# RECENT DISPLACEMENTS REGISTERED IN SELECTED CAVES OF DOBRÁ VODA KARST AREA IN SLOVAKIA

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**ABSTRACT**
Micro-displacement monitoring in Slopy and Zbojnícka caves is described. It started at the end of 2005 with the use of verified, stable and sensitive 3D crack gauges TM71 produced by GESTRA Sedloňov. Two gauges were installed in the caves across significant tectonic structures. Registered displacements are pertinent to the last significant earthquake events. The first one appeared in March 13, 2006 at Vrbové, M=3.2; and later in August 5-8, 2006, a swarm of 10 quakes $M_{max}$= 2.2 at Trstín was registered.
The results indicated trends of dextral strike-slip displacements across observed fault structures in both of those caves.

**KEYWORDS:** Slopy Cave, Zbojnícka Cave, micro-displacements, fault, earthquake

## INTRODUCTION

A bilateral project between the Czech and Slovak Academy of Sciences under the title "Tectonic Activity of the Northern Part of Malé Karpaty Mts." was oriented to investigate recent movements in selected caves of Dobrá Voda epicentral area where the so called Dobrá Voda karst can be found. Investigations into formation of caves due to the effects of recent tectonics was published by other authors (e.g. Pavlarčík and Peško, 1983; Petro et al., 2004; Stemberk and Štěpančíková, 2003; Šebela et al., 2004).

Caves with their relatively all the year round stable micro-climatic conditions represent very suitable objects for micro-movement investigation. Here, one can almost exclude any temperature dilatation effects that may interfere with the measurement. To monitor the movements, investigated objects in the selected caves were instrumented with extensiometers gauges type TM71 that has been successively applied in such studies for several last decades. Measurements during the important seismic events that appeared in the last year indicated changes in the behaviour of the rock environment where the caves developed. It was therefore in this period of monitoring when indications have been collected that the selected caves Slopy and Zbojnícka represent a dynamic system actively reflecting stress transformations in the wide fault zone of Mur-Münz-Leitha.

## CHARACTERISTICS OF THE SELECTED CAVES

### *SLOPY CAVE*

The cave is located in the northern part of Malé Karpaty Mts. (Brezovské Karpaty, Fig. 1), at the end of a ridge called Slopy, 500 m to E from the ruin of Dobrá Voda Castle on the cadastre of Dobrá Voda Village. The entrance is situated 416 m a.s.l. The cave is shaped as a lapies-well with an inclination of 70$^o$. It developed in Wetterstein limestone of Brezová elevation (Salaj et al., 1987; Marko et al., 1991) on a predisposed shear fracture 315$^o$/70$^o$.

Mitter (1983a) registered its length and depth 75 m and 30 m respectively. However, our measurements came to 36 m of vertical distance between the entrance and the bottom (Briestenský et al., 2006a). The depth was verified during the preparation of cave profiles (Fig. 2) with the use of a geological compass and a tape extensiometer, as well as with an altimeter system Paulin which works with accuracy of 0.5 m.

The position of Slopy Cave should be related to a large slope failure, which deformed NE slope of the Slopy ridge, and the cave is located in its southern section (Fig. 3). The size of the slope failure was registered and amounts 600 m in width, 110 m in length, and 36 m in high. It represents a tension fault structure which is built by shallow landslides in its southern part but to N it passes to a deep seated deformation. The faulting of Slopy Cave sector is not apparent on the surface but we assume that the structure developed along a NW - SE or WNW - ESE

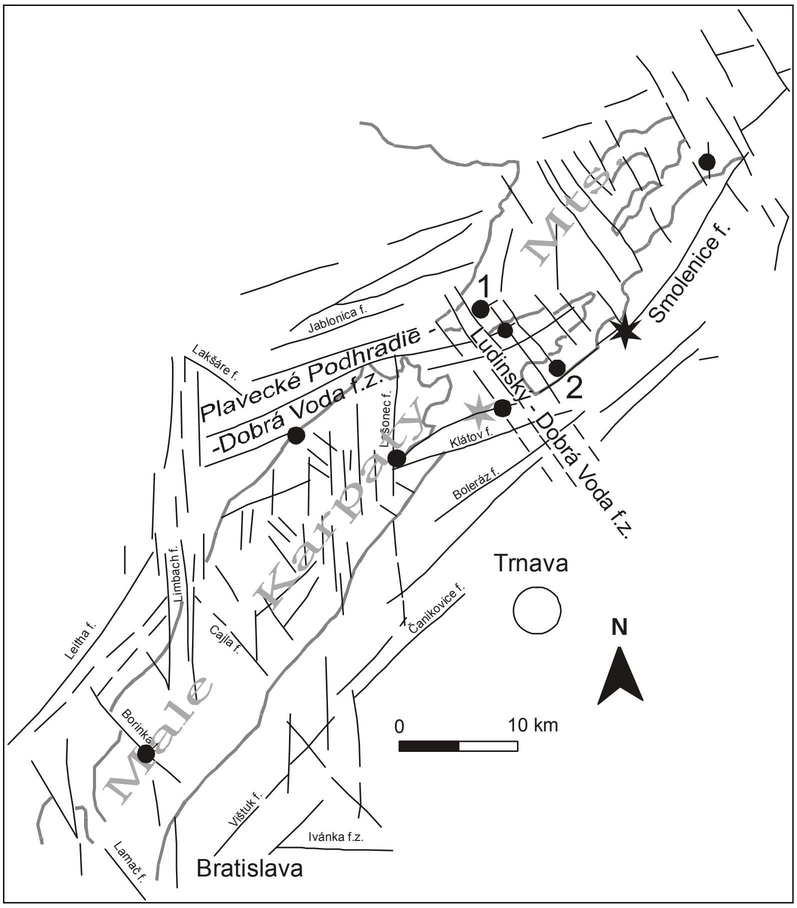


**Fig. 1** Tectonic sketch of the Malé Karpaty Mts. (modified after Kováč et al., 1989; Marko et al., 1991) and sites of the TM 71 gauges: black dots – contemporary gauge sites, 1 – Slopy Cave, 2 – Zbojnícka Cave, black star - 13th March 2006 earthquake epicentre, grey star – 5-8th August 2006 earthquakes epicentre.

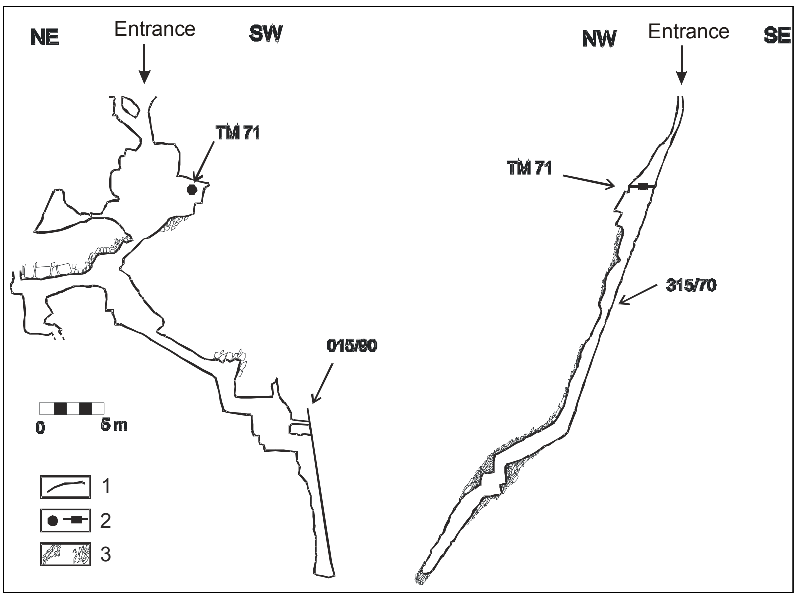


**Fig. 2** Vertical profiles of the Slopy Cave (Briestenský et al., 2006). 1-cave walls, 2 –TM71 gauge, 3-tectonic breccia.

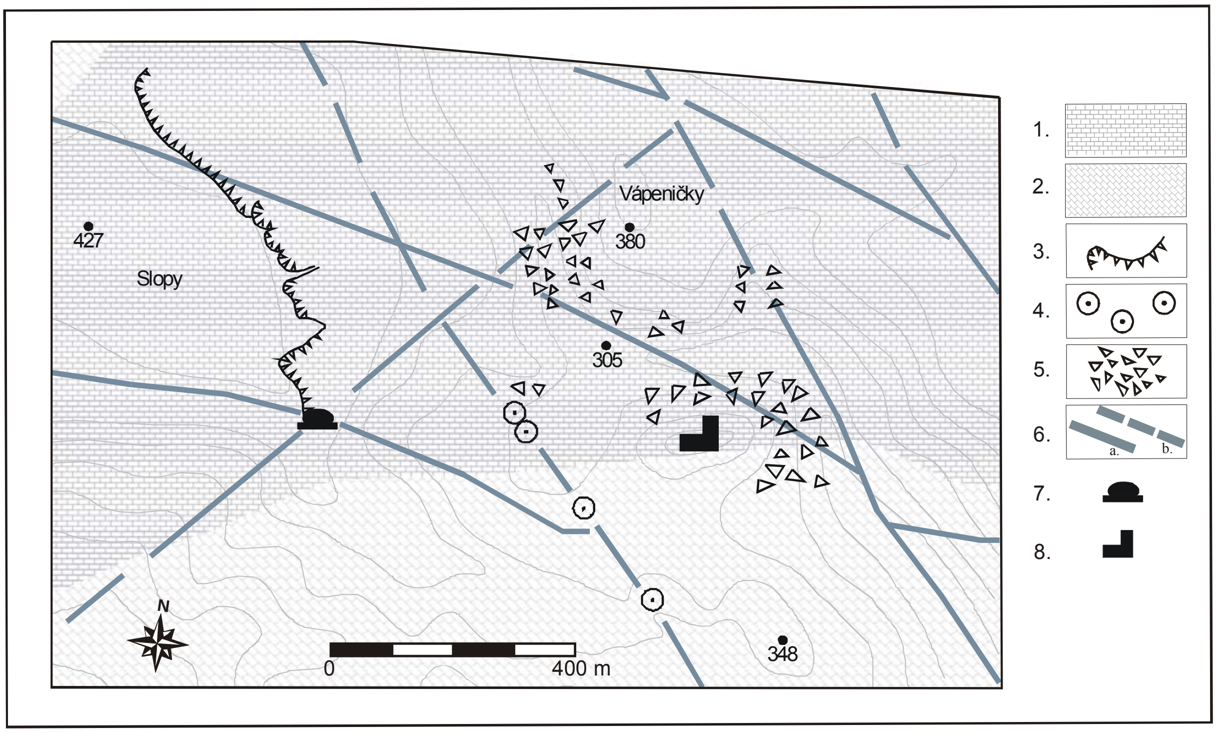


**Fig. 3** Geological setting of the Slopy Cave vicinity. 1 - Pre-Senonian limestones, 2 - Pre-Senonian dolomites, 3 – main scarp of the slope failure (after: Salaj et al. 1987), 4 - dolines, 5 - talus; 6a - proved faults, 6b - assumed faults (reinterpreted after: Dostál et al., 1991), 7 - Slopy Cave, 8 – Dobrá Voda Castle.

fault line, i.e. on a fault line parallel with the so called Ludin Fault (Hók et al., 2000), or possibly directly on it.

The cave developed along two fractures. The first, oriented NE - SW and sloping to NW is of an overthrusting character and is parallel with the faults of the NW boundaries of Dobrá Voda depression. Its slope is steeper in its upper part - up to 70$^o$ and becomes moderate in its lower part - 55$^o$. In the lower part of the cave one can see crossing of this fracture with another one - 015o/ 90$^o$ which comes to limit the cave to SWS (Fig. 2). Both the described fractures represent zones filled with a tectonic breccia (Fig. 4).

In its outcrops in the cave, the NE-SW fracture is characteristic of changing size in rock fragments of breccia. While the fragmentals measure about centimetres usually at the cave bottom, the fracture becomes wider towards the cave entrance and the filling is mainly found composed of blocks of a plate character having a meter or more in size. One can find fresh ripped off edges (Fig. 5) resulting from block subsidence.

In Slopy Cave the extensiometer gauge TM 71 was mounted 8 m under the surface across the fracture 315$^o$/70$^o$.

**Fig. 4** Tectonic breccia filling fault cracks in the bottom part of the Slopy Cave. Fragments are of several centimetres in size. Photo: M. Briestenský.


**Fig. 5** A fresh tensile crack demonstrates block sinking in the uppermost part of the Slopy Cave. Proved displacement is 4 cm. Photo: M. Briestenský.

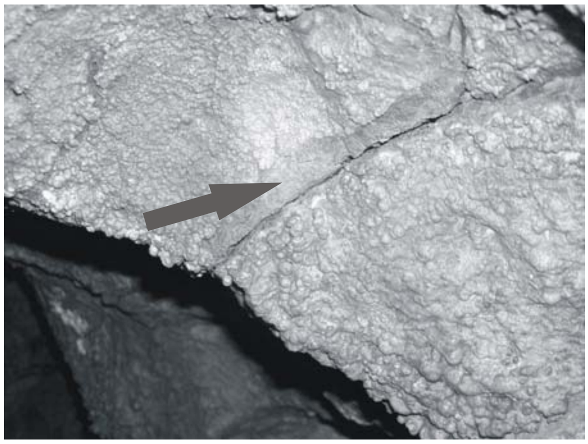

**Fig. 6** Fresh damages of the sinters in the cracks vicinity reflect contemporary displacements alongside the faults crossing the Zbonícka Cave. Photo: M. Briestenský.

**Fig. 7** The sense of relative movements on 260°/30° fault plane is documented by tool tracks and crescentic fractures (according to Petit´s description, 1987). The sense of the relative movement is therefore normal faulting. This fault controlled a section of the Zbonícka Cave gallery system. Photo: M. Briestenský.

***ZBOJNÍCKA CAVE***

The cave is located on the northern edge of a limestone hill at a valley bottom, 400 m SE from elevation Skala (346 m a.s.l), cadaster Chtelnica (Fig. 1). The entrance to the cave can be found at 278 m a.s.l.

The cave developed in Steinalm limestones (Salaj et al., 1987) of Dechtice elevation (Marko et al., 1991). The entrance gallery of the cave is 8 m deep and opens several holes to crawl into. According to Mitter (1983a) the cave is 250 m long and represents a fluvial-karst type of cave. Dripstone decoration is poor and suffered fracturing by young tectonic processes, which is obvious from fresh rupturing of the dripstones (Fig. 6).

Our measurements indicate that the cave is cut through by an important fault dislocation oriented NW-SE and inclined to SW. We have succeeded to find striations on one of the dislocation planes (Fig. 7), which indicate a displacement. One could conclude that this was a normal-fault but its recent activity was hard to prove.

The area where the cave is situated is interesting from the point of view of geodynamics (Fig. 8). The NE slope of the crest of Šidlová displays two large landslides. Its NE edge has been also disturbed, and Mitter (1983b) described it as a block field. This type of slope deformation can be traced even on the other side of the valley of Blava near Lažteky, where it passes into shallow and medium deep landslides of carbonate basement. The structure follows a fault line of a NE-SW orientation and has not been registered as yet. However, it was assumed by Labák (1997) as a hypothetical seismogenic fault line. We have succeeded to find outcrops of such fault dislocation walls with preserved striations in Egenburg conglomerates on SW slope of Šidlová Hill. Such dislocation walls show a significant karst disturbance, and they allowed for the said slipping. Lines of warm vapour that appear here during winter months witness that the system is deep seated.

Another important phenomenon of slope formation at this locality is a deep erosion of the superficial water. It is the SW and NE side of the klippe of Chtelnica, which suffered significantly. Numerous erosion gullies are found in the area of Kultúra and Čeklín. At the locality of Kultúra the depth of such gullies reaches up to 8 m. Significant

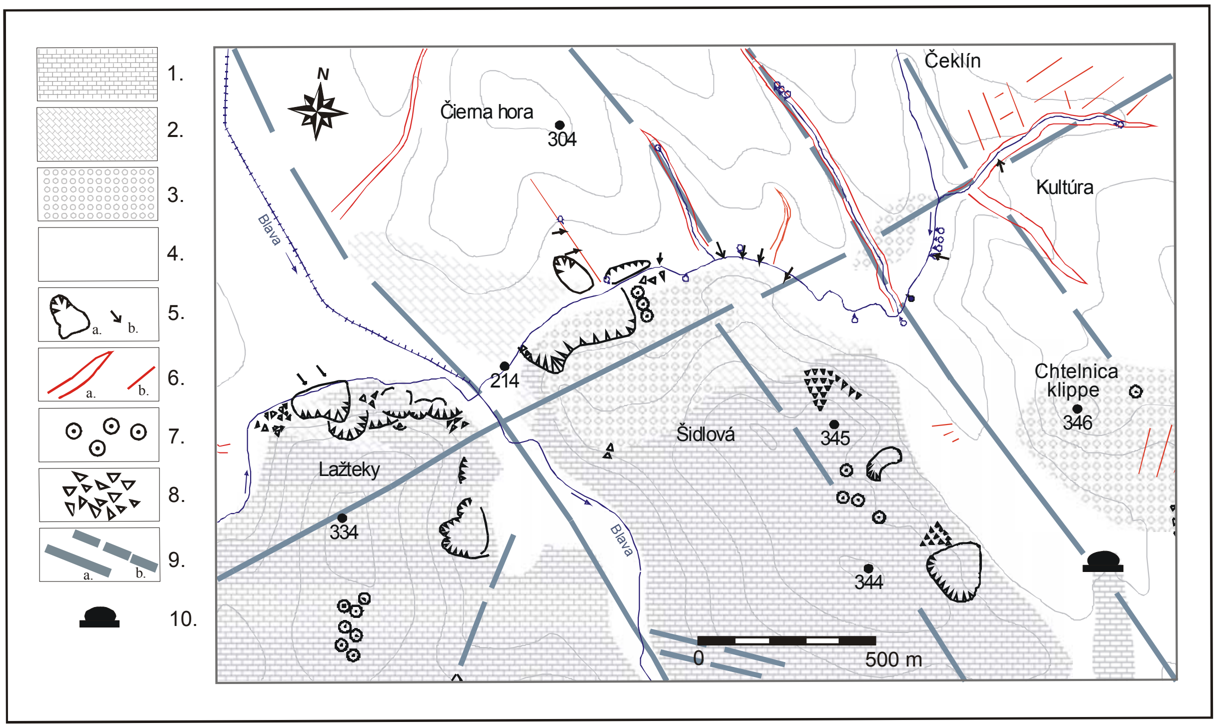


**Fig. 8** Geological setting of the Zbojnícka Cave vicinity. 1- Pre-Senonian limestones, 2 - Pre-Senonian dolomites, 3 - Senonian and Paleogene conglomerates of Myjavská upland, 4 – Miocene and Quarternary sediments, 5a – recent large sized lanslide, 5b – recent small sized landslide, 6a – large sized erosional gullies, 6b – small sized erosional furrows, 7 - dolines, 8 - talus, 9a - proved faults; 9b - assumed faults (reinterpreted after: Henkelová, 1994; Nahálka and Grófová, 1978; Kabina and Windt, 1967; Salaj et al., 1987), 10 - Zbojnícka Cave.

correlation between orientation of erosion gullies and tectonic faults was detected in Čeklín locality where both the system of erosion gullies and fault lines displayed in conglomerates outcropping at the bottom of the gullies are found to read 230$^{o}$.

There are five other registered caves in the neighbourhood of Zbojnícka Cave: Na Šidlovej, Ponorná Cave in shrubbery (Mitter, 1983a and 1983b), the cave under the klippe of Chtelnica, the cave in the klippe of Chtelnica, and the cave Fault in Chtelnica klippe (Archives SMOPaJ). From the geotectonic point of view Zbojnícka Cave is the most important one being built on active fault dislocations. Zbojnícka Cave is located under the bottom of the valley, which means that its origination as a gravitation induced form can be excluded. At the same time it proves its genesis due to faulting and further fluvial-karst modellation.

An extensiometer TM71 was installed across the fault 245$^{o}$/65$^{o}$ (Figs. 9 and 10). This was the dislocation where we previously detected a dextral horizontal shift of blocks by 0.3 cm, as well as a significant destruction of sinter dripstone (Fig. 10).

## MICRO-DISLACEMENT MONITORING AND PRESENT RESULTS

Long-term monitoring was carried out with the use of extensiometr gauge TM71 produced by GESTRA, Sedloňov and invented by B. Košťák for slow-movement registration on fault structures, block movements and displacements due to stress transformation parameters connected with seismic events (Košťák, 1991). The gauge shows advantageous properties like long-time resistance in variable outdoor conditions (Košťák, 2006), as well as no need of electrical supply. Data are collected manually with the use of a special photo-paper or digital camera. The indicator works on the principle of mechanical-optical interference (moiré effect) and provides data about relative movements between two blocks in three dimensions, in components *x, y, z* which are complemented with data about rotations in horizontal and vertical planes (gamma *xy* and gamma *xz*). The axis X represents opening and closing of the joint between the blocks, the axis Y represent relative side movements between the blocks in horizontal and the axis Z vertical movement, respectively. The accuracy is 0.01 mm in movements and 0.00032 rad in rotations (Košťák, 1991).

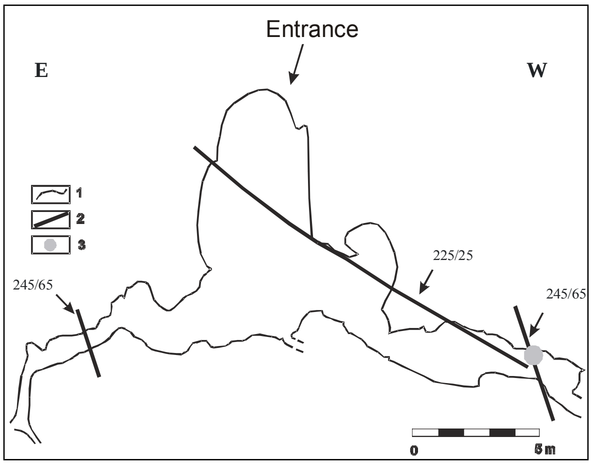


**Fig. 9** Vertical profile of the Zbojnícka Cave (Briestenský et al., 2006). 1 - cave walls, 2 - faults, 3 - TM71 gauge position.

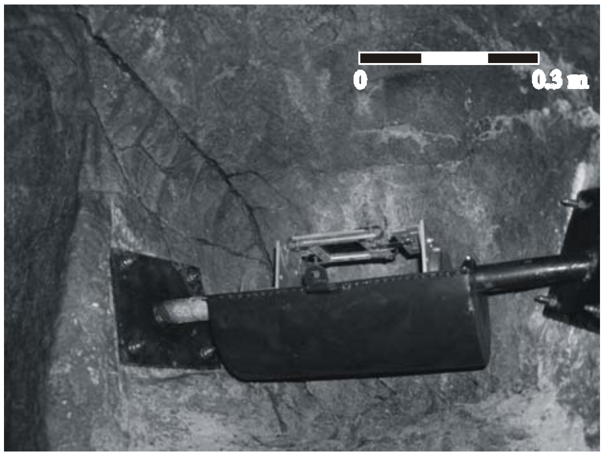


**Fig. 10** TM 71 gauge (extensiometer) in Zbojnícka Cave. The gauge was installed across 245°/65° failure plane, which significantly broke sinters in the gauge vicinity (according to Briestenský et al., 2007).

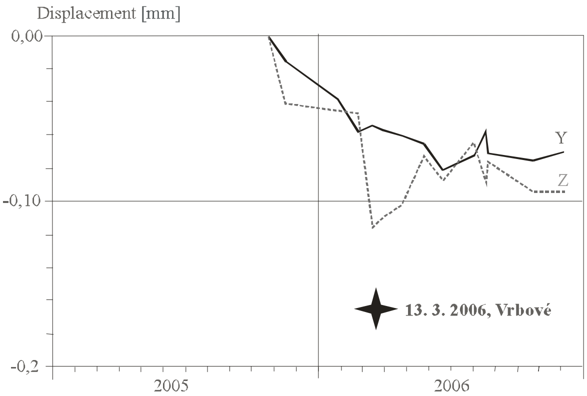


**Fig. 11** Displacements on the fault plane registered in Slopy Cave: -z = uplift of the NW block, -y = dextral strike-slip movement.

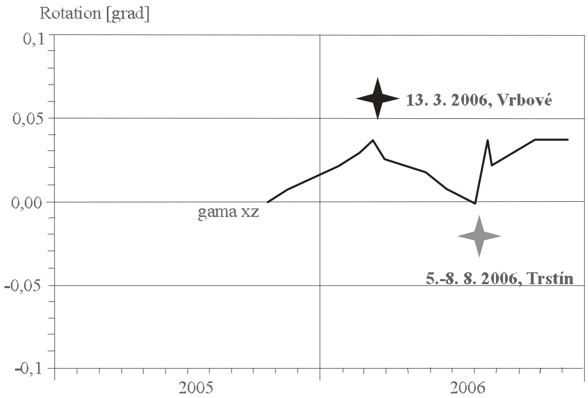


**Fig. 12** Rotation +gamma xz reflects crack opening in upward direction.

Micro-displacement monitoring in selected caves of Slopy and Zbojnícka started by the end of 2005 and has since been carried out continuously in regular monthly intervals.

**SLOPY CAVE**

Obtained results indicate that the observed fault discontinuity represents an active system with movements in both horizontal and vertical planes. The diagram in Fig. 11 shows that the fault is moving within a dextral strike-slip trend (-y trend), and at the same time an uplift of the SW block regarding the opposite in SE (-z trend) takes place. Dextral strike-slip trend coincides with the concept of sinistral strike-slip movements along the fault zone of Mur-Münz-Leitha where dextral block rotations must be induced (Briestenský et al., 2007).

One year of monitoring reveal a side slip movement of about 0.08 mm per year (see Fig. 11). The movement in vertical slips is about 0.1 mm per year. It indicates a permanent tendency of thrusting in the area of Dobrá Voda region.

Attention should be paid also to results of the rotation monitoring in the vertical plane xz (Fig. 12) since they allow to consider some complementary effects of earthquakes in the investigated region. Results show that before the earthquake, with reported epicentre near Vrbové Village (13. 3. 2006, M=3.2, http://www.seismology.sk), i.e. in a distance of 13.3 km SEE from the cave, the stress exhibites an increasing tendency and accordingly a shift of the NW block over the SE block accelerated until the time of the earthquake occurence. Later, relaxation took place (subsidence of NW block) which came to end by a series of earthquakes in the vicinity of Trstín Village

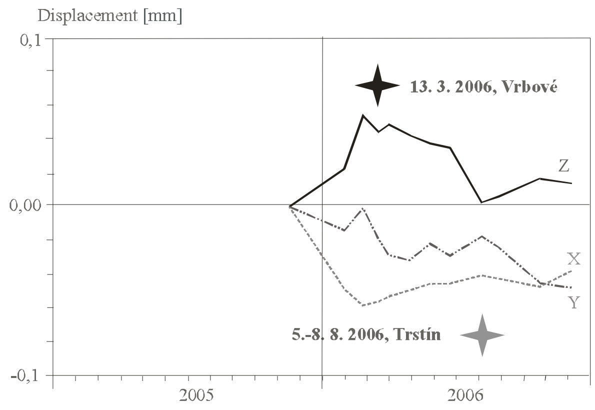


**Fig. 13** Displacements on the fault plane monitored in Zbojnícka Cave detected in three axes: +z = uplift of the SW block, -y = dextral strike-slip movement, -x =horizontal crack opening.

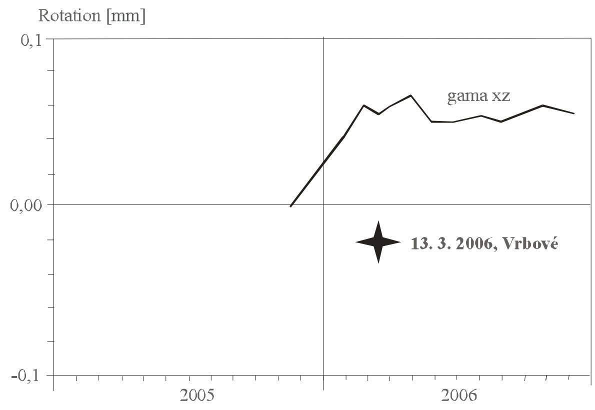


**Fig. 14** Rotation +gamma xz reflects crack opening in upward direction.

(5.-8. 8. 2006, 10 events, $M_{max}$= 2.2), at a distance of about 8.2 km SW from Slopy Cave. Later again the slip movements increase. The change in vertical movements during the earthquake of 13. 3. 2006 is clear even from registered displacements (Fig. 11).

## ZBOJNÍCKA CAVE

In accordance with the case of Slopy Cave, even the Zbojnícka Cave provides a chance to observe the dextral strike-slip trend (-y trend), as well as complementary effects associated with the earthquakes at Vrbové and Trstín (Fig. 13). Contrary to Slopy Cave results where stress changes connected with the earthquakes in the graph of rotation were observed, Zbojnícka Cave results show such changes on the vertical movement component z (Fig. 13). Before the Vrbové earthquake (13. 3. 2006), with an epicentre of 9 km NE from the cave, a considerable uplift (about 0.06 mm) of the SW block over the NE block took place followed by relaxation (SW block subsidence) which ended by a series of Trstín earthquakes about 9.8 km WSW from the cave. Finally, the SW block uplift trend was restored.

Registration of rotations in the vertical plane xz shows also an uplift trend of the SW block before the Vrbové earthquake. Subsequent Trstín earthquake series was not reflected in the results (Fig. 14) due to no rotational effects associated with vertical displacement. The displacement and rotation measurements are mutually independent, and some structurs can show just displacement or rotation blocks movement mechanism (e. g. Dobrá Voda gauge, Briestenský et al., 2007).

## CONCLUSION

Malé Karpaty Mts. belong to most extensive seismic regions of Slovakia. Extensiometers TM71 installed in Slopy and Zbojnícka caves create a part of the TM71 monitoring network to measure recent tectonic displacements in the region of Malé Karpaty Mts. The two last important seismic events of 13.03.2006 and 5.-8.08.2006 made it possible to conclude that the monitoring cave system in the investigated region is sensitive enough to reveal stress changes before and after near earthquakes. Moreover, dextral strike-slip movement trend was verified on the investigated structures. As yet the genetic process of the caves has not come to an end, and considering also hydrological conditions, one can anticipate further development in their formation.

## ACKNOWLEDGEMENT

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