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Effect of slope failures on river-network pattern: A river piracy case study from the flysch belt of the Outer Western Carpathians

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ABSTRACT

Landslides are important geomorphic agents in various mountainous settings. We document here a case of river piracy from the upper part of the Malá Brodská Valley in the Vsetínské Mts., Czech Republic (Rača Unit of the flysch Magura Group of Nappes, flysch belt of the Outer Western Carpathians) controlled by mass movement processes. Based on the field geological, geomorphological and geophysical data, we found out that the landslide accumulations pushed the more active river of out of two subparallel river channels with different erosion activity westwards and forced intensive lateral erosion towards the recently abandoned valley. Apart from the landslide processes, the presence of the N-striking fault, accentuated by higher flow rates of the eastern channel as a result of its larger catchment area, were the most critical factors of the river piracy. As a consequence of the river piracy, intensive retrograde erosion in the elbow of capture and also within the upper portion of the western catchment occurred. Deposits of two landslide dams document recent minimum erosion rates to be 18.8 mm.ky^{-1} in the western (captured) catchment, and 3.6 mm.ky^{-1} in the eastern catchment respectively. The maximum age of the river piracy is estimated to be of the late Glacial and/or the early Holocene.

1. Introduction

Landsliding is an important process influencing mountain range and landscape evolution (Shroder and Bishop, 1998; Kirchner and Lacina, 2004; Korup et al., 2010). Large landslides can impact catchment morphology (Korup et al., 2010), river long profiles (Hewitt, 1998), or sediment delivery (Hovius et al., 1997). Landslides may block river courses and form temporal dams (Costa and Schuster, 1988; Nicoletti and Parise, 2002; Baroň et al., 2004; Korup, 2004a,b; Pánek et al., 2007). Landslide dams could be rather short-lived phenomena (Ermini and Casagli, 2003), while others seem to be stable during the whole Holocene (Clague and Evans, 1994; Reneau and Dethier, 1996).

The interplay between drainage networks and hillslopes concerning the role of landslides can be grouped into the slope–fluvial (landsliding-channel initiation) and fluvial–slope (drainage headward extension-landsliding) relationships (Korup, 2005; Ng, 2006). Various causes of landslide initiation have been documented such as earthquakes, water-saturation of rock due to intense rainfalls, snowmelt, and, to a minor extent, stream piracy as was demonstrated for instance from the SE Spain (Mather et al., 2003). Korup (2004a,b) noticed avulsion (i.e., rapid abandonment of a river channel and formation of a new river channel in flat areas) due to landslides, by which pulsed or chronic supply of landslide debris to valley floors causes substantial aggradation and channel instability; he distinguished three types of landslide-induced channel avulsion: (i) upstream/backwater avulsions, (ii) contact avulsions, and (iii) downstream/loading avulsions.

Stream piracy is a process of fluvial erosion whereby headward erosion of one stream captures the upper part of an adjacent stream (Sala, 2004). River piracy and the corresponding incision into a bedrock as a result of an increased stream power usually induce change of hillslope geometry and subsequent landslides (Azañón et al., 2005). River piracy is common in tectonically active regions (e.g., Simoni et al., 2003; Stokes and Mather, 2003) where an excess of potential energy exists. Stream capture can be caused by headward erosion (Bishop, 1995), lateral erosion (Douglass and Schmeeckle, 2007), sapping (Pederson, 2001), and even regional tectonic movements when minor earth movements change slope inclination and thus have the potential to alter stream flow (Twidale, 2004). Stream piracy was also modelled in physical experiments (Douglass and Schmeeckle, 2007).

Stream piracy induced by landslide activity is rare in recent literature. In Southern Alps of New Zealand, Korup and Crozier (2002) documented river piracy of first-order stream channels by headward

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truncation and subsequent subsidence as a consequence of headward extension of new scarplets and tensional fissures. Oesleby (2005) mentioned a landslide aided stream piracy and abandonment of Unaweep Canyon in western Colorado.

The aim of this paper is to provide an insight into stream piracy in a typical landslide prone region, the Outer Western Carpathians. The paper will focus on (i) documenting a rare case of landslide-triggered river piracy in the Malá Brodská Valley, eastern Czech Republic, (ii) understanding the geological and geomorphic factors of the piracy, and (iii) evaluating the consequences of the piracy, i.e., estimate the change of local erosion rates caused by river caption.

2. Geological and geomorphic settings

The investigated site is situated in the upper part of the Malá Brodská Valley near Nový Hrozenkov, in the central part of the Vsetínské vrchy Mts. (Fig. 1). The highest point of the study site is the Tanečnice Mt. (912 m asl), and the lowest is the valley floor (559 m asl). The average slope is 19.5°; maxima are located near the elbow of capture and locally reach up to 48°. Topography of the Vsetínské Mts. has a character of uplands and highlands up to 1024 m asl, with major slope inclinations of 10° to 20° (Krejčí et al., 2002). It is of structural-denudational and erosion-denudational origin; the difference between competent and incompetent beds, mass movements as well as fluvial erosion played a basic role in forming the local relief (Kirchner, 2000). The mountain ranges have a typical strike ENE–WSW, predisposed by the geological structure.

The study area belongs to the Rača Unit of the Magura Group of Nappes (Fig. 1B), which is a part of the flysch zone of the Outer Western Carpathians (Pícha et al., 2006). The flysch zone is a folded, tectonically imbricated, thin-skinned thrust stack, which was thrust over the North European platform (Fennosarmatia) during Palaeogene and early Neogene phases of the Alpine orogeny (Pícha et al., 2006). The study site is located within the Vsetín Member of the Zlín Formation (Rača Unit, Magura Group of Nappes). It is mainly composed of alternating calcareous mudstone, shale, and metre-scale thick turbidite sandstone layers of Eocene to early Oligocene age. The bedrock is strongly weathered (Pícha et al., 2006). The ENE–WSW trending thrust faults and numerous radial faults frequently occur in the area. The study area has never been glaciated in the Quaternary (Nývlt et al., 2011), and it has been intensively affected by shallow to deep-seated landslides throughout the Holocene (Krejčí et al., 2002; Baroň et al., 2004; Pánek et al., 2013). Numerous examples of stream piracy can be seen in the flysch belt area (e.g., Vojtko et al., 2012), but the relationship between the gravity mass movements and stream capture has gained only little attention.

3. Methods

Landslide-related erosional features and their spatial distribution, dip direction, and dip angle of outcropping sandstones were mapped by means of the field geological and geomorphologic mapping in order to reconstruct the local geological structure and leading geomorphic processes. Bedding patterns and sedimentary structures of the Quaternary windgap sediments were studied in a 1.1-m-deep trench in the abandoned channel.

In order to get a precise digital elevation model (DEM), we carried out a field survey by using the Trimble 5503 total station. The resulting DEM has a 1-m resolution and covers all important terrain features in the area. With these data we were able to generate both longitudinal and cross-sectional profiles of the area.

In order to investigate subsurface structure of the landslide and the windgap, we conducted a two-dimensional (2D) electrical resistivity tomography (ERT) survey using the ARES automatic geoelectrical system

Fig. 1. General settings of the Malá Brodská Valley: (A) location of the site within central European context (location of Fig. 1B is marked as a rectangle, the study area is marked as the complex star); (B) geological map of the Vsetínské vrchy Mts. superimposed on the slope gradient map from the SRTM data; the brown colours represent flysch rocks of the Rača Unit, the green colours represent flysch rocks of the Silesian Unit, and the extent of Fig. 3A is defined by the black rectangle.
Source of data: Czech Geological Survey and USGS/NASA.