Quaternary International xxx (2017) 1–15

Contents lists available at ScienceDirect

Quaternary International

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

Last Glacial to Holocene vegetation succession recorded in polyphase slope-failure deposits on the Maleník Ridge, Outer Western Carpathians

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A R T I C L E I N F O

Article history:
Received 21 February 2017
Received in revised form
20 October 2017
Accepted 31 October 2017
Available online xxx

Keywords:
Landslide
Palaeovegetation
MIS 3
Late glacial
Holocene
Outer Western Carpathians

A B S T R A C T

Structural settings and palaeoenvironmental reconstruction of a polyphase Late Pleistocene deep-seated landslide at the Maleník Ridge in the Eastern part of the Czech Republic are presented. The deep-seated rotational landslide is about 480 m long and 1540 m wide and it is a part of much larger landslide complex. The depositional record of two generations of former near-scarp depressions revealed a multiple deep-seated landslide activity during the last Quaternary climatic cycle. With the minimum age of 47704 ± 2346 cal b2k, the landslide belongs among the oldest dated landslides in the outer Western Carpathians and Carpathian Foredeep in the Czech Republic. The younger reactivation started at 12662 ± 73 cal b2k during Younger Dryas. The palaeobotanical and depositional record from the landslide brought unique palaeoenvironmental data for two time intervals of the last Quaternary climatic cycle. The reconstructed MIS 3 forest vegetation with the predominance of stone pine-larch (*Pinus cembra* – *Larix*) taiga with *Pinus sylvestris* and *Betula pendula*/*pubescens* are the first evidences of the forest vegetation for the GS13 to GI12 transition in Outer Western Carpathians. Similarly, documented events of MIS 3 landslide activity from Outer Western Carpathians are rather rare. The Late Glacial to Holocene record from the younger near-scarp depression revealed vegetation and landscape changes during the Pleistocene/Holocene transition. The evidenced oldest parts of the landslide at the Maleník Ridge had to originate during more humid interpleniglacial conditions. The geomorphological evidence for landslide activity from this period has almost completely disappeared from the ground surface topography due to intensive periglacial processes operating later during the Last Glacial Maximum and subsequent fluvial and anthropogenic processes of the Holocene. The cold and relatively dry period of the pleniglacial is considered as a time when deep-seated mass movements use to be halted and overprinted by shallow solifluction of the active layer masking former deep-seated landslide features.

1. Introduction

Detailed reconstructions of past environments are essential for better understanding the on-going dynamics and trends of global environmental and climatic change (Andersen et al., 2006). Information on Quaternary palaeoenvironments is archived in plenty of terrestrial and subaqueous conditions, such as glaciers (Johnsen et al., 2001; Holzhauser et al., 2005), lacustrine deposits (Lotter et al., 1992; Lotter, 1999), peat bogs (Müller et al., 2003), or cave speleothems (Spötl et al., 2002, 2006) and others. Changes in local vegetation, humidity and temperature are relatively well understood in the areas with such natural archives.

Hilly to mountainous regions of Central Europe, where generally erosion prevails over deposition, are generally poor in sediments bearing suitable palaeoenvironmental information. In previously glaciated mountain ranges of Central Europe, palaeobotanical records could be achieved from lakes originating after the glacier

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https://doi.org/10.1016/j.quaint.2017.10.048
1040-6182/

melt (Engel et al., 2010; Vočadlová et al., 2015). However, in last decades the landslide related deposits were recognized to bring such reasonable data (Bookhagen et al., 2005; Margielewski, 2006; Dortch et al., 2009; Borgatti and Soldati, 2010; etc.). In non-glaciated mountain areas in the Bohemian Massif and the Outer Western Carpathians, the deep-seated gravitational slope failures are considered as mostly to be triggered by high precipitation and water saturation of rock (Baroň et al., 2005). Therefore dated mass-movement deposits could serve as a relatively good proxy for climate change, i.e. dry versus humid periods (Margielewski, 2006). Additionally, landslide-related basins and buried surfaces could preserve pollens and other datable plant remains (Pánek et al., 2013; Margielewski, 2014).

The Outer Western Carpathians are associated with one of the most extensive regional databases of dated landslides in the world (Margielewski, 2006; Pánek, 2015); deep-seated landslides generally originated during warmer and wetter stages of the Holocene with only a few exceptions dated to the Late Glacial (Margielewski, 2001, 2006; Hradecký and Pánek, 2003; Baroň et al., 2004; Baroň, 2007, 2011; Pánek et al., 2010) and two known cases from the late Pleistocene – up to date the oldest dated landslides in the area were the large successive gravitational slope failure from the marginal slope of the Upper Morava Basin and the Flysch Belt dated to the Marine Isotope Stage (MIS) 3 of the Late Pleistocene (Pánek et al., 2014; Špaček et al., 2017). Such a landslide activity concentrated to specific distinct periods was probably related to past climate conditions. The interstadial and interglacial periods, when landslides generally occurred, were relatively much more humid; the glacial stages and especially the coldest stadial stages characterised by arid conditions in Central Europe were seasons that could be considered as a time when deep-seated mass movements were halted in the Czech Flysch Carpathians, with shallow gelifluction of the active layer probably masking former deep-seated landslide features (Baroň et al., 2004).

We aim in this study to (i) present structural settings and (ii) palaeobotanical record of a polyphase deep-seated landslide and associated sedimentary depressions situated on southern margin of the Moravian Gate (MG) at the Maleník Ridge (MR) in the Eastern part of the Czech Republic (Fig. 1A); and (iii) reveal the timing of landslide activity and associated vegetation records.

2. Regional setting of the Maleník Ridge and the Moravian Gate

The Maleník Ridge and Moravian Gate are situated at the contact of the Bohemian Massif and the Western Carpathians in the eastern Czech Republic. The Maleník Ridge summiting at 479 m a.s.l. consists of Devonian and Lower Carboniferous flysch sediments being a part of the Bohemian Massif of the Variscan age.

Complex interaction of the Variscan basement and the moving Carpathian nappes caused a separation of blocks at the front of the Outer Western Carpathians and formed the Carpathian Foredeep – here represented by the Moravian Gate (Cogan et al., 1993; Špaček et al., 2015). The Moravian Gate is an ENE-WSW striking tectonic depression between the Nízký Jeseník Mts. and the Maleník Ridge sub-parallel to the Carpathian nappe front (situated to the South). Originally, the Maleník Ridge formed one single mountain complex with the Nizký Jeseník Mts. till the culmination of the Carpathian flysch nappes thrusting during the Langhian stage (16–14 Ma ago). Middle Miocene sediments of the Carpathian Foredeep were affected by compressional deformation connected with the movement of the Outer Western Carpathians (Havíř and Otava, 2004). Palaeomagnetic measurements have documented up to 25° anticlockwise rotation of sediments after Langhian (Márton et al., 2011).

To the South of the Maleník Ridge, there is a today's front of the Outer Western Carpathians (OWC), where the Cretaceous–Palaeogene flysch sediments were deformed by the Alpine orogeny. These flysch sediments were folded and thrust over the Bohemian Massif in Neogene (Dvořák et al., 1981; Čížek and Tomek, 1991; Ptáček et al., 2012). Erosion relicts of the Cretaceous and Palaeogene flysch sediments of the Carpathians (Subsilesian and Silesian units) occur also in the Moravian Gate. The Moravian Gate depression is about 5–7 km wide with margins exceeding 1000 m above the Paleozoic base; the Lower Badenian sediments of this basin reached thickness of 950 m (Hufová, 1974). According to drilling and geological mapping, the Pliocene deposits occur only to the south of the Maleník Ridge and in the Moravian Gate are missing. Quaternary sediments consist mostly of alluvial deposits and landslide colluvium on the slopes. For further details about the geological evolution of the area we refer to Mahel et al. (1968) and Picha et al. (2006).

The present-day topography of the study area is strictly controlled by ENE–WSW, NW–SE and N–S striking brittle faults (Figs. 1 and 2). Some of them have been active up to present according to local seismicity and trenching excavations (Špaček et al., 2015). Nowadays, the Maleník Ridge is a SE tilted block with an escarpment facing the Moravian Gate. The opposite slightly inclined SE surface of the Maleník Ridge gently transforms to smooth relief of the Kelč Upland of the flysch OWC. The NW slopes, however, are relatively steep varying from 5° to 50° and have been affected by number of polyphase gravitational slope failures (Figs. 2 and 3).

Current environment of the study area has been strongly influenced by intensive agriculture and artificial foresting since past centuries. The recent potential (not artificially altered) vegetation of the Malenik Ridge was presented by the geobotanical reconstruction map by Neuhäuslová and Moravec (1997), and Neuhäuslová et al. (1998). According to these maps, the *Quercion robori-petraeae* Braun- Blanquet, 1932 p.p. (acidophilus oak forest) geobotanical unit lies in the immediate surroundings of the study site (Mikyška et al., 1968 in Neuhäuslová and Moravec, 1997; and Neuhäuslová et al., 1998). It is bordered by *Luzulo-Fagion* Lohmeyer and Tüxen, 1954 p.p. (acidophilous beech forests) towards the northeast. The association *Carpinion betuli* Issler, 1931 p.p. (oak-hornbeam grove) covers large areas of Western Carpathians East of the site and eastern part of Bohemian Massif west of the Moravian Gate. Large parts of higher areas of adjoining flysch Carpathians are covered by beech forest (*Fagion* Luquet, 1926 emend. Pawlowski, 1928). The Moravian Gate area with western slopes of the Maleník Ridge is occupied by a mosaic of wetland habitats such as *Alno-Padion* Knapp, 1942 emend. Medwecka in Matuszkiewicz and Borowik, 1957, *Alnetea glutinosae* Braun–Blanquet and Tüxen 1943, *Phragmitetea* Tüxen and Preising, 1942 and others.

3. Methods

The extent of the landslides at the Maleník Ridge was recognized during the geological mapping of this area by the Czech Geological Survey (Otava et al., 2016). Thorough mapping of the superficial topographic features was conducted using analysis of airborne laser scanning (ALS) digital terrain models (DTM) of the Czech republic of the 5th generation (DMR 5G) with 1 m horizontal resolution and total mean elevation error 0.18 m in an open terrain and 0.3 m in a forested terrain. These data were obtained from the Czech Office for Surveying, Mapping and Cadastre (ČÚZK).

Lithostratigraphic description of sedimentary units was undertaken directly in the field. The organogenic material from the lower near-scarp depression was recovered from the depth of ~15 m by drilling of a well using a continuous flight auger. The palynological