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Fault slip versus slope deformations: Experience from paleoseismic trenches in the region with low slip-rate faults and strong Pleistocene periglacial mass wasting (Bohemian Massif)

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A B S T R A C T

Successions of colluvia and loesses covering the faults in the eastern and central parts of the Bohemian Massif were exposed in six trenches (two trenches at each fault, up to 6 m deep) and studied in detail in terms of stratigraphy and deformation. Based on OSL and radiocarbon ages these sediments were dated as Weichselian Early Glacial to Younger Dryas/Holocene (~120 ka to 11 ka). On the Kosíř fault (NW-SE strike), the offset strata bring evidence for Late Pleistocene oblique slip (normal and strike-slip components) on the main fault plane with minimum slip rate in order of 0.1 mm/a. Although the undisrupted topsoil suggests the absence of significant slip in Holocene and no clear evidence of paleoseismic events was found, this fault structure should be included in seismic hazard assessment. Conversely, on the Hluboká and Diendorf-Boskovice faults (NW-SE and NNE-SSW strikes, respectively), the tectonic slip is contradicted for the last 15–23 ka based on dating of undeformed strata sealing the fault planes. Multiple independent evidence suggests that these two faults were not active in Late Pleistocene at least and their prominent scarps is probably largely due to exhumation by differential denudation. Examples given document the mechanisms of slope-related deformations which may lead to destruction of the records of older faulting and occasionally produce deformation structures resembling the tectonic ones.

1. Introduction

The Bohemian Massif (BM) forms a part of the Alpine-Carpathian foreland (Fig. 1) which was affected in Tertiary by considerable faulting related to alpine collision and nappe thrusting. Locally observed Pleistocene faulting (e.g., Štepančíková et al., 2010; 2015a, Špaček et al., 2015b, section 3), significant subsidence in Neogene basins (e.g. Růžička, 1973; Špaček et al., 2015a) and increased levels of present-day seismicity (e.g. Kárník et al., 1957; Fischer et al., 2014; Špaček et al., 2015a, section 2.1) indicate that slow tectonic deformation has continued in Quaternary mostly in NW and NE parts of the BM (Fig. 1). The general uplift of the BM and its high relative elevation throughout Cenozoic (e.g. Malkovský, 1987; Zoetemeijer et al., 1999; Ziegler and Dèzes, 2007) has lead to long-term regional-scale erosion, including differential denudation and local formation of relatively high scarps often resembling those of large active faults. During cold periods of Middle and Late Pleistocene the continental ice sheet repeatedly proceeded to within 0–60 km off the northern limits of the BM (e.g. Ehlers et al., 2011, Fig. 1, section 2.2) and the topography of the scarps was often strongly affected by mass wasting, differential deflation by persistent winds, action of high-discharge rivers and other processes characteristic for periglacial zone. While the non-tectonically rejuvenated scarps of older faults may be misinterpreted as a signature of active tectonic slip, the permafrost-related process of slope degradation is the most serious obstacle to correct fault slip analysis since it largely overprints the possible record of tectonic faulting. This, together with the lack of suitable environments with sediment accumulation, is the reason for present poor knowledge on Quaternary slip history of most faults in the BM.

Due to very low (or zero) present slip rate at the faults of a stable

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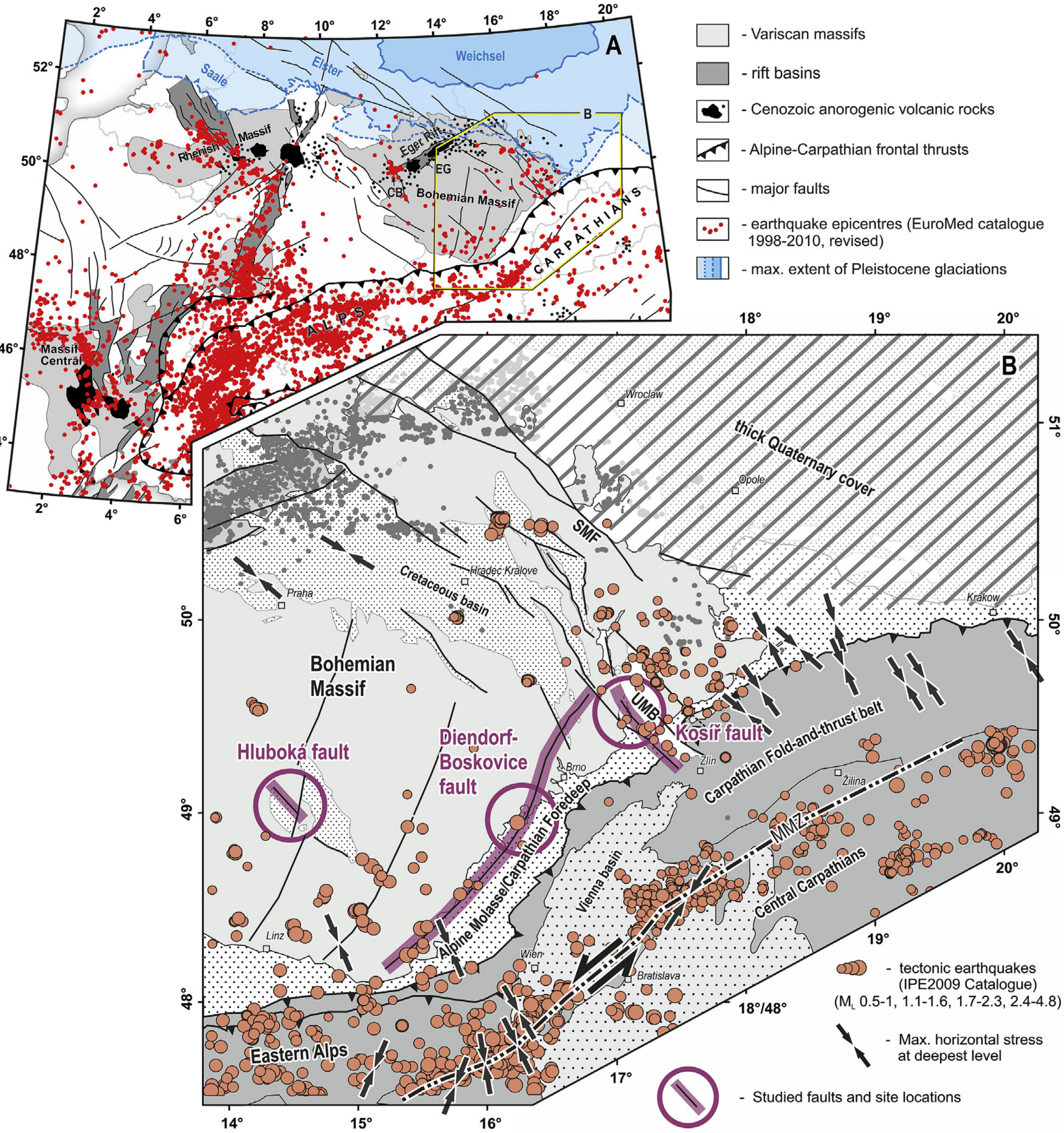

Fig. 1. Location maps showing the position of the Bohemian Massif (BM) and main geological and tectonic features in the Alpine-Carpathian-BM junction region (modified from Špaček at al. 2015a). Earthquakes EG – Eger graben; CB – Cheb basin; UMB – Upper Morava basin; SMF – Sudetic Marginal fault; MMZ – Mur-Mürz-Žilina Zone. Only earthquakes with magnitude ML > 0.5 are shown in figure B. Stress directions are adopted from Peška (1992), Reinecker and Lenhardt (1999), Jarosiński (2005) and Fojtíková et al. (2010). Note the NNW- to NW-oriented maximum horizontal stress in the BM and the increased seismicity along the Mur-Mürz-Žilina zone of sinistral shearing (MMZ). Maximum extent of ice is based largely on Ehlers et al. (2011).

crust of the BM the geodetic methods are of limited usability for the fault slip assessment. Data from earthquake focal mechanisms are limited to only few regions with increased seismicity (Havíř, 2000; Fischer et al., 2014; Špaček et al., 2015a) which is otherwise at very low levels. Thus the only reliable and most universal source of data for assessment of fault slip is the long-term geological records. Trenching studies using techniques similar to those of paleoseismology are most direct and efficient way to read and analyse these records. These studies have emerged in the last decade both within basic research or as a part of research applied to seismic hazard assessment for nuclear power plants (section 3). Here, three examples of recently performed research are given to illustrate the variety of observations relevant to fault slip assessment. The examples chosen include structures which may remind of tectonic deformation but which, as we believe, were formed largely by non-tectonic processes. These ambiguous structures deserve special attention since their correct interpretation is crucial for the assessment of past fault slip. Therefore, in addition to regional questions the below presented examples address some debated problems of more general importance, including:

1) complex sedimentary structures at slopes in periglacial zone and distinguishing them from tectonic deformations and earthquake induced liquefaction (e.g. Van Vliet-Lane et al., 2004; Lunina and Gladkov, 2016),
2) causal relations between the forebulge effects of glacial unloading (e.g. Muir-Wood, 2000) and the apparently increased rate of faulting in northern parts of central and western Europe during and after the Last Glacial Maximum (e.g. Houtgast et al., 2005; Štepančíková et al., 2013; Brandes et al., 2015), and

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