Geomorphology 259 (2016) 81–89

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Can deep seated gravitational slope deformations be activated by regional tectonic strain: First insights from displacement measurements in caves from the Eastern Alps

Ivo Baroň [a,*], Lukas Plan [a], Bernhard Grasemann [b], Ivanka Mitrović [a,b], Wolfgang Lenhardt [c], Helmut Hausmann [c], Josef Stemberk [d]

[a] Karst and Cave Research Group, Department of Geology and Paleontology, Natural History Museum, Burgring 7, 1030, Vienna, Austria
[b] Department of Geodynamics and Sedimentology, University of Vienna, Althanstrasse 14, 1090, Vienna, Austria
[c] Department of Geophysics, ZAMG - Zentralanstalt für Meteorologie und Geodynamik, Hohe Warte 38, 1190, Vienna, Austria
[d] Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic, V Holešovičkách 94/41, 182 09, Prague, Czech Republic

ARTICLE INFO

Article history:
Received 3 June 2015
Received in revised form 8 February 2016
Accepted 9 February 2016
Available online 10 February 2016

Keywords:
Tectonic strain
Slope failure
Earthquake
Eastern Alps

ABSTRACT

Tectonic elastic strain and ground deformations are documented as the most remarkable environmental phenomena occurring prior to local earthquakes in tectonically active areas. The question arises if such strain would be able to trigger mass movements. We discuss a directly observed fault slip and a subsequent minor activation of a deep-seated gravitational slope deformation prior to the M = 3 Bad Fischau earthquake between end of November and early December 2013 in NE Austria. The data originate from two faults in the Emmerberg and Eisenstein Caves in the transition zone between the Eastern Alps and the Vienna Basin, monitored in the framework of the FWF "Speleotect" project. The fault slips have been observed at the micrometer-level by means of an opto-mechanical 3D crack gauge TM-71. The discussed event started with the fault activation in the Emmerberg Cave on 25 November 2013 recorded by measurements of about 2 μm shortening and 1 μm sinistral parallel slip, which was fully in agreement with the macroscopically documented past fault kinematics.
One day later, the mass (micro) movement activated on the opposite side of the mountain ridge in the Eisenstein Cave and it continued on three consecutive days. Further, the fault in the Emmerberg Cave experienced also a subsequent gravitational relaxation on 2/3 December 2013, when the joint opened and the southern block subsided towards the valley, while the original sinistral displacement remained irreversible. The process was followed by the M = 3 earthquake in Bad Fischau on 11 December 2013.
Our data suggest that tectonic strain could play a higher role on the activation of slow mass movements in the area than expected. Although we cannot fully exclude the co-activation of the mass movement in the Eisenstein Cave by water saturation, the presented data bring new insight into recent geodynamics of the Eastern Alps and the Vienna Basin. For better interpretations and conclusions however, we need a much longer period of observations.

1. Introduction

Studies on contemporary regional tectonic strain are essential for a better understanding of recent tectonic processes and earthquake triggering (e.g. Papadimitriou et al., 2006) as it is one of the most remarkable environmental phenomena controlling local earthquakes (e.g. Kawakata et al., 2006; Tronin, 2010; Grant et al., 2011; Whitehead and Ulusoy, 2013; Wu et al., 2013; Zhao, 2010). Ground deformations can be observed at a distance of up to several tens of kilometres from the future epicentre by seismological methods (Bowman and King, 2001) or by means of remote-sensing approaches like radar interferometry (for references see Tronin, 2010). Along single activated faults associated to the main fault systems, the tectonic strain usually shows up as small displacements at micrometre-scale (Stemberk et al., 2008).

The question arises if such regional tectonic strain was able to trigger mass movements. Possible influence of active tectonics on deep-seated gravitational slope deformations (DSGSD) and other landslides is a frequently discussed topic throughout the literature (for the reference review, see e.g. Agliardi et al., 2009). Such influence could be direct or indirect; the indirect control is considered to be especially through the impact of tectonic deformation on the pattern of joints as future detachment planes and zones of weakness (Gupta, 2005), and through the

* Corresponding author.
E-mail addresses: ivo.baron@nhm-wien.ac.at (I. Baroň), lukas.plan@nhm-wien.ac.at (L. Plan), bernhard.grasemann@univie.ac.at (B. Grasemann), ivanka.mitrovic@univie.ac.at (I. Mitrović), wolfgang.lenhardt@zamg.ac.at (W. Lenhardt), helmut.hausmann@zamg.ac.at (H. Hausmann), stemberk@irsm.cas.cz (J. Stemberk).

http://dx.doi.org/10.1016/j.geomorph.2016.02.007

major role of tectonic forces in shaping the mountain topography, especially on the spatial orientation of valleys and drainage networks (e.g.: Abrahams and Flint, 1983; Embleton, 1987; Ollier, 1981; Pohn, 1983; Scheidegger, 1980). Direct control is considered to happen by shaking due to differential loading by seismic waves. According to Keefer (1984), all types of landslides can occur due to seismic tremors; at slopes in a marginally stable state even a weak earthquake could activate mass movement, e.g. a rockfall. About 20% of all registered landslides worldwide are supposed to be triggered by earthquakes (Wen et al., 2004) and significant casualties and material losses are associated with landslides triggered by earthquakes. Co-seismic landslides sometimes produce more victims than are due to building damage (García-Mayordomo et al., 2009), which seems to be also the case in the April 25, 2015, magnitude 7.8 Gorkha earthquake in Nepal (Petley, 2015).

However, the link between aseismic regional tectonic strain and DSGSDs in Alpine terrains still remains rather unknown. Here we discuss a directly observed fault slip and a subsequent minor mass movement activation prior to an M = 3 earthquake between end of November and early December 2013 in the Southern Vienna Basin (Austria).

2. Methods

The presented data originate from two out of seven sites, where we observe the contemporary displacements along active faults in the Eastern Alps in the framework of the Speleotect monitoring network (Baroň et al., 2014, 2015, Fig. 1). The fault slips are observed at the μm-level in 3D inside caves by means of TM-71, which is an opto-mechanical crack gauge device fixed to respective fault planes (Klimeš et al., 2012). The method gives excellent results in terms of accuracy, resolution and durability of long term monitoring of very slow displacements (Košt'ák, 1991, 2006; Stemberk et al., 2010; Briestenský et al., 2010, 2014).

The measuring principle is based on the mechanical interference between glass indicators with two optical grids causing moiré patterns (Koš'ák and Popp, 1966; Klimeš et al., 2012; Marti et al., 2013). Our glass indicators contain spiral grids with a density of 20 gratings per mm for displacement and the parallel-line grids of 100 lines per mm for rotations. The moiré patterns have to be transformed into the metric system by counting moiré fringes in the displacement and rotation fields of the glass plates, identifying the axis of symmetry and then solving specific mathematical equations (Koš'ák and Popp, 1966). The centre to centre distance between the glass plates is calculated using the number of fringes and the direction of the displacement as indicated by the principal axis of the symmetry pattern (see, for example, Rowberry et al., in print). When only the number of fringes is considered the instrumental resolution is 0.025 mm but this can be improved up to one micron by measuring changes in the principal axis (Rowberry, pers. comm.). The transformation is done manually and recently also automatically using a Matlab (MathWorks®) code (Marti et al., 2013). The most up-to-date comprehensive description of the TM-71 device and its application for active-tectonic purposes was recently presented by Briestenský et al. (2015).

The TM-71 devices were installed permanently and are measuring displacements and rotation of two respective blocks (i.e. both sides of the cave passages that are intersected by the faults) in 3D. Three-dimensional monitoring is important as displacements between joint faces are frequently accompanied by a rotational component (Košt'ák, 1991, 2006). The TM 71 crack gauges are complemented with automatic meteorological stations (registering air temperature, pressure and humidity at the devices) and devices for automatic readings based on web cameras connected to field computers. The measurements have

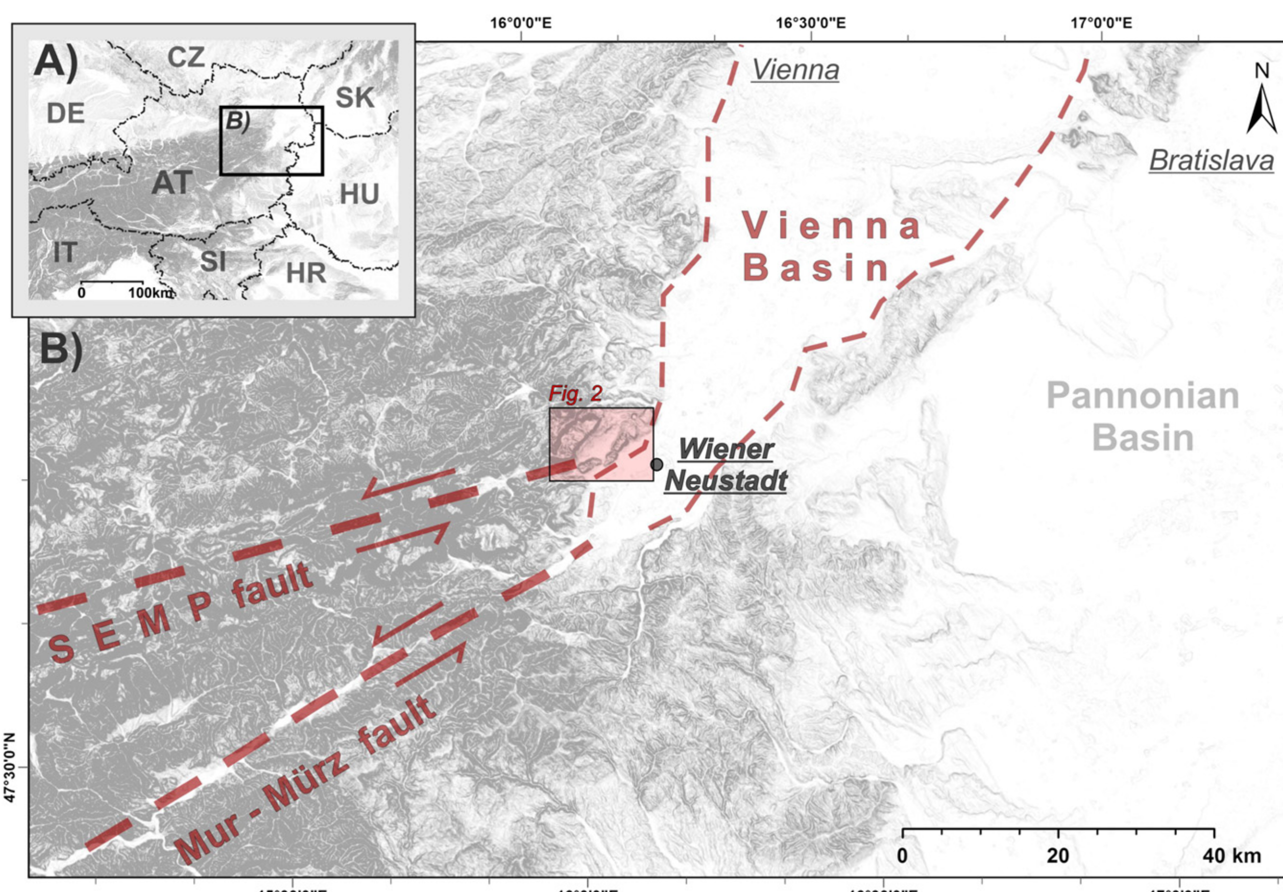

Fig. 1. Location of the study area: A) Position in Central Europe and B) general active-tectonic settings; SEMP – Salzach-Ennstal-Mariazell-Puchberg Fault (slope-gradient map in greyscale with horizontal as white and vertical as black derived from SRTM topographic data by USGS/NASA).