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The Cave under the Spišská hill: Preliminary monitoring results of the block movements

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Abstract

The Cave under the Spišská hill (Levočské vrchy Mts.) is the longest pseudokarst cave in Slovakia. Together with other caves it was formed by the movement of sandstone blocks and slabs along the bedding planes and fissures on the south and southeast slopes of the Spišská hill during the Quaternary. The movement can be defined as lateral spreading and very slow rock block sliding, less as toppling. Block movements inside the cave are monitored by the crack gauge of the TM-71 type since April 2007. The device is based on the moiré effect and is capable to detect 3D micro-displacements along three Carthesian coordinates – X, Y and Z with the accuracy up to 0.01 mm and rotations up to 0.01 [π/200]. The paper summarizes the preliminary monitoring results and provides their interpretation.

Key words: block movements, monitoring results, pseudokarst cave, Levočské vrchy Mts., Slovakia

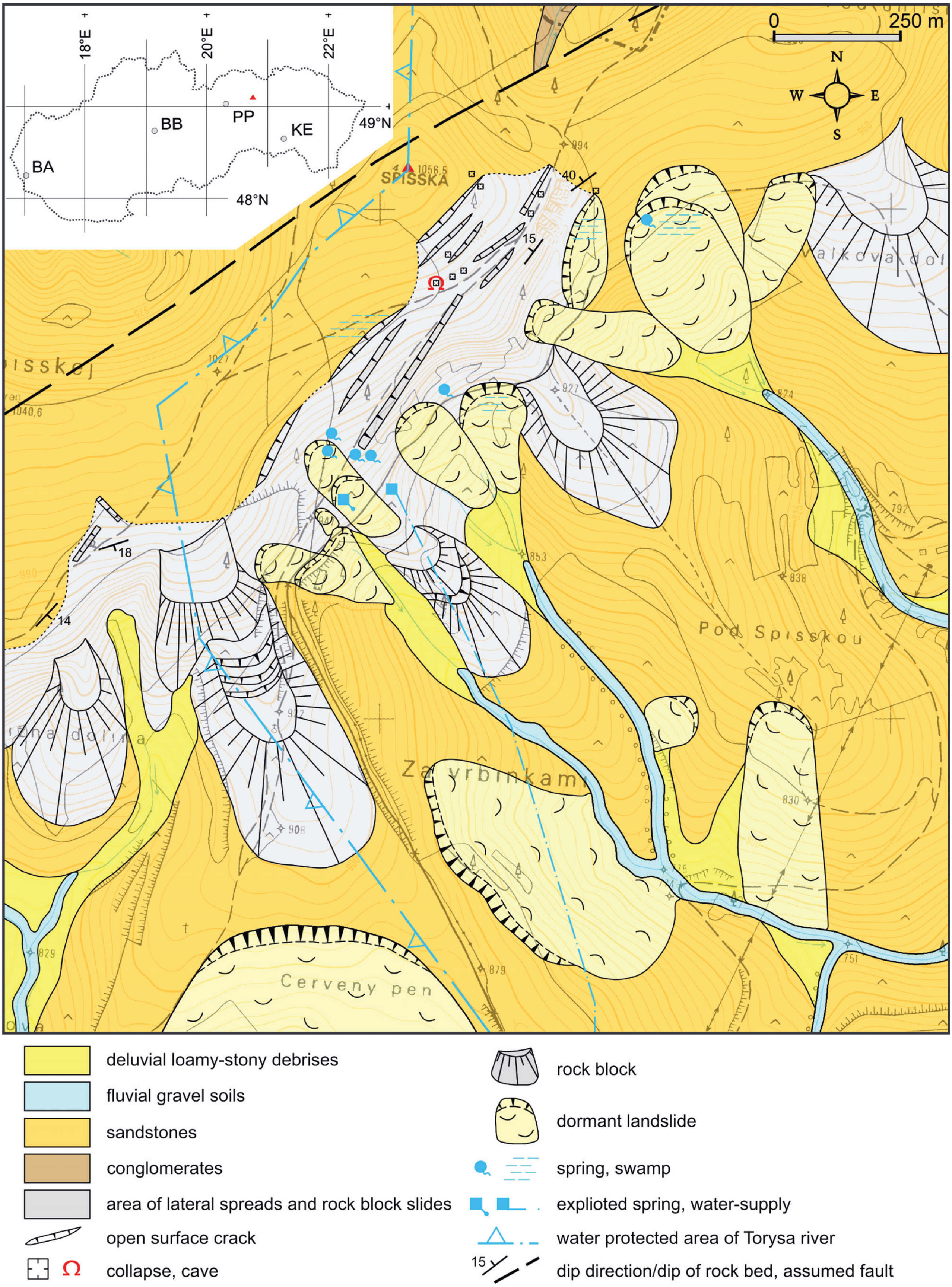
Introduction

The block failures represent one of the main types of the slope movements in Slovakia. They are represented by the lateral spreading and rock block sliding. They originate in the solid and semi-solid rocks with plastic underlier (e.g. claystones, siltstones, clays, silts) preferably due to the gravitation. Also block failures occur here with displacements along the predestined slip surface. Besides the gravitation, the tectonic predisposition (joints and faults) plays an important role in this case. The rate of the blocks displacement reaches several mm to cm per year. These failures are preferably concentrated into areas (Nemčok, 1982), where besides the above stated lithological contrast the bedding has a favourable dip towards the valleys. Such structures are relatively frequent also in the Levočské vrchy Mts. (Gross et al., 1999b).

In Slovakia the block failures occur mainly in the territories built by flysch and volcanic rocks (Nemčok, 1982), less by Mesozoic rocks, eventually other sedimentary sequences (Maas and Ondrášik, 1998; Nemčok and Baliak, 1977). Their occurrence is known also in travertines (Fussgänger, 1985; Vlčko, 2004). The Spišská hill massif (1 056.5 m a.s.l.) is typical site with extended block failures. It represents one of the highest peaks of the Levočské vrchy Mts., being located app. 2 km to NW of the Brutovce village (Levoča district). A relatively dense net of the block failures has originated on its southern and south-eastern slopes (Fig. 1). Mutually separated and shifted blocks of sandstones, less conglomerates, have formed a complicated net of underground spaces and the pseudokarst caves. The Cave under the Spišská hill represents the largest one from the viewpoint of the length of corridors (Imrich et al., 2007). The occurrence of the pseudokarst caves in other parts of the Levočské vrchy Mts. was described by Pavlarčík (1985), Pavlarčík and Vadovský (1994), Bella (1995) a.o.

Based on the project *Partial monitoring system – Geological factors*, subsystem *Landslides and other slope deformations*, one extensometer of TM-71 type (Fig. 2) was installed in the Cave under the Spišská hill in April 2007. The monitoring is financed by the Ministry of the Environment of the Slovak Republic. The extensometer represents a mechano-optical device applying the moiré principle. A long-time monitoring aimed to find the kinematics of the slow movement of the rock blocks and to predict the future evolution, as well as its eventual impacts on environment. In relation with the eventual construction of the water reservoir Tichý Potok the research obtained also a practical importance. The construction of the dam is planned in the Torysa valley (north of the Spišská massif), near the hill Čierna hora (1 090.6 m a.s.l.). The extended block failures were found on its southern slopes (Nemčok, 1982; Baliak and Malgot, 2008). A big pseudokarst cave system was developed also at this site (Majerníčková and Imrich, 2010).

The preliminary results of the block failures monitoring in the surrounding of the Cave under the Spišská hill with



0
250 m
N
W
E
S
18°E
20°E
22°E
49°N
48°N
BA
BB
PP
KE
SPISSKA
1056,5
994
40
15
18
14
1027
1040,6
927
853
824
838
792
830
751
829
879
908
Pod Spisskou
Za vrbinkami
Cerveny pen
deluvial loamy-stony debrises
fluvial gravel soils
sandstones
conglomerates
area of lateral spreads and rock block slides
open surface crack
collapse, cave
rock block
dormant landslide
spring, swamp
exploited spring, water-supply
water protected area of Torysa river
15
dip direction/dip of rock bed, assumed fault

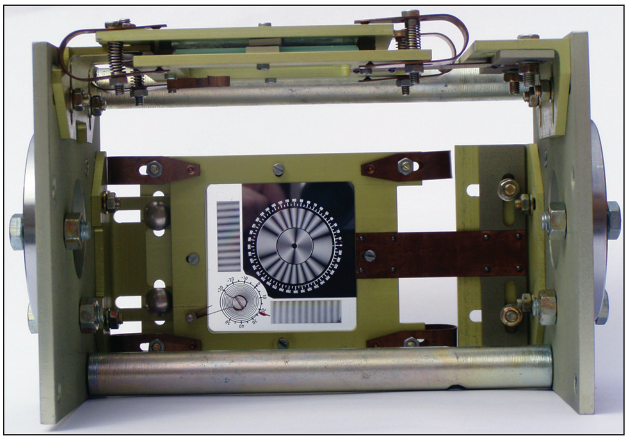


Fig. 2. The TM-71 mechanical-optical extensometer based on moiré effect used for 3D detection of the micro-displacements of rock blocks or tectonic movements.

Fig. 3. Fine-grained sandstone with a thin coal interbed (Cave under the Spišská hill). Photo by Petro (2007).

the short geological and tectonic descriptions of the studied area, as well as the cave alone, are presented in this contribution. If a construction of the water reservoir Tichý Potok is agreed, obtained results will be usable for the detail investigation of the surrounding area of the dam body.

Geological setting

Wider surrounding of the cave is built by the sediments of the Central Carpathian Paleogene Basin. They are divided into several formations forming the Subtatric Group of the Central Western Carpathians (Gross et al., 1983, 1999a, b). From the base upwards there were distinguished the Borové, Huty, Zuberec and Biely potok formations. The sequences of the last three mentioned formations build the Levočské vrchy Mts. According to the latest opinions the sediments have originated prevailingly in the deep-sea environment (besides the Borové Formation) in the period from the Middle Eocene (Bartonian) to Lower Miocene (e.g. Soták et al., 2001). After Oligocene, these sediments together with their older underlier were faulted during the Helvetian and younger phases of the Alpine orogeny. The fault systems are directed E–W, NW–SE, NE–SW and N–S (Gross et al., 1999a, b).

The immediate surrounding of the cave is formed by the sediments of the Biely potok Formation, forming the uppermost as well as youngest part of the Subtatric Group. Sediments are represented by the clastics of various granularities. The distinct prevalence of sandstones (less conglomerates) above mudstones is typical. Sandstones are classified as greywackes, less as greywacke and arkosic sandstones or carbonatic (limestone) sandstones. They are prevailingly medium- to very coarse-grained, massive, locally with preserved gradation. The fine-grained conglomerate is also present, though in smaller amount, in the lower part of the thicker beds. Sandstone beds reach thickness from 30 cm up to more than 4 m and alternate with the distinctly thinner mudstone beds (maximum thickness up to 5 cm). The finer-grained upper parts of the sandstone beds are horizontal, sinusoidal to ripple-cross laminated, and some have higher content of the white mica and coalified plant detritus. Only rare occurrences of the thin discontinuous coal beds are known (Fig. 3). The massive parts of the beds are characteristic with the presence of claystone intraclasts, being in numerous cases weathered with remaining distinct holes. The lower bed plains are bearing various sedimentary structures (e.g. flute and groove casts) originating during the transport and deposition of the sedimentary material from the various sedimentary gravity flows, as well as structures originating after the deposition of the sediment on the muddy sea bottom (load casts).

The sandstone beds are laying relatively flat in general NE–SW direction. Their mean dip to SE does not overreach 20°. The joint systems in the Spišská massif (Imrich et al., 2007) have regional directions, being generally demonstrated by Plička (1968) in his study of the Central Carpathian Paleogene Basin. This phenomenon was confirmed in the Podhale Basin in Poland by Boretti-Onyszkiewicz (1968), Mastella and Ozimkowski (1979) and the most recently by Ludwiniak (2010) in the Podhale Basin in Poland.

Based on geometric relationship of joints to the bedding (strike of beds) observed in the cave, the systematic joints were classified as diagonal joints D_R trending NNW–SSE and D_L trending NNE–SSW, longitudinal joints L trending ENE–WSW (E–W), sub-longitudinal joints $L´$ trending NE–SW and transverse joints T trending N–S (Imrich et al., 2007). A sparse occurrence of the T joints is interesting and of regional significance (Ludwiniak, 2010).

Geological and tectonic settings of the surrounding of the Cave under the Spišská hill are described in more details by Imrich et al. (2007).

Due to faulting of the flat-laying beds by the subvertical joints, being perpendicular to beds, and by the simultaneous

◀ **Fig. 1.** Geological map of the Spišská hill (Levočské vrchy Mts., Slovakia) with the distribution of main block failures (lateral spreadings and rock block slides), landslides and the pseudokarst Cave under the Spišská hill (according to Antonická and Fussgänger, 1998, modified).

action of gravitation, the intensive disintegration and fracturing of the south and southeast slopes of the Spišská massif have occurred. Due to disintegration of the sandstone beds there occur rock blocks of various dimensions, being separated by the fractures wide some cm to m (maximum 4 m). The blocks separation caused the origin of a net of underground passages. Until recent the detail investigation has revealed altogether 14 separate caves in the close surrounding of the apical parts of the Spišská hill (Fig. 1). In the particular case of the Cave under the Spišská hill the block movements were speleologically verified down to depth 25 m beneath the surface (Imrich et al., 2007). It is supposed that the depth of the block disintegration, resp. depth of the block failures reach down to 40 m. Besides the block failures numerous landslides as well as rare toppling were found.

The cave description

The Levočské vrchy Mts. belong among the most impressive pseudokarst regions in Slovakia. The Cave under the Spišská hill is located in the apical part of the Spišská massif (N = 49°06´14.4´´; E = 20°45´45.3´´). It is the longest pseudokarst cave in the territory of Slovakia (Imrich et al., 2007). The total length of until investigated passages is 740 m. The speleologists from the Speleoclub Šariš (2004 to 2006) and the Beskydy speleological club Debica (2006) greatly contributed by the mapping and precise measuring of the cave. The Cave under the Spišská hill and further 13 caves in this area represent a unique natural phenomenon. The absence of the cave decoration (speleothems) is caused by the subsidiary presence of carbonatic component in the sandstones. Therefore the occurrence of stalactites and sinters on the walls is very rare.

The origin of underground spaces in this site was influenced by the favourable geological factors. Firstly, it was a thick complex of sandstones with rare thin interbeds of mudstones and siltstones. The deep erosion of the slopes of the massif, as well as tectonic processes caused the relaxation of the tension stresses in the beds and a consequent origin of fractures. By means of gravitation the process of the massif disintegration has started and progressed into the stage of the block separation and origin of lateral spreading and rock block sliding. The origin of the atectonic joints in the thick sandstone beds cannot be excluded (Margielewski, 2006). The distribution of the superficial fractures is evident in Fig. 1. Internal spaces of the cave have character of elongated, mostly NE–SW (ENE–WSW) trending passages, originating after the sliding of individual blocks of sandstones. The width of passages is of dm to m order (Fig. 4 and 5). Numerous passages are barred by smaller blocks downfallen from the overlier or upper parts of the side walls. Locally there is possible to register the rotation of particular blocks,

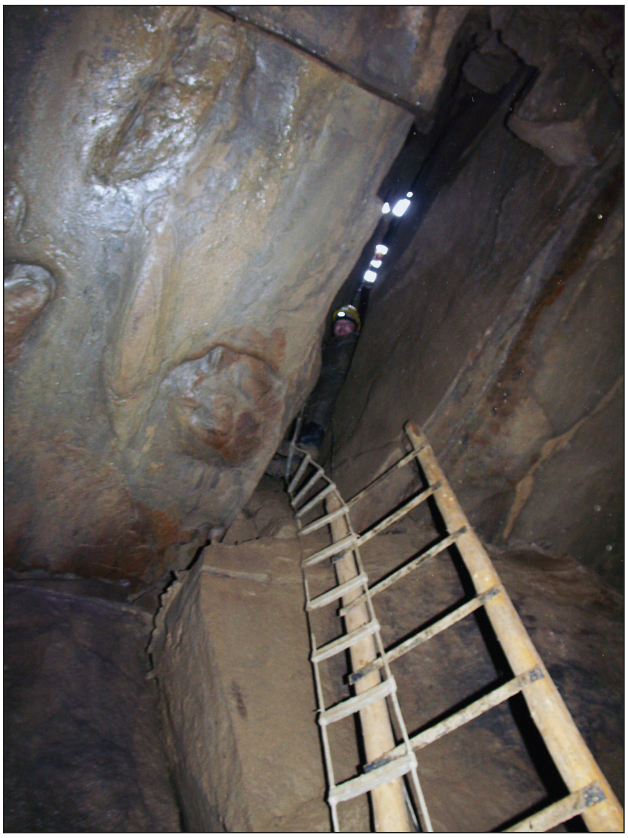


Fig. 4. Entrance to the Cave under the Spišská hill (about 12 m height and 40 cm wide sub-vertical fissure). Photo by Hajduk (2005).

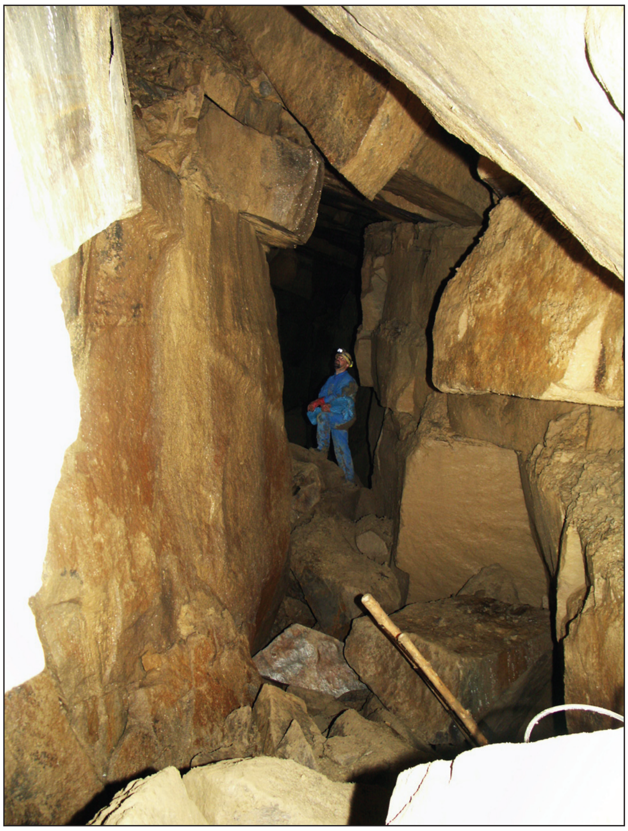


Fig. 5. Entrance to the Timur´s dome (Cave under the Spišská hill). Photo by Hajduk (2005).

so the dip of beds to NW does not correspond with the original bedding. In several places between two sandstone blocks lying one another, thin (several cm) beds of strongly weathered mudstones were found. Due to leakage of the superficial water the mudstones were changed to clays. Along such interbeds, but also along primary bedding the slow shift of overlying rock beds (blocks) occurs downward the slope.

Based on above stated facts and classifications used in Slovakia (Vítek, 1981; Bella, 1994; Gaál, 2003) the Cave under the Spišská hill can be characterized as (epigenetic) displacement crevasse cave. In the frame of the complex of pseudokarst caves in the Spišská massif, in the periphery parts of the slope, where block rotation applies, also declined and inclined crevasse caves were observed (Gaál, 2003).

Monitoring method

Because the supposed slow ***creeping*** movement of rock blocks, we used as a measurement device the mechanical-optical extensometer of TM-71 type, being approved in the praxis (e.g. Košťák, 1977; Fussgänger, 1985; Petro et al., 1999, 2004; Vlčko and Petro, 2002; Vlčko et al., 2002; Vlčko, 2004). This apparatus is protected by two patents in the Czech Republic (Nos. 131631 and 246454). It works on the mechanical-optical principle (Košťák, 1969, 1991). The relative movement of two neighbouring blocks along observed failure is realized by the mutual shift of two measurement units (plates) being equipped by optical grids and oriented in two mutually perpendicular planes (Fig. 2). The shift is evaluated as an eccentricity of fringe patterns. Data are obtained in the direction of coordinates *X*, *Y*, *Z* (displacements) as well as in the planes *XY* and *XZ* (rotations). For the easier interpretation of particular shifts, the *X* axis during its installation is oriented into the horizontal plain perpendicular to fracture direction and oriented into the massif. Axis *Y* is lying also in the horizontal plane and is perpendicular to *X* axis. Axis *Z* is vertical. Using this orientation of axes the displacements along them are oriented by the following way: *X* – change of the fracture width (extension, contraction), *Y* – horizontal shift of blocks in the fracture direction, *Z* – vertical shift (subsidence or uplift) of one block along the fracture. Besides displacements there is observable and measurable also rotation of blocks, in both – horizontal plane *XY*, resp. vertical plane *XZ*. Measuring by the device TM-71 allows the displacement accuracy 0.01 mm and rotation accuracy 0.01 [π/200]. Concerning the relatively stable microclimatic conditions in the cave (average annual air temperature 5 °C varies in the range +/– 1 °C), the temperature influence on the measuring accuracy is only minimal.

The selection of the space suitable for the location of the extensometer has respected its technical parameters and site accessibility. The apparatus was placed in one of the main passages of the cave, near the place named Crossing, located in the north-eastern Spiš part of the Cave under the Spišská hill (Imrich et al., 2007) on 27. 4. 2007 (Fig. 6). The passage has a character of the subvertical ENE–WSW trending tectonic joint. Up to present altogether 15 visual readings were done with the frequency 3–4 readings per year. The evaluation of the measured data was done by means of the special software MS-Dilat.

Fig. 6. Installation of the TM-71 extensometer inside one of the main passages of the Cave under the Spišská hill (behind the place called Crossing). The NE–SW oriented passage (footwall) has inclination of 12°. Photo by Petro (2007).

Results of measurements and their valuation

More than four years lasting monitoring of the block movements in the Cave under the Spišská hill by the device TM-71 can be regarded as sufficiently long for preliminary interpretation of the results. From the graph of displacements (Fig. 7a) there is evident a progressive trend of widening (opening) of the fracture and a subsidence of the southern, i.e. lower block in comparison with the opposite northern block. Total until registered value of the fracture widening (displacement in the direction of the axis *X*) from April 2007 reached 0.290 mm. The average annual value of the displacement represents 0.0725 mm. Simultaneously with the widening of the fracture the extensometer has confirmed a total subsidence (shift in direction of *Z* axis) of southern block by 0.150 mm, annually representing 0.05 mm per year. The sliding along the monitored fracture (in direction of the axis *Y*) can be evaluated as negligible. Similarly insignificant ($\leq 0.05 \times \pi/200$) is also a rotation movement of blocks in the planes *XY* and *XZ* (Fig. 7b).

There is interesting also a comparison of measurement results obtained by the extensometer TM-71 and registered

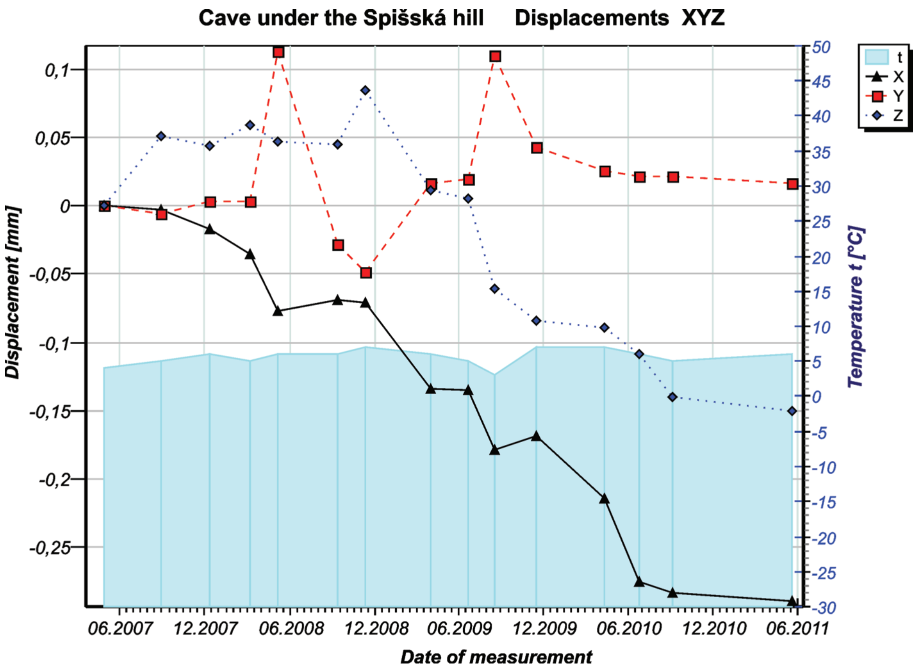


Fig. 7a. Diagram of 3D displacements of sandstone blocks located inside the Cave under the Spišská hill since 27. 4. 2007.

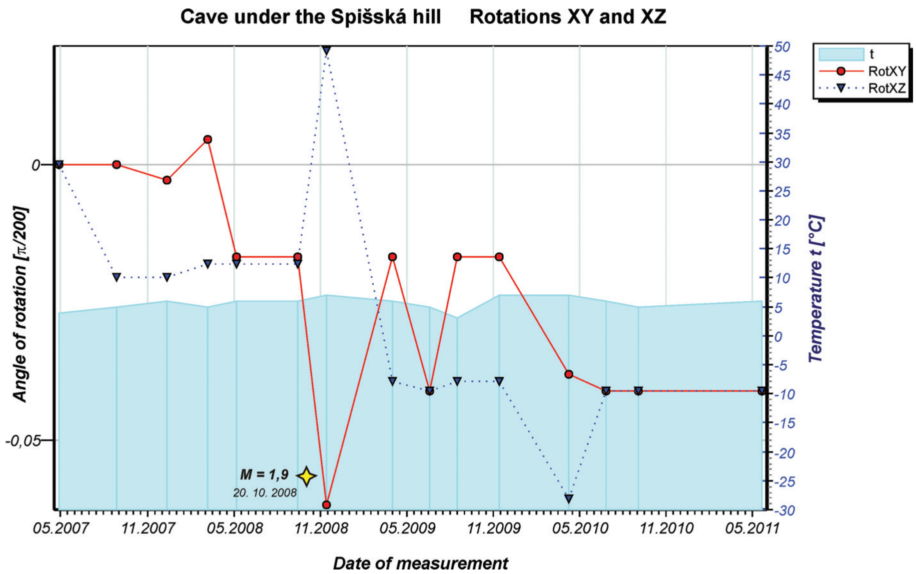


Fig. 7b. Diagram of 3D rotations of sandstone blocks located inside the Cave under the Spišská hill since 27. 4. 2007 with delineation of the M = 1.9 earthquake located at the area of the Vihorlat Mts. on the 20. 10. 2008 (http://dionysos.gssr.sk/cmsgf/select/db_select_seizmika.html).

earthquakes in the Slovak territory in 2007–2009 (http://dionysos.gssr.sk/cmsgf/select/db_select_seizmika.html). In the graph of rotation (Fig. 7b), being very sensitive on seismic events, an anomaly of ca 0.04 x [π/200] in the period October–November 2008 occurs in both planes (horizontal and vertical). It corresponds well to the earthquake with magnitude M = 1.9 localized in the Vihorlat area on 20. 10. 2008 (Fig. 7b).

Conclusions and suggestions

The monitoring of the block movements in the locality Cave under the Spišská hill has demonstrated following facts:

1. More than four years of measuring has revealed a recent movement of the sandstone blocks being expressed by the widening of the monitored fracture and subsidence of the block located in lower position.

2. Found extent of the block displacements reaches tenths of mm per year, confirming very slow movement.

3. The fractures in the area of block failures correspond mainly with the course of the main tectonic elements, especially the systematic joints.

4. The minimum influence of rainfalls on the development of the deep block failures is known (Fussgänger, 2006) and the measurements in this locality confirm it. Neither an extreme rainfalls from May and June 2010 have an influence on the rate and magnitude of the blocks displacements.

5. The origin of some fractures in sandstone beds has probable also an atectonic origin.

6. Block failures and landslides in this locality threaten the only access route to forest cover and agrotechnically used land and pastures, as well as the access to springs of potable water used by the village Brutovce.

7. The measurements of rotations of both monitored blocks have demonstrated the relation with the seismic event from 20. 10. 2008. Because the investigated locality belongs to areas with the intensity of seismicity ≤ 6° EMS 98 (Schenk et al., 2000; Hrašna, 2007), the influence of earthquakes on block stability must be admitted in the future. Similar earthquakes will act not only as triggering factor, but also as a movement accelerator.

Taking into account the above stated facts we suggest the future continuation of the monitoring of the block movements in this locality with the frequency min. four times per year. Only such number of measurements can guarantee the sufficient interpretation of obtained data and effective prognosis of the evolution of the slopes deformations, and by this way also the stability of the accessing road. Such interpreted data will be possibly analogically usable also at evaluation of the territory feasibility for the construction of the water reservoir Tichý Potok in the locality Čierna hora (Židova cave), being known by the extended occurrence of the block failures in the more advanced evolution phase than in the locality Cave under the Spišská hill.

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