.9 mm with a measurable discharge of groundwater of 5.2 l.s^{-1}.km^{-2}, being dependent on the hydrological situation, which can be greatly varying. Thus, in the following years, it may also be zero without any infiltration of groundwater (as was the case in the 2012 hydrological year), but also tripled 459.5 mm at a specific runoff of 14.6 $l.s^{-1}.km^{-2}$, as was the case for hydrological year 2010. It is assumed that the Eveteš spring and the feeding waterways of the Eveteš spring may be tapped during the excavation of the tunnel tubes and the whole capacity of the spring may be drained. Taking into account the previous observations of the hydrological period 1964-1997, its yield ranged from 0 to 680 $l.s^{-1}$ with an average value of 46.5 $l.s^{-1}$. The actual size of the spring water drained depend on the technical solution and dimensions of the tunnel pipes and the hydraulic properties of the rock massif through which the tunnel will be driven.

The great attention was given to karst phenomenon during the detailed engineering-geological and hydrogeological survey of the tunnel section, for they will influence the technology of a tunnel excavation to a certain extent. Particular attention will therefore be required to the remediation of these karstic phenomena during the tunnel excavation, whether open caverns protruding into the tunnel tubes or caverns beneath the level of the tunnel tubes, or under the level of the slab track, since it will be of prime importance to ensure the safety of traffic in tunnel tubes. The method of remediation of karstic phenomena (grouting, bridging) will depend on the extent and course.

Conclusions

In the stage of engineering-geological and hydrogeological exploration of the motorway R2 Rožňava – Jablonov nad Turňou, applying engineering-geological drilling, structural analysis supplemented by geological mapping of the surrounding of the tunnel area, the understanding and improved knowledge of engineering-geological, geotechnical and hydrogeological conditions of the area was done.

We found out that the boundary between Szin Beds and Gutenstein Formation is tectonic, represented by an important subhorizontal tectonic zone, dipping towards SW in the area of tunnel tubes. The Gutenstein Fm. displacement vergency towards N-NE over the tectonically overprinted Szin Beds is interpreted taking into account the regional observations. Petrographic analysis determined that the Szin Beds are slightly metamorphosed (typical for Turnaicum). Moreover, in 2.1 km along the Soroška tunnel route the Szin Beds are tectonically reduced along a steep S-vergent overthrust zone oriented towards E-W to ESE-WNW dipping to the N on which the Werfenian rocks (Szin Beds) were shifted over the limestone massif. Results of communication tracking tests showed common direction of the groundwater currents in karstic-fissure environment in the Eveteš groundwater source and Hrušovská jaskyňa cave in Hrušov as well as connections of the tunnel section with springs in the Krásnohorska Dlha Lúka.

In the tunnel tubes quasihomogeneous blocks were selected in which the quality of rock massif based on classifications from Bieniawski (1989) and Tesař (1989) was evaluated. Based on characteristics of selected areas the quality of the rock massif ranges from very bad to satisfactory grade. The quality of the rock massif is influenced mostly by the presence of groundwater, density and spacing of discontinuities, filling and discontinuity orientations. From the geotechnical perspective the distinctive heterogeneity in geotechnical properties mostly in sections with the Werfenian rocks occurrence (Szin Beds and minor occurrences of Bódvaszilas Beds) was observed. Distinctive differences in strength and deformability characteristics were caused by alternation of beds of stronger limestones, sandstones with weaker marlites (marl slate). Another negative factor was represented by common a tectonic zones with occurrences of brecciated rocks, or highly fractured rocks with clay fill.

Based on geotechnical parameters, Middle Triassic limestones and dolomites with the highest strength are the most suitable rocks for the tunnel excavation.

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Inžinierskogeologické, geotechnické a hydrogeologické pomery horninového masívu tunela Soroška

V etape podrobného inžinierskogeologického a hydrogeologického prieskumu úseku rýchlostnej cesty R2 Rožňava – Jablonov nad Turňou sa realizáciou inžinierskogeologických vrtov a štruktúrnou analýzou doplnenou geologickým mapovaním okolia trasy tunelového úseku zhodnotili a spresnili poznatky o inžinierskogeologických, geotechnických a hydrogeologických pomeroch územia.

Územie, ktorým prechádza tunel Soroška, patrí do subprovincie Vnútorné Západné Karpaty, do oblasti Slovenského rudohoria, celku Slovenský kras s podcelkami Silická planina a Horný vrch. Masív má zložitú geologicko-tektonickú stavbu s výraznými krasovými procesmi. Pre územie Slovenského krasu je charakteristický krasový typ reliéfu s plochými planinami, rozčlenenými veľmi strmými okrajovými svahmi s výskytom závrtov, škrapov, priepastí a jaskýň. Jeho horninové prostredie tvoria spodno- až strednotriasové horniny mezozoika silického príkrovu masívu Silickej planiny a Horného vrchu (Kozur a Mock, 1973 a, b; Mello, 1996) a kvartérne deluviálne/proluviálne sedimenty.

Tunel Soroška je súčasťou rýchlostnej cesty R2 Rožňava – Jablonov nad Turňou, ktorej dĺžka je 14,1 km. V zmysle STN 737507 je naprojektovaný ako tunel kategórie 2T-8,0 s dočasnou obojsmernou premávkou cez severnú tunelovú rúru (STR). Projekčne sú navrhnuté dve tunelové rúry s označením tunel Soroška (severná tunelová rúra) a úniková štôlňa (južná tunelová rúra). Celková dĺžka tunela (severná tunelová rúra) je 4 264,3 m, v staničení tunela 0,528 7 – 4,793 km. Samotný tunel Soroška je situovaný súbežne s Jablonovským železničným tunelom vo výškovej úrovni zhruba 50 m pod železničným tunelom.

Skúmané územie má komplikovanú geologicko-tektonickú stavbu. V trase tunela majú najvýraznejšie zastúpenie systémy zlomov priebehu SV – JZ a V – Z až VJV – ZSZ so sklonom na SZ a S, zlomy s priebehom SZ – JV so sklonom na SV a zlomy s priebehom S – J so sklonom na Z aj V (obr. 1). Na zlomoch smeru SZ – JV a V – Z až VJV – ZSZ bol preukázaný smer prúdenia stopovačov z vrtov v trase tunela unášaných prúdom podzemnej vody smerom k vodnému zdroju Eveteš a prameňom v Krásnohorskej Dlhej Lúke.

Najstarším členom v skúmanom území v úseku 4,525 – 4,725 km trasy tunela sú bodvasilašské vrstvy (griesbach – namal; Kovács et al., 1989) reprezentované pestrými ílovitými bridlicami a jemnozrnnými pieskovcami v rôznom stupni zvetrania. Merania štruktúrnych prvkov v odkryvoch poukazujú na to, že tieto vrstvy sú generálne sklonené na sever, s priemerným sklonom 50 – 60°.

V nadloží bodvasilašských vrstiev v úseku 0,5 – 1,725 km a 4,2 – 4,525 km trasy tunela vystupujú sinské vrstvy (namal – spat; Kovács et al., 1989) tvorené striedajúcimi sa laminami a vrstvami ílovitých bridlíc, jemnozrnných vápnitých pieskovcov, slieňovcov a slienitých vápencov. Petrografické analýzy v sinských vrstvách preukázali, že tieto vrstvy sú slabo metamorfované (typické pre turnaikum). Meraniami štruktúrnych prvkov na odkryvoch, ako aj vo vrtoch sme zistili, že sinské vrstvy sú v úseku 0,5 – 1,725 km trasy tunela prevažne sklonené na J, s priemerným sklonom 40 – 50°, a v úseku 4,2 – 4,525 km sú tieto vrstvy generálne sklonené na S, s priemerným sklonom 45 – 70°. Mikrotektonická stavba v úseku 0,5 – 1,1 km trasy tunela poukazuje na detailné tektonické prepracovanie hornín, ktoré sa prejavuje výrazným prevrásnením a zbrekciovatením hornín s vrásovými a poklesovo-prešmykovými štruktúrami (obr. 2). Karbonátové vrstvičky sú miestami detailne prevrásnené na systém disharmonických izoklinálnych ptygmatických vrás, ktoré sú redukované a prestrihnuté strmými poklesovo-prešmykovými diskontinuitami. Karbonatické polohy sú často vrásovo deformované, v niektorých polohách aj budinované. V plastickejších polohách slieňovcov sú karbonáty budinované na šošovky. Sinské vrstvy sú porušené tektonickými poruchami, ktorých priebeh je často zhodný s vrstvovitosťou a ktoré sú vyplnené pevnými tektonickými brekciami. Okrem týchto tektonických porúch sa vo vrtoch zistili a geofyzikálnymi metódami indikovali aj strmé tektonické poruchy, ktoré sú vyplnené rozdrvenou horninou a úlomkami. Prebiehajú prevažne v smere SV – JZ, kolmo na tunelové rúry. V úseku 2,1 km trasy tunela sú sinské vrstvy tektonicky redukované pozdĺž strmej tektonickej prešmykovej línie s priebehom V – Z až VJV – ZSZ sklonenej na S, na ktorej je verfénske súvrstvie juhovergentne vyzdvihnuté a nasunuté na vápencový masív (obr. 1, 3, 6). Táto priepustná tektonická línia vyplnená vodou (zachytená v dvoch vrtoch) je porušená mladšou subvertikálnou až vertikálnou štruktúrou smeru SV – JZ, na ktorej sú založené dominantné jaskynné systémy (kaverny s výškou od 13 do 20 m zistené vo vrtoch; Szabó in Grenčíková et al., 2018). Štruktúrne analýzy z orientovaného jadra v priestore, kde sú sinské vrstvy tektonicky redukované v intervale 160 – 190 m, poukazujú na prednostnú orientáciu štruktúr (zlomy) v smere SV – JZ so sklonom na SZ (obr. 3c). Na základe vyhodnotenia orientovaných štruktúr vo vrtoch, konštrukcie rezov, geofyzikálnych meraní (Komoň in Grenčíková et al., 2018; Záhorec in Grenčíková et al., 2018) a v neposlednom rade získaných údajov z razenia Jablonovského tunela (evidenčný list č. 430) so zistením rozhrania vápencového masívu a verfénskych vrstiev v danom priestore sme zistili, že výrazná prešmyková línia má priebeh v smere V – Z až VJV – ZSZ.

Fácie karbonátovej platformy stredného triasu v úseku 1,725 – 2,3 km trasy tunela sú zastúpené gutensteinským súvrstvím (spodný anis), ktoré tvoria tmavosivé lavicovité a doskovité vápence, dolomity, brekcie a rauvaky. Teleso gutensteinských vápencov je uložené plytko, má hrúbku do 60 m a generálne je sklonené na J a JZ, so sklonom 20 – 45°. Prechod z podložných sinských vrstiev do nadložného gutensteinského súvrstvia je tektonický a zistil sa vo vrtoch (obr. 6). Ide o významnú subhorizontálnu severovergentnú násunovú tektonickú líniu hrubú do 20 m v oblasti tunelovej rúry s priebehom v smere SZ – JV, sklonenú na JZ, v širšom okolí skúmaného územia s priebehom SZ – JV a V – Z (Szabó in Grenčíková et al., 2018).

V nadloží gutensteinského súvrstvia v úseku 2,350 – 4,2 km trasy tunela vystupujú steinalmské a wettersteinské vápence (anis, bityn – ilýr; Schréter, 1935; Balogh, 1940; Pia, 1940; Bystrický, 1964). Sú svetlé, masívne, organogénne, miestami až brekciovité, s krasovými prejavmi a sú generálne sklonené na J a JZ, so sklonom 20 – 45°. Ich rozlíšenie je možné len na základe zistených fosílií, preto sú na geologickej mape a v profile vyznačené len na základe petrografickej analýzy vzoriek z vrtov a povrchu a hranica ich rozlíšenia je vyznačená čiarkovane. Vo vrtoch aj na povrchu sa zistili aj polohy reiflinských a pseudoreiflinských (vrchný anis – ladin), jemne laminovaných vápencov a polohy dachsteinských a schreyeralmských vápencov patriacich k svahovým a panvovým fáciám karbonátovej platformy (Soták in a Grenčíková et al., 2018). Ich určenie sa opiera o podobný litofaciálny charakter pri neprítomnosti mikrofosílií. V masíve sú zistené prevažne strmé tektonické poruchy, z ktorých viaceré sú pravdepodobne vyplnené vodou, s priebehom SV – JZ, S – J a V – Z, lokálne skrasovatené s výskytom jaskýň, a zlomy s priebehom SZ – JV a SV – JZ s kinematikou sinistrálnych a dextrálnych smerných posunov. Vo vrtoch sa zistili aj subhorizontálne zlomy s výplňou tektonického ílu, na ktorý je viazaná sulfidická mineralizácia (FeS_2) tvorená kubickými kryštálmi pyritu s veľkosťou do 0,5 cm. V úseku 3,250 km trasy tunela v hĺbke 30 m je vo vrtoch zistená krasová dutina (časť jaskynného systému s dĺžkou min. 150 m) prebiehajúca v smere SV – JZ (Szabó in Grenčíková et al., 2018; obr. 4). Na základe dokumentácie vrtov môžeme konštatovať, že v priestore trasy tunela Soroška vystupujú minimálne 4 výškové úrovne (horizonty) krasových dutín. Sú zistené od povrchu v hĺbke s rozsahom 30 – 45 m, 50 – 80 m, 90 – 110 m a 240 m.

V tunelových rúrach boli vyčlenené kvázihomogénne bloky (tab. 1), v ktorých bola hodnotená kvalita horninového masívu na základe klasifikačných systémov RMR (Bieniawski, 1989) a QTS (Tesař, 1989). V úseku severnej tunelovej rúry bol masív rozčlenený na základe IG štruktúrnych vrtov a geofyzikálnych metód na 22 úsekov – kvázihomogénnych úsekov (tab. 1) s podobnými inžinierskogeologickými a geotechnickými charakteristikami horninového masívu, ktoré sú definované na základe zastúpenia jednotlivých litologických typov hornín, stupňa pevnosti, zvetrania, tektonického porušenia, vrstvovitosti, roztvorenosti, výplne, hustoty puklín, RQD, klasifikácie podľa RMR a QTS a prítomnosti podzemnej vody. Tieto charakteristiky majú najväčší vplyv na spôsob razenia, dĺžku jednotlivých záberov a stabilitu masívu. V úseku južnej tunelovej rúry bol masív rozčlenený na základe IG štruktúrnych vrtov a geofyzikálnych metód na 25 úsekov – kvázihomogénnych úsekov.

Kvalita horninového masívu v oblasti portálových úsekov je veľmi zlá. Na ZP vzhľadom na prítomnosť deluviálnych sedimentov v úvodných metroch, zónu zvetrania a tektonicky porušené, rozpukané horniny môžeme očakávať veľkú nestabilitu čela vyrúbu, bočných stien a stropu kaloty a vznik nadvýlomov s prítomnosťou podzemnej vody. Na VP je zistené stabilizované zosuvné teleso. Pri razení v prevažne zvetraných a tektonicky porušených horninách s nízkym nadložím a šmykovou plochou zosuvného delúvia budú strop kaloty, čelo výrubu a bočné steny veľmi nestabilné, s vypadávajúcimi úlomkami v strope a vznikom nadvýlomov s prítomnosťou podzemnej vody.

V trase tunela sú podľa geotechnických klasifikácií ako najhoršie hodnotené kvázihomogénne bloky 8, 17 (9, 20 v JTR), blok 11 (12 v JTR) a bloky 13 a 15 (14, 18 v JTR). Tieto úseky sú charakterizované na základe prítomnosti rôznych litologických typov (prechod z vápencového masívu do sinských vrstiev; obr. 6) a rôznych geotechnických vlastností, ako aj prestúpením masívu strmými aj subhorizontálnymi tektonickými poruchami a výskytom krasových dutín v úrovni tunela. Vzhľadom na prítomnosť kaverien a prestúpenie masívu strmými aj subhorizontálnymi tektonickými poruchami, z ktorých viaceré sú pravdepodobne vyplnené vodou, sa predpokladá, že masív bude v týchto úsekoch výrazne tektonicky porušený, s veľkou nestabilitou čela výrubu a stropu kaloty, lokálne aj bočných stien, so vznikom nadvýlomov a s väčšími prítokmi podzemnej vody.

Hydrogeologické pomery v študovanom území trasy tunela Soroška sú podmienené geologickou stavbou územia, tektonickým porušením a geomorfologickými, hydrologickými a klimatickými pomermi územia. Tunel Soroška bude razený v dvoch litologicky odlišných prostrediach.

Západný portál tunela je umiestnený do nehomogénneho prostredia svahov budovaných kvartérnymi deluviálnymi a proluviálnymi sedimentmi. Podzemná voda je akumulovaná v kvartérnych deluviálnych íloch a sutinách s výplňou piesčitých ílov a proluviálnych íloch, ktoré z hydrogeologického hľadiska predstavujú kolektor s akumuláciou podzemnej vody s medzizrnovou priepustnosťou a so vztlakovými účinkami. Podložie kvartérnych zemín budujú silne zvetrané slienité bridlice, ílovce a vápence sinských vrstiev.

Východný portál tunela je umiestnený do svahov budovaných kvartérnymi deluviálnymi sedimentmi a zeminami zosuvného delúvia. Z hydrogeologického hľadiska predstavujú bodvasilašské vrstvy a sinské vrstvy s prevládajúcou puklinovou priepustnosťou hydrogeologický izolátor bez významného zvodnenia alebo významnejších akumulácií podzemnej vody. Podzemná voda sa však môže akumulovať v ich stykovej zóne a v pripovrchovej zóne rozloženia alebo zvetrania. Podzemná voda môže byť viazaná aj na tektonicky porušené zóny, kde môže zostupovať aj do hlbších úrovní.

Tunelový úsek sa bude raziť v horninovom prostredí sinských a bodvasilašských vrstiev verfénu s puklinovou a medzirnovou priepustnosťou aj v prostredí mezozoických karbonátov silického príkrovu s puklinovou a puklinovo-krasovou priepustnosťou. Priepustnosť horninových sekvencií sa overovala vodnotlakovými skúškami. V sinských vrstvách podľa klasifikácie priepustnosti hornín (Jetel, 1982) ide o dosť slabo priepustné prostredie s triedou priepustnosti V až veľmi slabo priepustné prostredie s triedou priepustnosti VII. V strednotriasových karbonátoch podľa klasifikácie priepustnosti hornín ide o dosť silno priepustné prostredie s triedou priepustnosti III až veľmi slabo priepustné prostredie s triedou priepustnosti VII (Coplák et al. in Grenčíková et al., 2018). V stykovej zóne krasových a nekrasových hornín sa odhadoval aj najvyšší okamžitý prítok podzemnej vody do každej z tunelových rúr pri raziacich prácach približne 30 – 35 l . s^{-1} (Szabó in Grenčíková et al., 2018).

V rámci prieskumu sa riešila problematika nielen posúdenia vplyvu hydrogeologických pomerov na razenie projektovaného cestného tunela Soroška, ale aj posúdenie vplyvu tunela na kvantitu a kvalitu vodárensky využívaných zdrojov pitnej vody v dotknutých obciach, zdrojov individuálneho zásobovania studňami a tiež problematika drenážneho dosahu vplyvu tunela na kvantitu povrchových tokov v území. S týmto cieľom sa realizovali stopovacie skúšky na overenie vzájomnej komunikácie podzemnej vody medzi jednotlivými časťami hydrogeologickej štruktúry (obr. 7). Výskyt bol monitorovaný na 11 kontrolných miestach (v NPR Hrušovská jaskyňa, vo využívaných vodárenských zdrojoch pitnej vody Eveteš, Mezeš a Studená studňa, v Záhradskom potoku, v troch prameňoch v Krásnohorskej Dlhej Lúke, na dvoch bočných prítokoch do hlavného toku v NPR Krásnohorská jaskyňa a v studni v obci Jablonov nad Turňou).

Stopovacími skúškami sa preukázalo vzájomné prepojenie a smery prúdenia podzemnej vody, rýchlosť prúdenia stopovača unášaného prúdom podzemnej vody, čas zdržania v masíve, a najmä hydrologické prepojenie podzemnej vody v úseku staničení tunela v km 2,13, v km 2,3 a v km 3,24 s prameňom Eveteš. Na rozsah freatickej zóny poukazuje vypočítaná rýchlosť (tab. 2), akou sa stopovače dostali z miest ich aplikácie do pramenného vývеru krasového prameňa Eveteš. Hydroindikačnými skúškami sa počas podrobného prieskumu zároveň preukázalo, že hydrogeologická štruktúra, ktorej časťou bude razený tunel Soroška, je sčasti zároveň aj zbernou oblasťou podzemnej vody prameňov Pri kaplnke a Pod kameňolomom v Krásnohorskej Dlhej Lúke. Zberná oblasť týchto prameňov sa v minulosti zisťovala stopovacími skúškami v strednej časti Silickej planiny (Roda et al., 1986; Erdös, 1995), ale našimi stopovacími skúškami sa preukázalo, že zberná oblasť týchto prameňov je rozšírená až do oblasti priesmyku v Jablonovskom sedle, kde sa predpokladá hydrologické rozhranie štruktúry Veľkej skaly a Horného vrchu. Prítomnosť stopovača rodamín B aplikovaného do vrtu HG7 v stykovej zóne krasových a nekrasových hornín, ktorý bol detegovaný v Hrušovskej jaskyni, poukazuje na možné podzemné prepojenie, resp. aj pokračovanie ďalších, doteraz nezmapovaných podzemných priestorov Hrušovskej jaskyne. Treba ale podotknúť, že stopovacie skúšky prebiehali za nízkeho stavu nasýtenia masívu podzemnou vodou, keď mohol byť obeh podzemnej vody v niektorých častiach masívu utlmený a vzhľadom na dlhší transportný čas stopovače na niektorých miestach počas stopovacej skúšky trvajúcej 3 mesiace nemuseli byť detegované (tab. 2).

Základným predpokladom hodnotenia dosahu razenia, ale aj prevádzky tunela na odtokové pomery územia bolo vyčlenenie infiltračnej oblasti prameňa Eveteš odvodňujúceho Silickú planinu a planinu Horného vrchu. Predpokladá sa, že pri razení tunelových rúr a nafáraní prívodných ciest prameňa Eveteš môže byť znížená aj výdatnosť prameňa Eveteš. Vzhľadom na doterajšie pozorovania výdatnosti za hydrologické roky 1964 – 1997 sa jeho výdatnosť pohybovala od 0 do 680 l . s^{-1} s priemernou hodnotou 46,5 l . s^{-1}. Reálne množstvo drénovanej vody prameňa bude závisieť od technického vystrojenia a dimenzovania tunelových rúr a hydraulických vlastností hornín, cez ktoré bude tunel razený.

Počas podrobného inžinierskogeologického a hydrogeologického prieskumu tunelového úseku sa venovala pozornosť aj krasovým javom, pretože do určitej miery budú ovplyvňovať technológiu razenia. Zvláštnu pozornosť si preto počas razenia tunela vyžiada sanácia týchto krasových javov, či už ide o otvorené kaverny zasahujúce do priestoru tunelových rúr, alebo kaverny pod niveletou dna tunelových rúr alebo pod úrovňou pevnej jazdnej dráhy, lebo prvoradé bude zaistiť bezpečnosť komunikácie v tunelových rúrach. Spôsob sanácie krasových javov (injektáž, premostenie) bude závisieť od ich rozsahu a priebehu.

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