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Archaeological evidence for Holocene landslide activity in the Eastern Carpathian lowland

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A B S T R A C T

Landslides are widespread phenomena that contribute to shape the landscape. Assessing the time sequence of landslide activity during the Holocene can help (i) better frame the present day landslide distribution in the wider context of climate change and (ii) better define landslide hazard to take adequate mitigation measures to preserve the elements at risk such as archaeological heritage and currently used structures and infrastructures. Rigorous image interpretation criteria applied to the interpretation of remote sensing images can be a valuable tool to derive information on landslide spatial and temporal distribution. However, it only allows to broadly estimate the relative age of landslides based on their morphologic signature. In this work, we investigate the topological relations between landslides and archaeological sites for nine selected settlements in the Moldavian Plateau, situated on ridges and hillslopes. Landslides and sites were mapped using high resolution LiDAR DEMs and extensive field validation activities. Landslides were classified as very old (relict), old, and recent, according to their morphologic appearance. We argue the possibility of (i) assigning a relative age to the three main classes of landslides as they appear on the present day topography, and (ii) assessing the landslide activity during the Holocene. Using this information, we set up a model of landslide evolution during the Holocene for the lowland of Eastern Carpathians. Based on collected data, we cannot exclude the Pleistocene age for some very old landslides, whereas the old and recent landslides appeared during the Holocene. We think this approach can be extended to other archaeological sites of the study area, and to other areas. Furthermore, similar studies can prove useful for landslide hazard analyses, helping to adopt adequate protection and mitigation measures, framed in a climate change scenario.

1. Introduction

Landslides are natural phenomena which occur in clusters over space and time (Trauth et al., 2000, 2003; Unkel et al., 2013). The spatial clustering of landslides consists of the appearance of landslides events around the same slope or catchment, where preconditioning, preparatory, and triggering factors are present (Pánek, 2015). In particular geological, geomorphological, structural, climatic conditions (e.g., alpine or tropical environments), and following high energy triggers (e.g., Marc and Hovius, 2015) landslide clustering can be particularly emphasized. Furthermore, depending on the intensity of the erosional processes, the climatic zone, and the size of the single landslides, the signature of past slope failures can be visible on the topographic surface over time (McCalpin, 1984; Wieczorek, 1984; Keaton and DeGraff, 1996). Pánek (2015) summarize that translational and rotational landslides have episodic reactivations of up to ~10^4 years, while for earth-flows and debris flows the recurrence interval is of 10^1–10^3 years. The same author summarizes that, for arid climates, the landslides signatures can persist for periods of 10^4–10^6 years, while in humid temperate climates they rarely exceed 10^3 years. In his extensive review on landslide dating methods, Pánek (2015) concludes that the radiocarbon dating of landslide-dammed lakes proves to be the most precise method for landslide events. Further dating opportunities are provided by evidence of landslides occurring in the Pleistocene, and retained in terrace deposits (Starnberger et al., 2013), whereas morphologic evidences of Holocene relict landslides appear all over the world (Pánek, 2015).

In hilly and mountainous environments, human society has always had to face landslide hazards. In the seven years between

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2004 and 2010, 2620 fatal (fast moving) landslides were recorded worldwide, causing a total of 32,322 recorded fatalities, with a toll of around 4620 fatalities per year (Petley, 2012). Furthermore, according to Schuster and Fleming (1986), economic losses due to landslide in the United States, Japan, Italy, and India exceeded $1 billion for each country, still confirmed as an average value in Italy for the period 1944–2011 (ANCE-CRESME, 2012). Being a widespread phenomenon that influences (Santangelo et al., 2013) or drives the landscape evolution (e.g., Korup et al., 2010), landslides have been dealt with by older societies, which is possibly recorded in archaeological and historical anthropic sites (Shuzui and Kamai, 2004; Sassa et al., 2005; Guttormsen, 2008).

Human interaction with landslides is shown at least from Upper Pleistocene (McIntosh et al., 2009), and mainly during the Holocene or historic times (Pánek, 2015). Human society is affected by landslide events nowadays, archaeological and historic sites being one of the most affected anthropic features (Sassa et al., 2005; Guttormsen, 2008). Archaeological sites are mainly spread in the lowland areas, where dating landslides is problematic (Pánek, 2015), due to, for example, long term agricultural and reclamation practices, and/or humid climate settings. Archaeological and historical evidence of spatial interaction between landslides and archaeological sites were used by some authors (Jørstad, 2002; Rohn et al., 2005; Sveian et al., 2006; Wechsler et al., 2008) to infer the age boundaries of landslides in an area.

Despite many efforts towards landslide dating techniques, still in the majority of the cases such techniques are inapplicable, mainly due to the lack of datable elements. This is commonly due to (i) the impossibility to reconstruct morphologically single landslides, or (ii) the high frequency of newer landslides partially covering the older ones, (iii) the morpho-climatic regime that shortens the persistence time of the landslides morphologic signature. In all these cases, the use of archaeological evidence can be of great help, in establishing the temporal boundaries of slope failures. Landslide events can be related with (i) the destruction of an archaeological site before (Christoskov et al., 1995) or after it was deserted by the population, both by old (Shuzui and Kamai, 2004; Delle Rose and Parise, 2004; Iai et al., 2006) or recent (Delmonaco et al., 2013) landslides, or (ii) its abandonment by the population because the landslide effects made it uninhabitable (Rohn et al., 2005; Wechsler et al., 2008).

In this work, we aim to study the activity and evolutionary pattern of landslides in the Eastern Carpathian lowland area from its spatial interaction with the human society along the Holocene. We selected nine archaeological sites situated on ridges and along hillslopes (Fig. 1), for which the relation between landslides and archaeological remains was evident, both on high resolution DEMs and in the field. Both landslide and archaeological sites information were derived from the systematic analysis of high resolution Digital Elevation Models (DEMs) and accurate field checks.

2. Study area

2.1. Geological and geomorphological framework

The Moldavian Plateau region (Fig. 1) is a 24,803 km^2 landslide prone area (Mărgărint and Niculiţă, 2016) in North-Eastern and Eastern Romania. Here, elevations range between 6 m a.s.l. and 794 m a.s.l., with an average of 199 m, whereas the terrain slope spans between 0° and 32° with an average of. 4.7°. The general morphostructural setting consists of a monocline with cuesta landforms. The strata are gently dipping from northwest to southeast, therefore the Miocene to Pleistocene deposits sequence that crop out in the area get younger from north to south (Ionesi, 1994). The lithology is characterized by successions of clays with sands, 200–300 m thick, and thin layers (2–30 m thick) of limestones and sandstones in Suceava Plateau and Jijia Hills (Lower and Medium Sarmatian deposits), and sands with clays, 150–200 m thick and thin layers (2–5 m thick) of limestones and andesitic cinerites in Bârlad Plateau (Upper Sarmatian to Pleistocene deposits) (Ionesi, 1994). Gravels appear to the west and southeast at the contact with the molasse and alluvial plains, respectively. The landscape is dominated by the cuesta landforms. Such a structural setting produces two substantially different type of slopes: cuesta dip slopes, gently east and southeast dipping (Niculiţă, 2011), and characterized by a low roughness; anaclinal, cataclinal, and orthoclinal slopes (cuesta scarp slopes), facing north, northwest and west, are steeper than the cuesta dip slopes, and generally affected by deep river incision at the base, by diffuse and well defined rill and gully erosion along the slopes, and by landslides. The bedding attitude, generally subhorizontal, is clearly visible both in the clayey and sandy layers and in the harder sandstone, limestone and andesitic cinerite layers, and produces typical step-like profile slopes, particularly evident in the upper parts of the slopes, and especially in landslide scarps.

Especially on the cuesta dip slopes and on fluvial terraces all over the study area, a layer of loess was deposited, showing various thicknesses. Generally the loess cover has depths under 2 m (Haase et al., 2007), but in the Jijia Hills, Huşi Depression and Covurlui Plateau (Fig. 1) the thickness of the loess cover can be between 15 and 30 m (Cazacu, 2001; Munteanu, 2006; Haase et al., 2007; Haesaerts et al., 2007).

Landslides in the study area are characterized by a strong temporal and spatial clustering, and are strongly influenced by the morpho-structural setting (Mărgărint and Niculiţă, 2016), as in other places of the world characterized by stratified layered rocks (Guzzetti et al., 1996; Santangelo et al., 2015a). In such areas, the morpho-structural setting sets the hydrogeological and morphological conditions for landslide occurrence. The general appearance of most landslides bearing slopes is characterized by the presence of large old (sometimes relict) landslides which morphological signature is often partially hidden by younger slope failures. Following a simplification adopted by Santangelo et al. (2015b), the relative age of the landslides can be grouped in three main classes according to similar morphological features, very old (L_{VO}), old (L_O), and recent (L_R) landslides. Among L_O, image interpretation distinguished multiple generations of landslides overlapping over time, but still showing morphological features younger than L_{VO} and older than L_R. Such a “mother-to-son” topological relationship allows for a relative age assessment within the same landslide cluster, whereas no information can be inferred for L_O relative age when landslides do not overlap.

2.2. Climate evolution during Late Pleistocene and Holocene

General characteristics of the Late Pleistocene and Holocene climate for the territory of the Moldavian Plateau can be derived from the paleoclimate models of the Central Eastern Europe. In particular, it was generally included in the major framework of the Last Glacial and Holocene periodization, including the Eastern Europe extension of the Blytt-Sernander classification system (Panin and Popescu, 2006; Chiriloaiei et al., 2012). Based on vegetation response to past climate variability, Feurdean et al. (2014) determined that, for the Central and Eastern Europe the Last Glacial-Holocene interval corresponds to an interval of time between 60 ka and 8 ka BP. Within this interval, they identified four climatic successions: the second half of the Last Glacial, the Last Glacial Maximum (LGM), ca 22–18 ka cal BP, the Lateglacial period (ca 14.7–11.7 ka cal BP), and the early Holocene (ca 11.7–8 ka cal BP). Furthermore, they indicate two corresponding Marine Isotope