CURRENT RESULTS FROM 3-D MONITORING OF ACTIVE FAULTS IN THE WESTERN CARPATHIANS

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(Received May2004, *accepted* October 2004)

ABSTRACT
3-D monitoring of movements on tectonic structures was initiated in four selected sites in the Western Carpathians. Crack-gauge TM-71 has been used for monitoring of micro-deformations. Clear tectonic activity out of monitoring results is confirmed at Košický Klečenov, Slanské Vrchy Mts., only. Ipel´ pilot gallery site shows a trend in vertical movement that coincides with local GPS results. Other sites need a longer observation period to be interpreted.

KEYWORDS: Western Carpathians, active faults, 3-D monitoring, TM-71 crack-gauge

1. INTRODUCTION

Tectonic failures represent a significant geological factor that has a character of geobarrier from the viewpoint of engineering geology. Rocks inside the faults and in their surroundings are usually fractured and weathered. This is the main reason of their increased permeability and degraded physical-mechanical properties. Areas with active faults complicate planning of special engineering structures (e. g. highways, tunnels, deep-seated repositories, dams, nuclear facilities etc.) and endanger not only their construction but also existing objects and human lives. Vertical displacements along some failures (e.g. grabens) may lead to change slope gradient and induce slope movements (Petro et al., 1999a) or may result in earthquake occurrence (Avramova-Tacheva – Košťák, 1995).

Measurement of displacements on landslides as well as on tectonic failures in the Western Carpathians started in 1974 (Košťák, 1993). A recent monitoring network comprises 13 sites located beneath historical structures (castles, monasteries), inside nature protected areas, caves, highway tunnels, pilot galleries and investigation tunnels. Current monitoring results from four sites covered by international project COST Action 625 „3-D monitoring of active tectonic structures", are presented in this paper.

2. MONITORING SITES

A series of faults with proved or assumed recent activity have been selected in the Western Carpathians as a first step of the investigations. Selected sites were evaluated concerning their physical availability, vulnerability, practical importance and distance from the processing centre, legislative and property barriers and technical parameters of crack-gauge TM-71. Regardng these criteria our attention was focused especially on tectonic failures beneath the surface located inside planned or existing pilot galleries, tunnels and caves. The wider selection comprised sites as follows: Važec, Demänová, Harmanec, Belá, Dead Bats and Gombasek caves, Višňové, Ipeľ, Branisko and Ružín pilot galleries/tunnels and Dobrá Voda fault.

Taking into account the majority of criteria required and financial possibilities three new monitoring sites – Demänová cave of Liberty, Branisko and Ipeľ pilot galleries (Fig. 1) have been established in the Western Carpathians since 2000. The Košický Klečenov (Slanské vrchy Mts., Eastern Slovakia) site (Fig. 1) monitored within the National Project „Partial monitoring system – geological factors; landslides and other slope movements" since 1993 has also been incorporated into the COST Action 625 network because of its neotectonic character. Interpretation of monitoring results is realized in cooperation with Institute of Rock Structure and Mechanics of the Academy of Sciences of Czech Republic in Prague.

3. METHODOLOGY OF MEASUREMENT

Regarding a character of geological setting of the Western Carpathians and distribution of neotectonic as well as seismoactive zones (Hók, 2000) it is possible to expect very slow and not striking displacements. For monitoring of extremely slow tectonic movements, we applied the crack gauge TM-71 constructed by Košťák (1969). This device is capable of detecting movements and micro-displacements in three dimensions. It works on the principle of optical interference (moiré) which records displacement as a fringe pattern on superposed optical grids that are mechanically connected to opposite crack faces. Data are obtained in three Cartesian coordinates (x – across a crack enabling to measure compression or extension of a crack width, y – horizontal (shear) displacement along crack and z – vertical (shear) displacement) calculated from recorded interference patterns. The accuracy of TM-71 is ≤ 0.1 mm. Displacement records are performed visually, by using special photographic paper or digital/movie camera. Data obtained are computed by special software named SM-Dilat (not published yet). The SM-Dilat is application for 3-D evaluation of data recorded by TM-71 crack-gauges prepared in DELPHI for MS Windows platform. The application consists from several parts. Table and interactive graphic parts are in operation this time.

This measuring device has been successfully employed in several countries like Bulgaria (Košťák and Avramova-Tacheva, 1988; Avramova-Tacheva – Košťák, 1995), Canada (Košťák – Cruden, 1990), Peru (Košťák et al., 2002), Czech Republic (e.g., Zvelebil – Stemberk, 2000), Poland (Cacon – Kontny, 2003), Greece (Maniatis et al, 2003) and Slovakia (Vlčko et al., 1998; Petro et al., 1999b; Vlčko, 2001, 2002; Vlčko – Petro, 2002).

4. EVALUATION OF CURRENT MONITORING RESULTS

4.1. *KOŠICKÝ KLEČENOV LANDSLIDE*

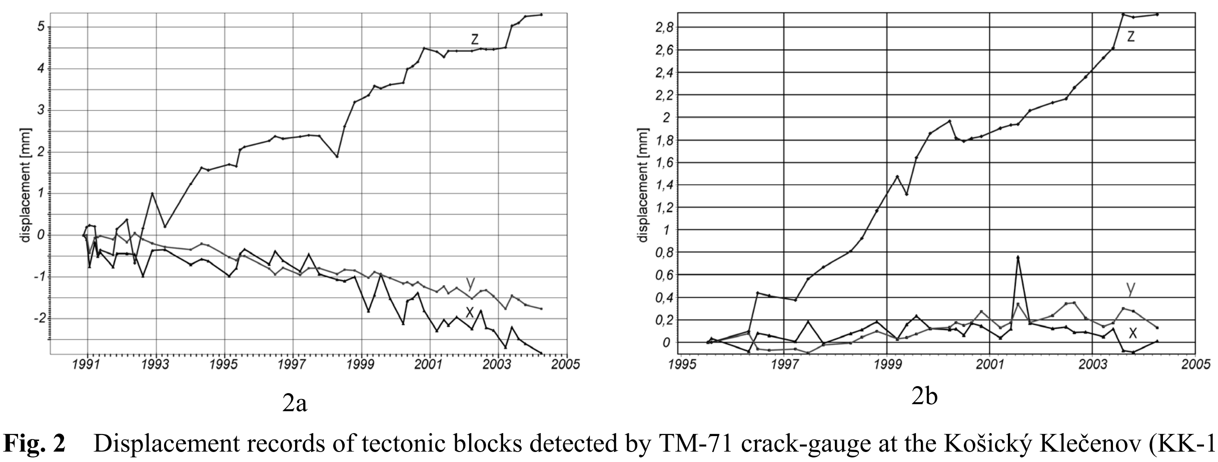
The site is located at the western margin of the Strechový vrch stratovolcano (central part of Slanské vrchy Mts.) near Košický Klečenov village about 20 km to the East of Košice (Fig. 1). Two TM-71 crack-gauges were installed at this site in 1990 (KK-1) and 1995 (KK-2). Both devices are situated inside wide N–S-oriented tension cracks in the marginal part of the lava flow. The cracks are parallel to a morphologically distinctive fault of the same orientation. This active fault (Janočko, 1989) represents a tectonic contact between volcanic complexes and sedimentary layers. The whole area is a part of the largest landslide (typical complex spreading) in the area of Slanské vrchy Mts. (11.2 km^2).

First measurement revealed continuous vertical uplift of marginal andesite blocks interpreted as tectonic activity of related fault as one of possible reasons of displacements (Petro et al., 1999b). Permanent vertical uplift of blocks is evident from the latest monitoring results (Fig. 2). Almost 3 mm total uplift of the internal block in the profile has been detected since 1995 (KK-2). The external block has been uplifted about 5.2 mm since the end of 1990 (KK-1). Average velocity of this block uplifting is 2.6 mm/year. Displacements along the axis x and y are not so significant. The latest interpretation (Petro et al., 2004) explains the vertical uplift of blocks as a result of different plasticity of underlying Neogene deposits but effect of tectonic activity cannot be rejected.

4.2. *BRANISKO PILOT GALLERY*

The site represents a 5 km long pilot gallery located in the central part of the Branisko Mts. (Eastern Slovakia, Fig. 1). Since July 2003 the gallery operates as emergency exit for parallel highway tunnel. One crack gauge TM-71 was installed on 0.6 m thick fault located near the eastern gallery mouth in December 2000. The normal fault represents a tectonic contact between Paleosoic migmatites and Paleogene sandstones/conglomerates and according to latest Quaternary research it is supposed to be active (Maglay et al., 1999).

The interpretation of preliminary results (Fig. 3) indicates a small vertical displacement (> 0.5 mm) along the fault (*z* axis) up to the middle of 2002. A small movement trend along the failure (*y* axis) has also been detected. The displacements may reflect the



2a 2b

Fig. 2 Displacement records of tectonic blocks detected by TM-71 crack-gauge at the Košický Klečenov (KK-1 and KK-2) during the period 1990 – 2004.

deformations of rock massif due to highway tunnel construction (end of 2002) in the excavation damage zone (EDZ). Explanation of several fresh cracks that originated in the concrete tunnel tube as well as confirmation of the tectonic activity of the fault requires probably higher frequency of readings, over a longer monitoring period.

4.3. DEMÄNOVÁ CAVE OF LIBERTY

The whole underground karst system of the Demänová River valley has a total length of 33 km. The National Nature Monument Demänová Cave of Liberty discovered in 1921 is one of the largest caves of this system (total length 8 126 m, accessible for public 2 150 m) and is located in the northern part of the Low Tatra Mts. National Park (Fig. 1) (Bella, 2003). The mountains are the second most uplifted structural unit of the West Carpathians (Maglay et al., 1999). The cave was mainly formed in the Middle Triassic limestones (Krížna nappe). The underground spaces are concentrated along the NNW–SSE oriented faults. The faults are quasi-parallel with an active fault in the Demänová valley (Hók et al., 2000) and are supposed to be responsible for several mm wide freshly opened cracks in several stalagnates in most beautiful part of the cave (so-called Charming room). For this reason, the site was selected for monitoring. After getting permission from Slovak Cave Administration one TM-71 crack-gauge was installed in an inaccessible part of cave in August 2001.

Conditions inside the cave are suitable for precise measurement because of small variations in temperature (from 6°to 7°C) and relative humidity (from 95% to 99%). An interpretation of actual measurements (Fig. 4) revealed only a very small displacements along the *x*, *y* and *z* axis (0.1 mm per 31 months only). Recorded micro-displacements reflect probably the small temperature changes inside rock massif along the fault planes.

4.4. IPEĽ PILOT GALLERY

The site is located in south-western part of the Stolica Mts. (Fig. 1) near Ipeľ village. The pilot gallery has been driven in connection with projected pump-storage power station and is abandoned now. The Muráň fault system, one of the most significant tectonic failures in the Western Carpathians is running along the Ipeľ river valley. The TM-71 is installed inside the pilot gallery, on a fault which is parallel with the main fault mentioned. Suitability of the site is emphasized by perspective of the power station as well as by existing of GPS network created in the Ipeľ valley (Matejček et al., 2002).

In spite of the short monitoring period (in-tallation in summer 2002) about 1.4 mm displacement in vertical shear per one year along the tectonic failure plane has been detected here (Fig. 5). At the same time significant angular deviation around horizontal axis has been indicated by the instrument. The vertical movement detected here corresponds well with results from twelve years of GPS deformation monitoring (Vázal and Ondrášik, 2004). Monitoring at this site is therefore of high interest and is likely to provide significant results in the near future.

5. CONCLUSIONS

1. 3-D monitoring of displacements on tectonic failures takes place at four selected sites in the Western Carpathians (Košický Klečenov, Bra-isko, Demänová and Ipeľ). It is covered by the international project COST Action 625.
2. Selection of monitoring sites has been done not only regarding of faults with assumed activity but also in the perspective or existing engineering structures as well as protected nature areas. This aspect emphasizes their practical significance.
3. Widely acceptable interpretation of monitoring results needs long-term and regular measurements and their correlation with other monitoring techniques (e.g. GPS, geodetical etc.)

Fig. 3 Displacement records of tectonic blocks detected by TM-71 crack-gauge installed inside the Branisko pilot gallery since 2000.

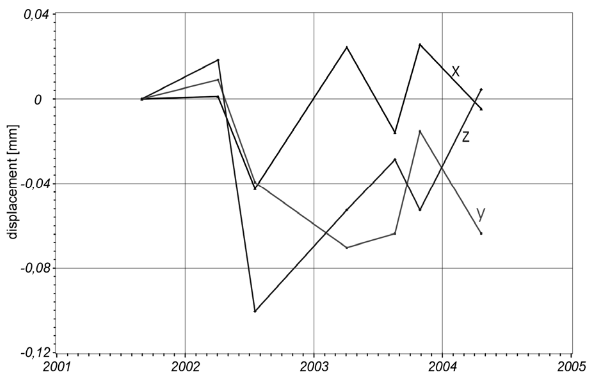


Fig. 4 Displacement records of tectonic blocks detected by TM-71 crack-gauge installed inside the Charming room of the Demänová cave of Liberty (The National Nature Monument, Low Tatra Mts.) since 2001.

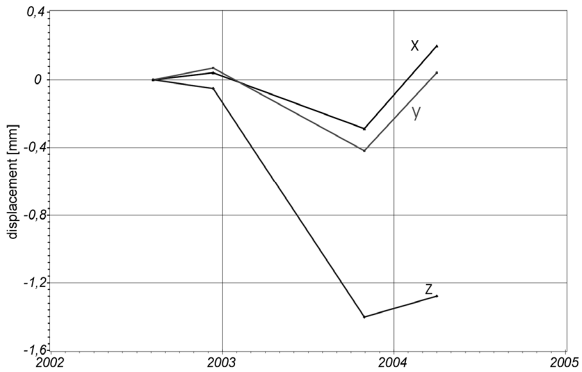


Fig. 5 Displacement records of tectonic blocks detected by TM-71 crack-gauge installed inside the pilot gallery at the Ipeľ village since 2002.

4. Current monitoring results from the four sites in the Western Carpathians revealed clear tectonic activity only at the Košický Klečenov site (Slanské vrchy Mts.). Also, a trend in vertical movement along the Muráň fault system (, Ipel´, Stolica Mts.) has been indicated. The result corelates with GPS measurements at the site. The introductory period of measurements was too short to come to a final interpretation regarding tectonic activity.
5. It is necessary to enlarge the monitoring network in the Western Carpathians for COST Action 625 main objectives to be achieved. Several new sites should be instrumented (e.g. Dobrá Voda fault) with new TM-71 crack-gauges, and to supplement such measurement with GPS technique at the sites where the highest displacements would be recorded. Slovak national COST project should be approved for that.

ACKNOWLEDGEMENTS

This paper was prepared as a part of the COST Action 625 "3-D Monitoring of Active Tectonic Structures" as well as the "Partial monitoring system of geological factors of the environment in Slovakia". The authors are thankful to the Ministry of the Environment of the Slovak Republic, Geological Survey of Slovak Republic, as well as Ministry of Education and Physical Culture of the Czech Republic (project OC 625.10), and COST Secretariat, Brussels, for their kind support.

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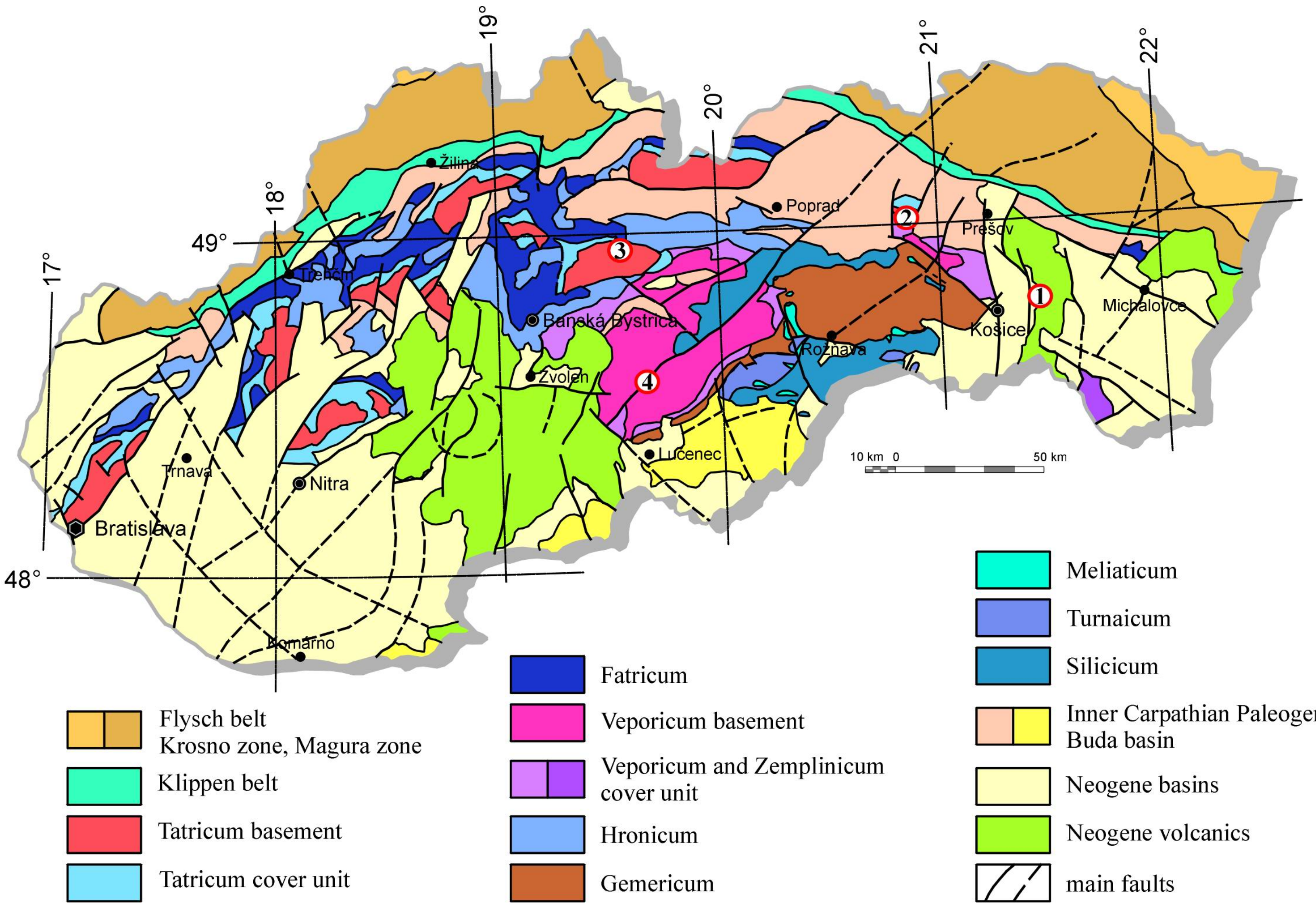

Fig. 1 Tectonic sketch of the Slovak part of the Western Carpathians (after Biely et al., 1995) with location of monitoring sites. 1 - Košický Klečenov (Slanské vrchy Mts.), 2 - Branisko (Branisko Mts., pilot gallery), 3 - Demänová Cave of Liberty (Low Tatra Mts.), 4 -Ipeľ (Stolica Mts., pilot gallery for planned pumped-storage power station).