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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 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.

(GF Instruments, Czech Republic). The Wenner–Schlumberger array of 64 electrodes was used with a 3-m electrode spacing. The 237-m total length of the section was accomplished using the roll-along method with a 16-electrode (48-m) increment. Stacking of four pulses with a 0.5 s pulse length was used in each measured point. The maximum depth of the apparent resistivity pseudosection was 33.7 m. Inverse model resistivity section was produced from the apparent resistivity pseudosection by least-square inversion method using RES2DINV software (Loke, 1997).

The age of the landslide was estimated by AMS radiocarbon (^{14}C) dating of ~2.2-m-thick fluviolacustrine deposits originated as a result of the blockage of adjacent valley by right-lateral levee of the landslide. Sediments at the deepest part of the lake were drilled by the Eijkelkamp peat sampler with 60 mm diameter. We dated needles of *Abies alba* situated at depths of 223 and 88 cm in order to state the onset and range of the sedimentation behind the landslide barrier. Dating was carried out at the University of Georgia, Center for Applied Isotope Studies. Radiocarbon dates were converted into calibrated ages using IntCal 09 calibration curve (Reimer et al., 2009) in OxCal v 4.1.7 software (Bronk Ramsey, 2009). Calibrated ages are presented in the form of their 1σ probability ranges.

To compare the erosional dynamics before and after the river piracy, we calculated a minimum denudation rate (DR_{min}) for the captured catchment and neighbouring noncaptured catchment. Both catchments were previously blocked by different phases of the described slope deformation (captured valley in 1997 — still existing lake, the adjacent valley — lake filled with sediments, see above). For estimation of the denudation rate we formulated this equation:

$$DR_{min} = (V_L/t)/A_C;$$

where DR_{min} (mm.ky^{-1}) is the minimum denudation rate in the catchment above the particular landslide-dammed lake, V_L (m^3) is the volume of sediments trapped in the landslide-dammed lake, t (year) is the duration of sedimentation, and A_C (km^2) is the area of the catchment above the particular landslide-dammed lake. The duration of sedimentation (t) was acquired as a difference between medians of the probability density functions of the calibrated radiocarbon dates.

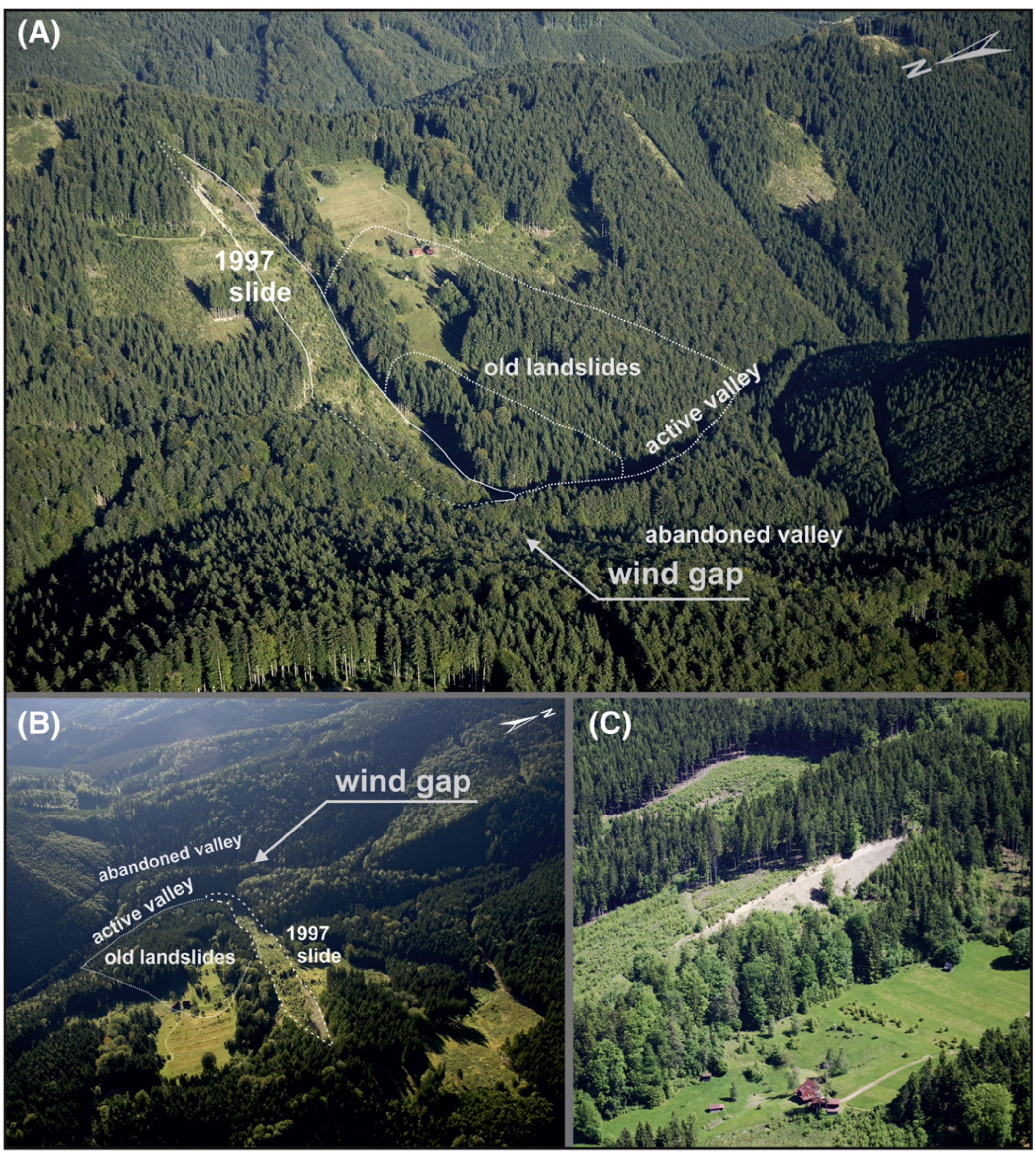

Fig. 2. Airborne oblique photos: (A) of the entire studied area from the NW, (B) of the 1997 landslide from the east, and (C) detail of the depletion zone of the recent landslide from the SW. Photos by Ivo Baroň.

Medians were chosen as the most appropriate central values for calibrated dates (Telford et al., 2004; Engel et al., 2010).

Bathymetry of the existing lake was measured in 2009 (the 2009 bottom and the original 1997 ground-surface levels) and again in 2012, using probe and Topcon 232 total station. Thickness of the sedimentary infill of the silted lake was measured in 2010 (using the same equipment). Volumes of the sediments in both lakes were calculated from the acquired digital depth models in Surfer 8 (Golden Software). To get the duration of sedimentation in the lake completely filled with fluviolacustrine deposits, we used medians of the calibrated ^{14}C dates as a robust central-point estimate of the age (Telford et al., 2004). Area of both catchments was acquired in ArcGIS 10 (Esri) from the DEM mentioned above.

4. Results

4.1. Local topography

The studied case of stream piracy has evolved in a catchment for as large of only about 1 km^2. From the field survey it was possible to identify the following features related to stream piracy: an abandoned valley, a wind gap, a ridge, old inactive landslides and a landslide reactivated in 1997, an elbow of capture, deeply incised upper part of the captured stream, remnants of a strath, and a knickpoint in the abandoned valley where a small original tributary overtook the role of the active stream (Figs. 2–4).

The *abandoned valley* is about 400 m long, trending NNE–SSE, widely opened, and mild with a dry bottom of the former streambed. The maximum slope gradient of the abandoned valley is about 7–10°, and the abandoned valley has a U-shaped cross-section. Looking upward the abandoned channel suddenly ends in the *wind gap*, which is situated 12 m above the active streambed and which indicates the minimum depth of erosion since the river piracy. The *ridge* is about 130 m long, N–S trending and it constitutes a local divide between the abandoned valley and the main active one. The ridge shape is not strictly controlled by competent sandstone beds. The upper part of the captured stream is deeply incised in the bedrock; the incision is the most intense at the junction with the main stream and it disappears upward in 250 m. The longitudinal channel profile is influenced by outcrops of competent sandstone beds, which form series of cascades. At the level of the abandoned valley floor upward, the strath terrace occurs at western slopes along the pirated stream; this is an erosional remnant of the former streambed. The strath terrace is only minor with a maximum width of 2–3 m.

The abandoned valley is dry only in its 150-m-long upper course. Two minor tributary streams, which joined the original (now pirated) main stream a few hundreds of metres downward from the wind gap, flow in the valley. The resulting stream has much lower erosive capacity than the main active stream. This is well evident at the place of the junction of the remnant and the main active streams. Several strath terraces of about 5 m elevated above the riverbed of the active stream are cut by the residual stream in the abandoned valley, which erodes the bottom of the abandoned valley floor. Headward erosion by the residual stream continues progressively forming the strath terraces from the smooth floor of the abandoned valley. At the place of most intense headward erosion an ~1.5-m-high knickpoint occurs (Fig. 4).

The eastern slopes of the main active valley are formed by distinct, deep-seated landslides of different morphology and activity state (Figs. 2 and 3). East of the site of the capture, a large complex flow-like landslide is situated; the landslide was activated on 7 July 1997 following distinct heavy rainfalls and floods in the eastern Czech Republic (Rybář and Stemberk, 2000; Krejčí et al., 2002). The landslide is 685 m

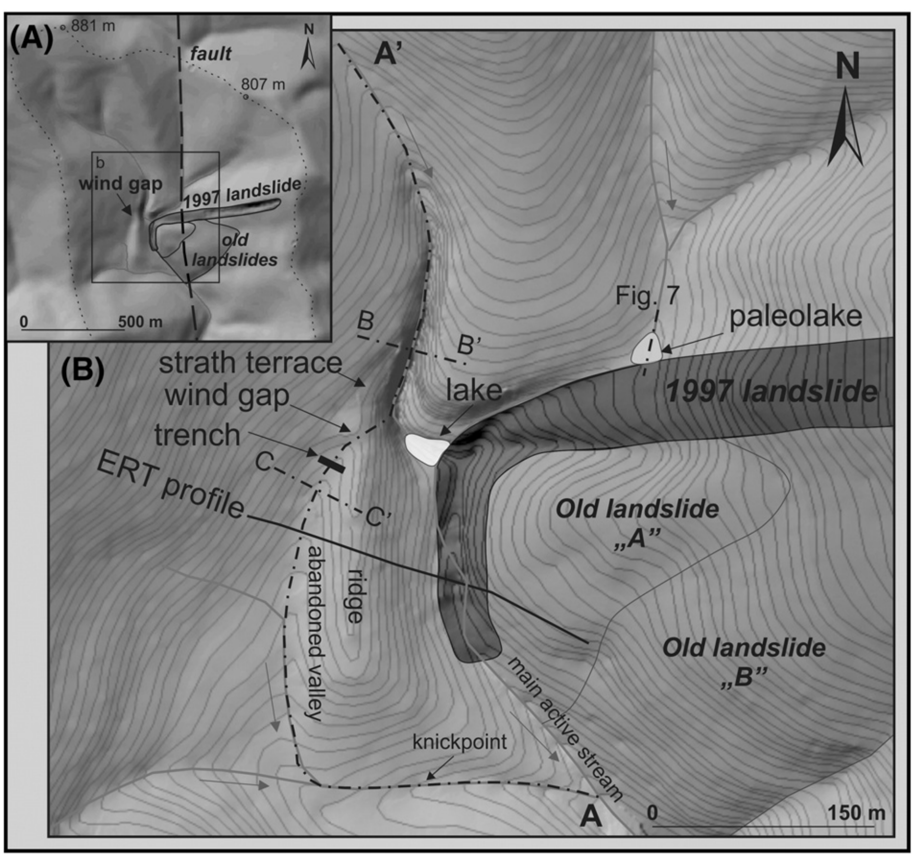

Fig. 3. Topography of the study site: (A) DTM of the upper part of the catchment of Malá Brodská River with major studied features; (B) detail view of the active and abandoned valleys, accumulation zones of the active and dormant landslides, dammed lakes, and profiles.
Source of data: ZABAGED.

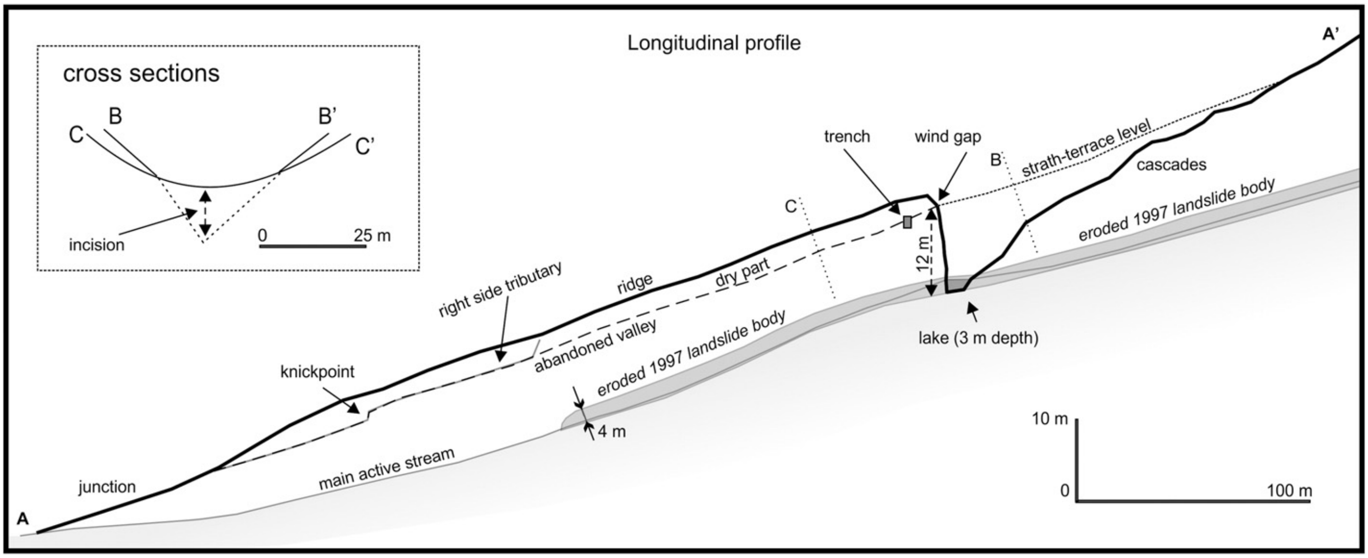

Fig. 4. Topographic profiles of the abandoned and active valleys with marked major studied features: (A) longitudinal profile, (B and C) cross profiles; for their location see Fig. 3B.

long (total volume of ~0.3 × 10^6 m^3), and it is situated on the west-facing slope of the Zadní Kyčera hill (802 m asl). It has a distinct trough-like morphology and extremely low width-to-length ratio (maximum width of landslide is ~50 m). The wedge-like morphology of the detachment zone of the landslide area was controlled by the intersection of steeply inclined bedding planes and a normal fault striking ENE–WSW. A basal sliding surface is exposed in the upper part of the slope, where the landslide mass liquefied and transformed into an earthflow. Several 2–6 m high levees occur along the middle part of the landslide. The lower part of the earthflow completely buried the valley floor and caused blockages of two adjacent streams. One of these blockages emerged during the July 1997 event and still accommodates a small permanent lake. The lake is recently about 20 × 10 m in size and 3 m deep. An older lake (paleolake) is situated upward of the main active stream (Fig. 3B) and it is now completely filled with fluviolacustrine deposits. The recent landslide developed within more extensive, old deep-seated landslides affecting ca. 20 ha of slope (Figs. 2 and 3). Based on their topography, they are both rotational and at least two distinct bodies could be distinguished. Their geomorphic features are, however, very smooth in contrast to the recent landslide.

Active processes, related to the 1997 landslide, changed some original features related to stream piracy. In particular, a part of the main active valley was filled by the landslide's accumulations and the entrance to the gorge was filled with water thus reducing its relative depth (Fig. 4). More recent processes also include subsequent incision into the landslide body forming a new course of this stream.

4.2. Geological structure

The local geology of the investigated area consists of steeply dipping, almost vertical, competent sandstone beds up to 2 m thick and less competent calcareous shale and claystone beds up to 10 m thick, alternating here in several similar sequences. The general strike of the flysch beds is about ENE–WSW, oblique to the river channels. The competent sandstones tend to build ridges and act as protective dams in a newly incised

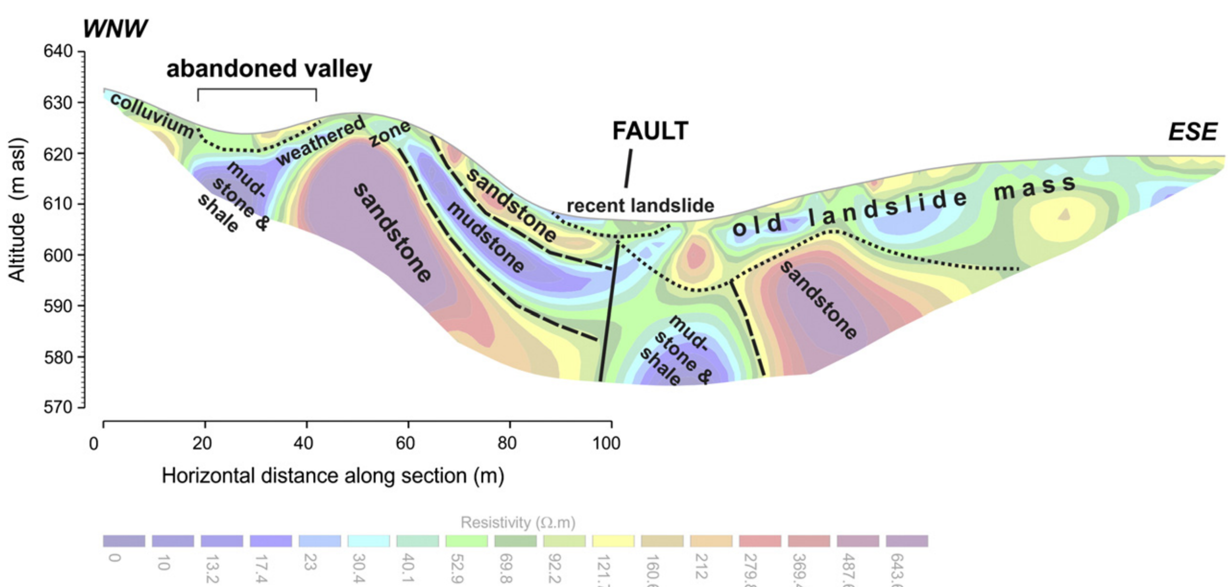

Fig. 5. Interpreted ERT profile indicating the local geological structure, presence of the subvertical N-striking fault, old and recent landslide accumulations, sediments of the abandoned channel, colluvium, and intense weathering; for localization of the ERT profile, see Fig. 3.

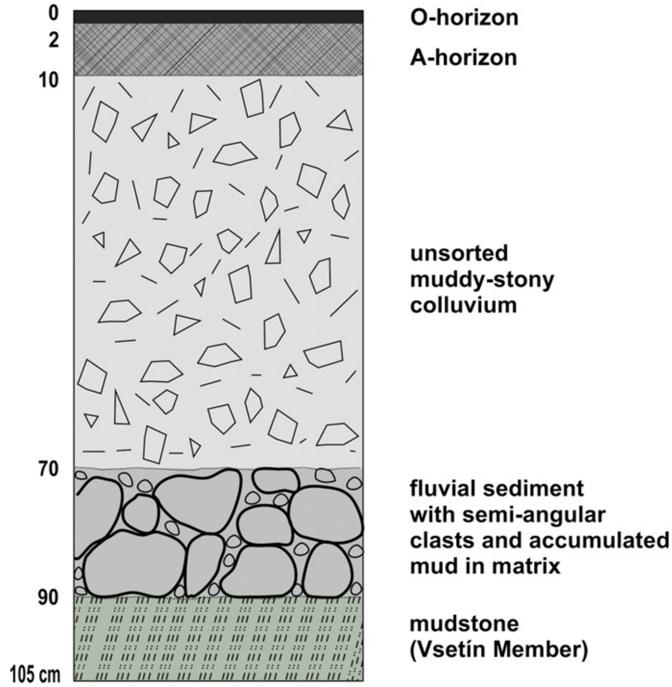

Fig. 6. Schematic sketch of the sedimentary log of the trench with main lithologic characteristics evidencing the presence of fluvial deposits of the original brook; for localization of the trench, see Figs. 3 and 4.

piracy stream significantly reducing erosion. On a broader scale, the area is affected by south-dipping thrust faults with general strike ENE–WSW and NNW–SSE trending radial faults.

The ERT survey (Fig. 5) revealed distinct, high resistivity (~280 to ~650 Ω.m) domains, which are interpreted as thick layers of unweathered sandstones. These domains alternate with low resistivity (~10 to ~70 Ω.m) ones interpreted as shales and calcareous mudstones. Being steeply inclined to ESE in the WNW–ESE profile, their boundaries correspond to the regional dips of the flysch beds (toward the south). This layered pattern is disturbed in the middle part of the ERT profile, at ~100 m distance, by a subvertical zone, which is interpreted as a radial fault (running approximately N–S, consistent with the geology of the broader region). The resistivity values are highly variable, ranging from ~30 to ~250 Ω.m, in a near-surface domain, ~3 to ~5 m thick, which are interpreted as colluvium or landslides (Fig. 5). The relatively shallow-seated 1997 landslide as well as the deep-seated old landslide can be visible in the ERT profile.

A trench, dug out in the upper central part of the abandoned valley about 10 m below the wind gap (Figs. 3 and 4), revealed about a 20-cm-thick layer of clast-supported gravel composed of imbricated, semiangular sandstone clasts, generally 10–20 cm in diameter (Fig. 6). The matrix of the sediment contains (probably secondarily) a significant amount of clay. This layer is interpreted as fluvial sediment (stream channel residue). The fluvial sediment lies at 70 to 90 cm deep below the ground surface, overlying flysch mudstone of the Vsetín Member. Above it, about 60-cm thick, unsorted muddy–stony colluvium (clast-rich muddy diamicton according to Moncrieff, 1989) with angular clasts up to a few centimetres in diameter is deposited, overlain by about 10-cm-thick soil with O and A horizons.

4.3. Slope-failure history

Morphological evidence shows that the slope transects with the July 1997 failure is particularly prone to recurrent landslides/earthflows. A dammed palaeolake (Fig. 3B), now completely filled by 2.2-m-thick sediments, was formed as a result of some earlier phases of landslide activity. Dating of the basal lacustrine deposits to 1170–1060 cal BP (Fig. 7) provides a minimum age estimate of a major ancient landslide that occurred at the site and was likely the immediate trigger responsible for the river piracy as a consequence of the permanent landslide-induced shift of the stream against the opposite east-facing slope. Besides lacustrine and palustrine deposits, two intercalations of alluvial gravels (200–212 cm; 69–88 cm) reveal high energy sedimentary inputs to the reservoir (Fig. 7). The lake is still subject to fluviolacustrine sedimentation, which is suggested by almost recent age (290–0 cal BP) of organic particles deposited at the depth of 88 cm below the surface.

Sediment volumes trapped in both lakes (Fig. 8) enabled a rough estimation of the denudation rates in the contributing subcatchments of the pirating stream. Areas of both subcatchments are very similar (0.356 km^2 for the adjacent catchment and 0.352 km^2 for the captured

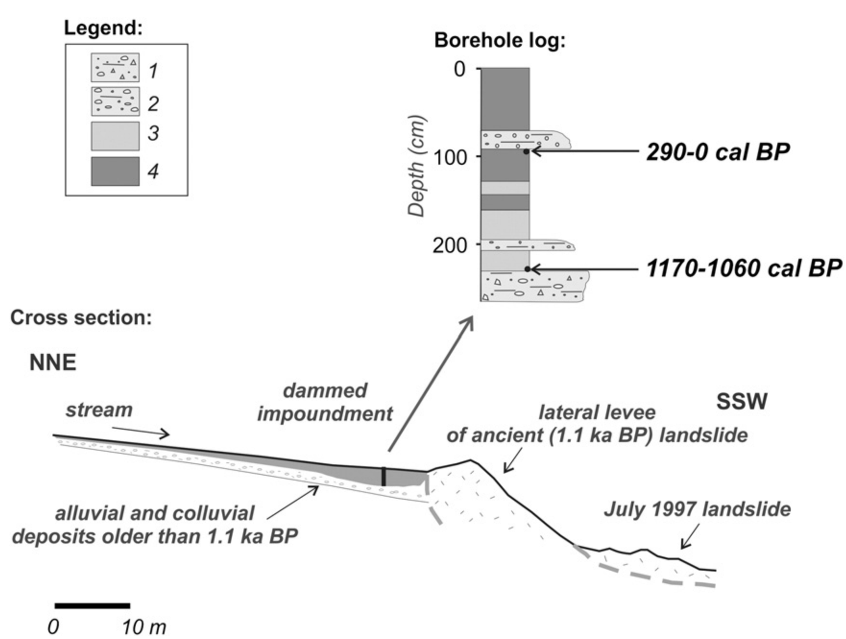

Fig. 7. Schematic cross-section of the upper dammed lake and sedimentary log with dated fluviolacustrine deposits: 1 — alluvial channel deposits; 2 — high energy sandy and gravely deposits; 3 — lacustrine silts; 4 — organic-rich silts deposited in swampy environment; the calibrated ages of the deposited organic matter are presented.

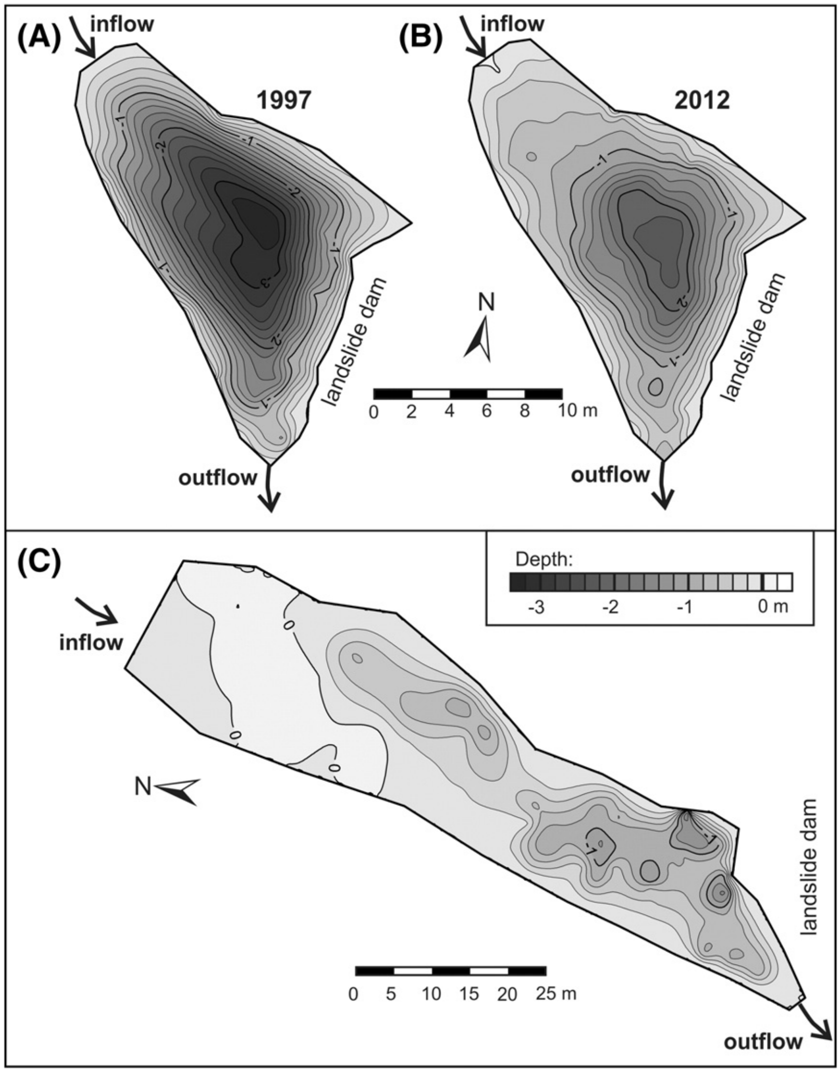

Fig. 8. (A, B) Sedimentation in the recent landslide-dammed lake reflected in the bathymetry changes between the years 1997 (initial state) and 2012. (C) Depth of sedimentary fill in the palaeolake.

catchment), whereas the size of the palaeolake is ~3.5 times larger than the 1997 lake (660 and 190 m^2 for the palaeolake and existing lake, respectively). Calculated denudation rate (DR_{min}) for the captured catchment is 18.8 mm.ky^{-1}. The result was acquired from sediment volume accumulated between the years 1997 and 2012. Denudation rate for the adjacent (noncaptured) catchment is 3.6 mm.ky^{-1} and it was calculated from sediment volume accumulated between 180 cal BP (median of the probability density function of the calibrated radiocarbon date from the basal lacustrine deposits) and the present.

5. Discussion

The presented site in the Malá Brodská Valley in the flysch belt of the Outer Western Carpathians documents well a rare case of stream piracy induced by gravitational mass movements. Our reconstruction shows that the accumulations of deep-seated landslides pushed one of two subparallel river channels with different erosion activity westward. This has forced an intensive lateral erosion toward the recently abandoned valley and caused the piracy (Fig. 9). These geomorphic features of the piracy here are of local scale, but such a complex topography at a small area is rarely seen in the flysch Carpathians.

The most critical factor of the river piracy seems to be the occurrence of two subparallel river channels with different erosion activities; the eastern (recently active) channel performed much deeper incision, which was probably enhanced by the estimated N–S striking fault indicated by its geomorphic appearance on DTMs and detected by the ERT survey. The contrast between incisions of the eastern (pirating) and western (pirated) channels was also accentuated by higher flow rates of the eastern one as a consequence of its larger catchment. As a result, the elevation gradient between these parallel channels was about 12 m in a horizontal distance of about 50–80 m.

Accumulations of the two dormant old landslides and of the original flow-like landslide, which was reactivated in 1997, pushed the stream westward and forced intensive lateral erosion of the active channel toward the recently abandoned one. When the lateral erosion reached the western channel, the less active river changed the course out of the former valley. Later on, intensive retrograde erosion in the elbow of capture and also within the upper portion of the western catchment occurred. The coarse fluvial deposits of the abandoned channel were subsequently buried with about 60-cm-thick colluvium.

As landslides directly controlled the evolution of the studied case of river piracy and the paleofluvial deposits of the abandoned channel were not datable, we tried to achieve information on the age of stream truncation through dating the landslides. The oldest achieved age of the

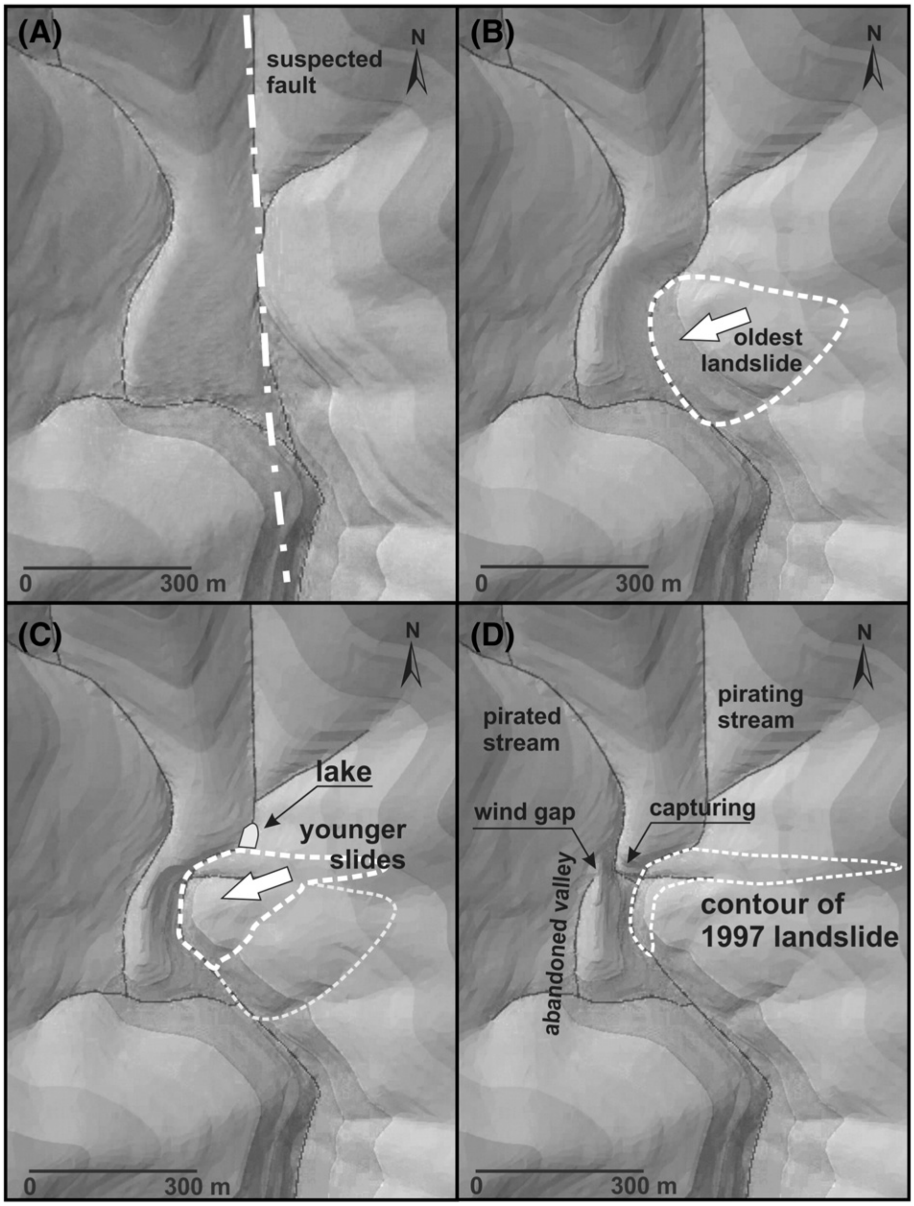

Fig. 9. Interpretative model of the evolution of river piracy in the Malá Brodská Valley: (A) reconstructed topography of the original state with a trace of the suspected fault that probably enhanced faster erosion in the eastern valley, (B) the oldest and largest landslide slightly pushed the eastern valley westward, (C) younger (dated) landslides pushed the eastern valley more to the west and intensified lateral erosion toward the recently abandoned valley, which (D) caused capturing of the western stream and caused the piracy (present day topography).

complex flow-like landslide was about 1170–1060 cal BP by indirect dating of the ancient landslide dam (dating of basal lacustrine sediments, which evolved after the damming). This landslide was, however, preceded by two deep-seated (recently inactive) landslides to the south of it, which could unfortunately not be dated because no datable deposits were found there. Based on the rather smooth shape of the old landslides and the analogy with other dated landslides of the same magnitude in this area (e.g., Kobylská landslide; Baroň et al., 2004), we can only speculate about the age of the river piracy to be of early Holocene and/or late Glacial.

Although this case of river piracy induced by landslides is rather small, it documents the high rate of recent erosion and slope processes in the area of the mountains of the flysch belt of the Outer West Carpathians. Topographic gradient between the pirating and pirated streams enhanced deep incision and relatively high erosion rates of the western (pirated) stream. Recent high erosional dynamics in the western catchment is still detectable by comparing the denudation rates calculated from sediments trapped in the landslide-dammed lakes (Fig. 8). We consider the acquired denudation rates to be minimum values because an unknown amount of sediments might be missing as a result of possible suspended load outflow in both lakes and because of the higher rate of the sediment compaction in the palaeolake. In the western (captured) catchment (18.8 mm.ky^{-1}), the value is five times higher than in the adjacent catchment (3.6 mm.ky^{-1}). Though some levels of uncertainty exist in the calculated values, we think it clearly shows the higher recent erosional dynamics in the captured stream. Our estimation of the erosion rate of the captured catchment is, however, an order of magnitude smaller than the recent denudation rate within a similar catchment of the Bystřička River also situated in the Vsetínské Mts. Baroň et al. (2010) estimated it by balancing the artificial dam clastic sediments with the area of the catchment above and assumed it to be between 82.1 and 28.7 mm.ky^{-1} by not considering and considering porosity of the dam deposit, respectively. Contrary to our study site, the Bystřička River catchment is much larger and comprises large portions of arable land and pastures. For a longer period, Bíl et al. (2004) calculated the erosion in the flysch belt of the Outer

West Carpathians since the Sarmatian (Neogene) by analysing anisotropy of magnetic susceptibility, vitrinite reflectance, and K/Ar dating of volcanic rocks to be 1400 m; i.e., the mean erosion rate was 102–127 mm.ky^{-1}. These values are higher than the recent erosion rates obtained from the sediment accumulation in the Bystřička River reservoir probably as a result of more sparse vegetation cover in the flysch Carpathians during cold periods of the Pleistocene, which could not protect the land surface from sheet erosion. Isolated forest vegetation similar to the present Siberian coniferous taiga surrounded by a mosaic of steppe communities and tundra patches occurred in the area during the last glacial period (Jankovská and Pokorný, 2008). The high erosion rates calculated by Bíl et al. (2004) are probably influenced by periods of high tectonic activity of the Western Carpathians in the Neogene (Golonka and Pícha, 2006).

Although the recent erosion rate of the pirated stream in the Malá Brodská Valley is much lower than the previously published values, it is slightly higher than the range of late Holocene denudation rates of 2.5–13.4 mm.ky^{-1} calculated for several Holocene landslide-dammed catchments in the Outer Western Carpathians by Pánek et al. (2010). All of these values are probably low because of the dense forestation of the studied catchments in the Holocene, which considerably slows down sheet erosion, whereas the piracy-induced intensification of erosion had only a local occurrence.

6. Conclusions

This paper presents results of the field investigations of river piracy in the Malá Brodská Valley in the flysch belt of the Outer Western Carpathians controlled by mass movement processes. Based on the field geological, geomorphological, and geophysical data, we could roughly summarize a scenario of this river piracy case. The landslides' accumulations pushed the more active river westward and forced intensive lateral erosion towards the recently abandoned valley.

Except for the landslide processes, the occurrence of two subparallel river channels with different erosion activity and the presence of a N-striking fault, accentuated by higher flow rates of the eastern channel as a consequence of its larger catchment area, were the most critical factors of the river piracy.

Later, intensive retrograde erosion in the elbow of capture and also within the upper portion of the western catchment occurred. Slope mass-transport processes subsequently buried the coarse fluvial deposits of the inactive channel with about 60-cm-thick colluvium.

The maximum age of the river piracy is estimated to be of late Glacial and/or early Holocene. The presented case of river piracy as a result of slope failures documents recent erosion rates in the area of the mountains of the flysch belt of the Outer Western Carpathians.

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