EROSION-ACCUMULATION PROCESSES ON AN ALLUVIAL FAN: A CASE STUDY FROM THE MORAVSKO-SLEZSKÉ BESKYDY MTS. (CZECH REPUBLIC) BASED ON DENDROGEOMORPHOLOGICAL METHODS

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Abstract

Alluvial fans are important landforms whose origin and evolution is the result of a wide range of geomorphological processes. Records on the evolution of alluvial fans in the Moravskoslezské Beskydy Mts. (Moravian-Silesian Beskids Mts.) are so far lacking. This study analyses current processes at work on the surface of a selected alluvial fan making use of dedrogeomorphological methods. The growth-disturbance analysis of 30 increment cores together with the cell-anatomy analysis of 12 exposed roots revealed that 13 accumulation and 7 erosional events occurred on the alluvial fan in the last 45 years. The origin of almost all the dated processes can be correlated with extreme meteorological events such as short-term rains of very high intensity or rapid snow thawing in spring.

Shrnutí

Současná geomorfologická aktivita na aluviálním kuželu (příkladová studie z Moravskoslezských Beskyd (Ceská republika) s využitím metod dendrogeomorfologie

Aluviální kužely jsou významnou formou reliéfu, jejichž vznik a vývoj je spojen s pestrou škálou geomorfologických procesů. Podrobné záznamy o vývoji aluviálních kuželů v Moravskoslezských Beskydech však dosud chyběly. V této studii byly procesy, modelující dnešní povrch vybraného kuželu, analyzovány pomocí dendrogeomorfologických metod. Analýzou růstových disturbancí z 30 vrtných jader a analýzou anatomických změn buněk z 12 obnažených kořenů bylo zjištěno 13 akumulačních a 7 erozních událostí na kuželu za posledních 45 let. Vznik téměř všech datovaných procesů je možné vysvětlit extrémními meteorologickými událostmi, jako jsou velmi vysoké krátkodobé srážky nebo rychlé jarní tání sněhu.

Key words: *dendrogeomorphology, alluvial fan, erosion, debris flow, Moravian-Silesian Beskids Mts., Czech Republic*

1. Introduction

Alluvial fans occur in abundance on almost all relief types (Harvey et al., 2005). Source basin parameters determine the dominant processes at work on the formation of alluvial fans. In principle, two major types of processes can be distinguished: slope processes dominate in the morphometrically defined and rather exposed areas (e.g. mountain units), whereas fluvial processes act on the less dynamic relief. Generally, however, these two types of processes alternate. Surface morphology of alluvial fans whose evolution is controlled by the activity of debris flows shows the presence of erosion channels, longitudinal levees and accumulation lobes. (Jackson et al., 1987; Kostaschuk et al., 1986; Bollschweiler et al., 2008). On the other hand, the morphology of alluvial fans controlled by fluvial processes is flatter and characterized by the branching channels of permanent or intermittent streams. Potentially, changes in environmental conditions can bring about a total change in the type of process affecting a fan, with this often accompanied by erosive deepening of existing channels. A radical change in fan-surface formation processes can be caused by a distinct climatic change, by a change in the base level or by anthropogenic interference into land use. Although alluvial fans represent a common feature in the Moravian-Silesian Beskids Mts. (Šilhán, 2009), a detailed analysis of their evolution focusing especially on fan-forming processes has yet to be accomplished.

Dendrogeomorphological methods were used to carry out a detailed analysis of a selected alluvial fan in the eastern part of the Moravian-Silesian Beskids Mts. This approach enables a highly accurate analysis of accumulation slope processes (Strunk, 1997), fluvial processes (Gottesfeld and Gottesfeld, 1990) and erosive processes (Malik, 2008). Dendrogeomorphological methods start from the basic premise: process – event – response (Shroder, 1978; 1980). A process is understood as any geomorphological feature (e.g. a debris flow) that causes an event, e.g. stem damage on a tree. If the tree survives the event, its further growth represents a response to the event (e.g. callous tissue is formed and the injury is overgrown to leave a scar). This study deals with the effect that accumulation processes have on the growing trees (Stoffel and Bollschweiler, 2008, 2009) and also with the tree root exposure caused by the vertical deepening of gullies during erosive processes (Vanderkerckhove et al., 2001, Malik, 2008). The aim of the study is

1. to verify the use of dendrogeomorphological methods to analyze processes on a selected alluvial fan in the Moravian-Silesoan Beskids Mts.,
2. to reconstruct the frequency and character of the processes, and
3. to analyze the meteorological conditions leading to these processes.

2. Locality

The study area is in the eastern Moravian-Silesian Beskids Mts. (49°35′17″N; 18°41′45″E). The selected alluvial fan is located on the right bank of the Kopytná River, with its source basin on the slope under Mt. Kozubová (981 m a.s.l.); the source zone is found at an elevation of 590 m a.s.l. with the very top of the fan at an elevation of 490 m a.s.l. From a geological point of view, the Moravian-Silesian Beskids Mts. represent a young nappe mountain range composed of flysch deposits gently inclined (10–20°) to the SSE. The source basin of the fan is predominantly composed of Istebna Formation composites (thickly bedded flysch with prevailing sandstones and conglomerates) passing into the middle member of the Godula Formation (thick layers of sandstones and conglomerates) in the upper part of the basin. These two rock formations are separated by a fault. (Menčík et al., 1983).

The accumulation body at the mouth of the source basin is composed of three overlapping fans. Forming the western lower part of the whole complex, the first alluvial fan is ~60 m wide, currently inactive and overgrown by meadow grasses (the middle fan). The second alluvial fan forms the highest part of the complex (the highest fan). It overlaps the upper half of the middle fan as well as the edge of a ~3-m-high fluvial terrace. This fan, void of surface accumulation, is partially covered by mature forest. It is cut from top to bottom by a 30-m-long gully of variable width (0.5–2.5 m) and depth (0.2–1.7 m). The bottom of the gully is very uneven and characterized by four distinctive steps up to 1.3 m high. In one place the gully cuts down to bedrock. Moreover, the forefront of the alluvial fan is cut by a further gully that is 8 m long and 0.5 m deep at maximum. The youngest alluvial fan has formed at the mouth of the upper, larger gully (the lowest fan). It is ~40 m wide and overlaps the middle alluvial fan on its western side. This fan, including the mostly active central part where fresh material is accumulating, is covered by a mature forest of Picea abies. The location and geomorphic features of the alluvial fan complex are shown in Fig. 1.

3. Methods

3.1 Fieldwork

The alluvial fans complex and its wider surroundings were mapped at a scale of 1:500 focusing on the accumulation (fans) and erosion (gullies) features; selected trees affected by accumulation activity on the active part of the alluvial fan (the lowest fan) were sampled using a Pressler increment borer. Two increment cores were taken from each tree: one in the direction of processes and the other from the opposite direction. The sampling height was selected based on the way a specific tree was affected. Trees whose stem bases had been buried were sampled as low down as possible, whereas sporadically scarred or tilting trees were sampled at the height of damage or maximum stem flexion. Exposed roots growing across gullies were sampled by cutting cross sections: this also required recording the exact position of a sample (height above the gully bottom, depth from the alluvial fan surface, original orientation of the sample and its distance from the gully edge). Emphasis was placed on sampling near the centre of the gully. A total of 30 increment cores and 12 cross-sections were taken from the trees of *Picea abies*. In order to determine "common" growth conditions, 20 more increment cores were taken from trees unaffected by geomorphological processes (growing in the stable part of the slope at ~100 m distance from the fans complex) and a reference chronology was compiled (Cook and Kairiukstis, 1990) (Fig. 3c).

Samples for sedimentological analyses were taken from representative (both naturally and artificially) exposed areas. About 500 g of material of < 20 mm

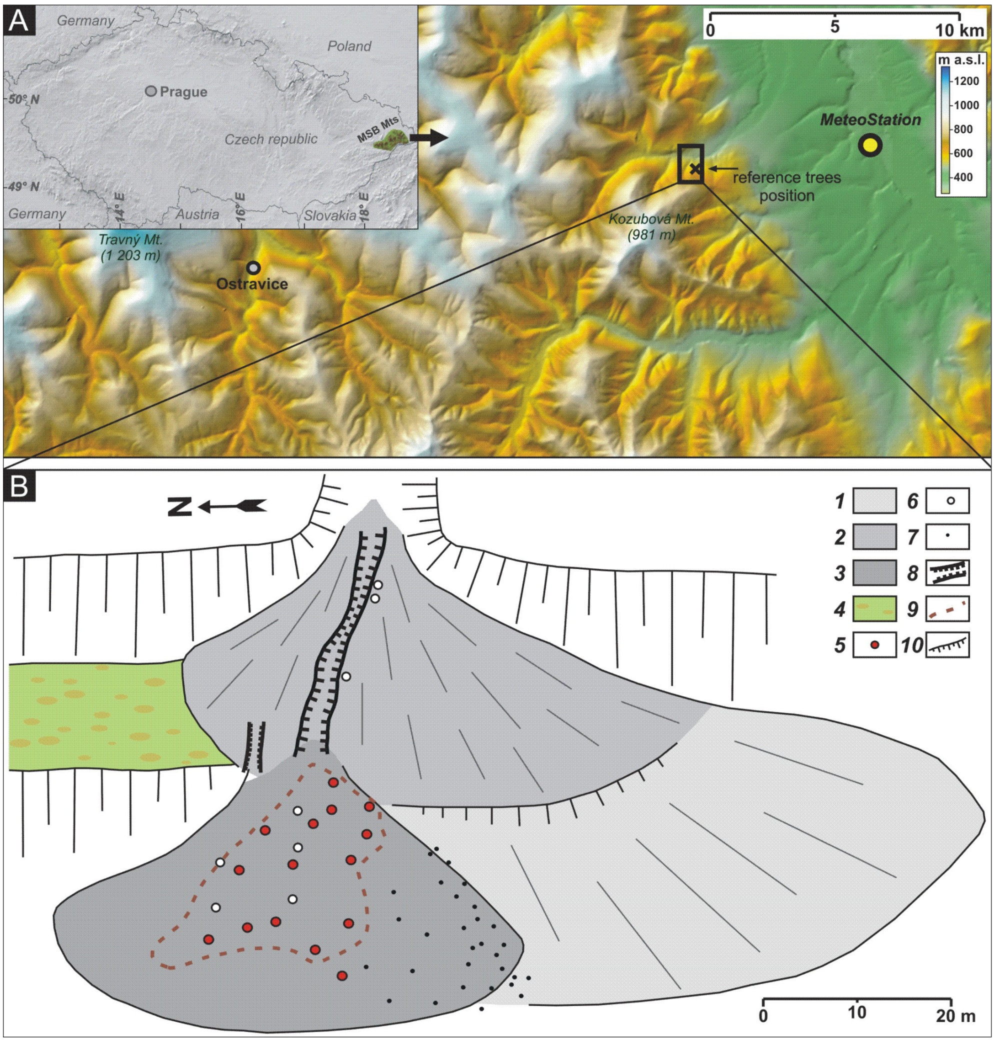

Fig. 1: A – Location of the study area (in the Czech Republic. B – geomorphological features (1 – middle fan surface 2 – highest fan surface , 3 – lowest fan surface , 4 – fluvial terrace, 5 – sampled tree, 6 – sampling site for sedimentological analysis, 7 – unsampled trees growing outside the active area of the fan, 8 – gully, 9 – active zone within the fan surface, 10 - fluvial terrace)

diameter were taken in order to carry out grain-size analysis and 50 clasts of 20–100 mm were taken to evaluate clast shape and roundness.

3.2 Laboratory approach

Samples intended for dendrogeomorphological analysis were processed in compliance with standard procedures described by e.g. Stoffel and Bollschweiler, 2008. The samples were left to dry, inserted into stabilization grooves, smoothed and polished. Tree-rings were counted and tree-ring widths were measured using the TimeTable measuring device and the PAST4 programme (V.I.A.S., 2005). False or missing tree-rings, identified by comparison with the reference chronology tree-ring series from the 20 unaffected trees, were subsequently corrected using the cross-dating method.

Granulometric analysis was carried out by means of the wet sieving method (sieves: 10.000, 5.000, 2.000, 630, 200, 63, and 20 μm) and evaluated in the Gradistat 4.0 programme (Blott and Pye, 2001). Clast roundness, assessed subjectively according to a grade scale introduced by Krumbein (1941) and modified by Powers (1953), was expressed by means of the RA index (percentage of angular and very angular clasts in a sample). Individual clast axes (a, b, c) were measured with an accuracy of 1 mm. The clast shape was expressed by means of the C40 index (percentage of clasts with c/a axial ratios ≤ 0.4; Sneed and Folk, 1958).

3.3 Identification and reconstruction of geomorphological events

The effect on increment cores of geomorphological processes on tree growth was identified based on the following visual features (Fig. 2):

a) (Figs. 2c, 3b), abrupt growth suppression (response of a stressed tree to buried stem base or mechanical wounds to tree-stem surface) (Fig. 2c),
b) abrupt growth release (response to stem damage in a remoter part of its circumference) (Figs. 2d, 3a),

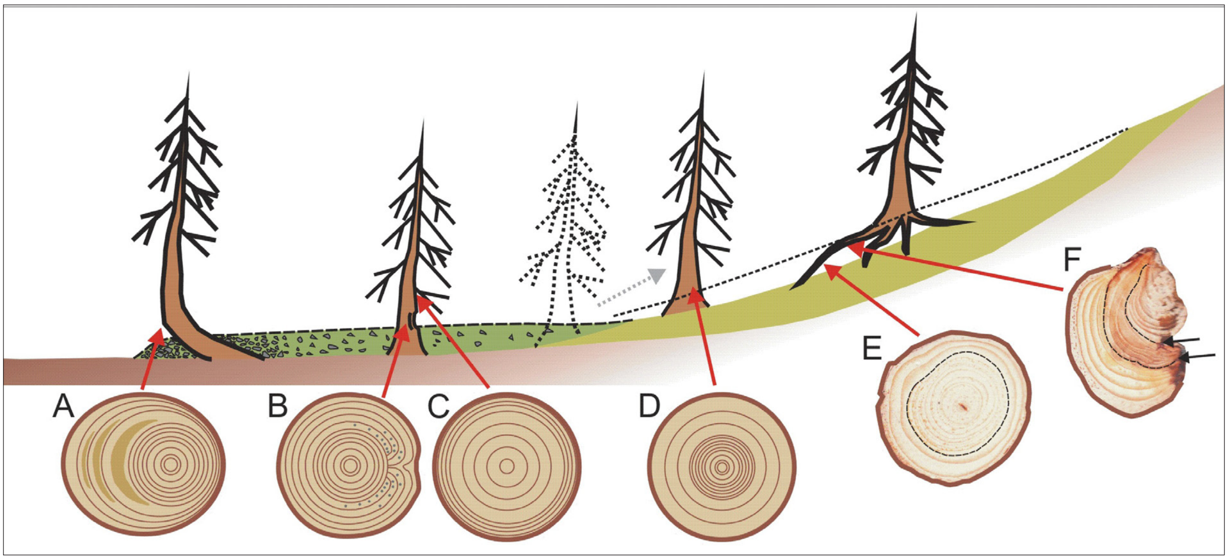

Fig. 2: Tree growth response to accumulation and erosive processes on the alluvial fan. A – reaction wood formation as a response to tree tilting, B – formation of scars and traumatic resin ducts due to stem damage, C – sharp narrowing of tree-rings due to stem base burial, D – abrupt widening of rings due to elimination of adjacent trees (dotted outline), E – change in the structure of tree-root wood after exposure (dashed line = surface erosion), F – formation of scars on roots following damage (black arrows = ring boundaries dating location of damage)

c) compression wood in coniferous trees (response to tilting) (Fig. 2a),
d) formation of tangential rows of traumatic resin ducts – TRDs (in response to mechanical wounding caused by a geomorphological process) (Fig. 2b),
e) scar formation (in response to tree surface wounding) (Fig. 2b).

In order to be sure that the identified tree-ring width changes resulted from the impact of geomorphological process, only severe growth suppression (55%) and strong growth acceleration (200%) were considered plausible evidence (Schweingruber et al., 1990).

Moreover, only growth changes, which significantly differ from reference chronology variations are considered as results of geomorphological process impacts (Fig. 3).

Erosive events in gullies were identified by means of root cross-sections. Once exposed, the roots of coniferous trees respond almost immediately by a change in the size of new cells. An exposed root produces up to 50% smaller cells, as compared with cells of an unexposed root (Gärtner, 2007; Malik, 2008) (Fig. 2e). Root exposure also makes possible identification of early wood and late wood within a tree-ring. Likewise,

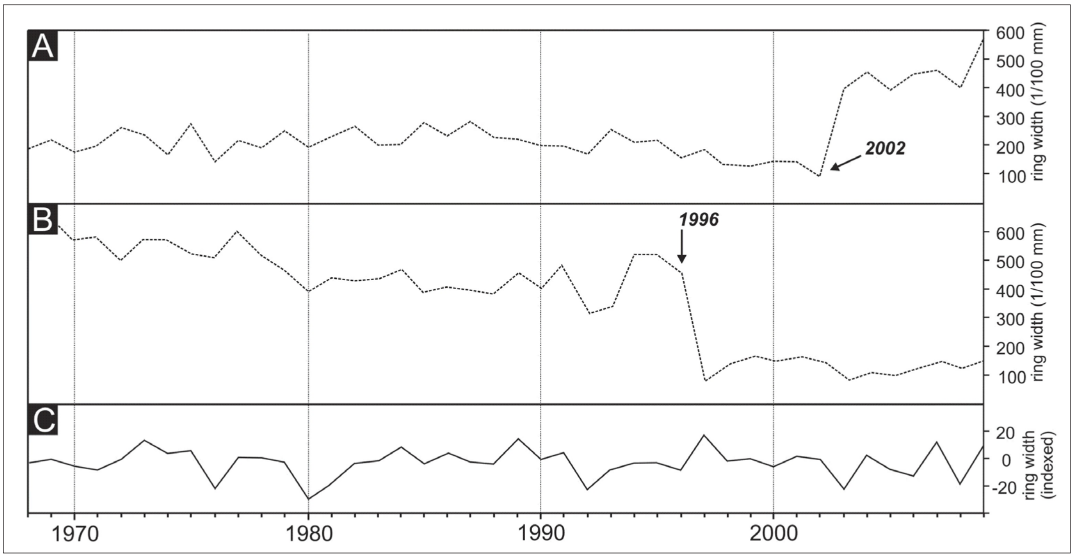

Fig. 3: Comparison of increment curves from disturbed trees with reference chronology. A – abrupt growth release, B – abrupt growth suppression, C – reference chronology

erosive events may induce root wounding followed by scar formation (Fig. 2f). Anatomical changes in cell size were analyzed using a binocular microscope.

Reconstruction of erosive and accumulation events was derived from a minimum number of samples with respect to their spatial position (Bollschweiler and Stoffel, 2010). Years in which particular geomorphological processes originated were taken as those indicated by at least two samples whose mutual position related logically to the geomorphological event. Years indicated by only one sample were recorded as probable events.

Meteorological data necessary for the analysis of major influences on the activity of geomorphological processes were obtained from the Jablunkov-Návsí (380 m a.s.l.) meteorological station ~6 km from the fan (Fig. 1).

4. Results

Number of trees, samples, dated disturbances and reference chronology

Trees that grow in the largely active zone of the lowest alluvial fan were sampled in order to assess the distribution of accumulation processes on the fan. The oldest sampled tree was 55 years old, whereas the youngest was 43 years. Average age was 49.2 years. The average age of the surrounding forest is ~100 years. This is why the forest on the fan complex was probably "managed". The increment cores helped to identify and date 51 growth disturbances related to accumulation processes on the alluvial fan. Major reactions of trees included abrupt growth suppression (41%) compression wood formation (19%), traumatic resin ducts (TRD) (16%), scars (14%) and abrupt growth release (10%). All abrasion scars were oriented in the geomorphological process direction, and occurred at heights up to 20 cm above the ground. Absolute values of the number of dated accumulation events in individual years are shown in Table 1. All identified disturbances were compared with reference chronology. Only those that did not correspond with ring width changes in reference trees were considered as result of geomorphological process impact. Climatically driven narrow rings (pointer years) funded from reference chronology were 1976, 1980, 1992 and 2003. All these years correspond with the findings of Čermák et al. (2010) from the near Silesian Beskids Mts.

Erosive events in the gullies were dated using cross-sections taken from exposed roots. The oldest root showed 48 rings, whereas the youngest one 15 rings. Average root age was 32.6 years. Attention was paid to root exposure as indicated by abrupt reduction in cell size and root damage connected with scar formation. Detailed analysis of cross-section surfaces supplied 18 dates for erosive events. Root exposure accompanied by anatomical changes in cell size was dated in 67% of all samples. Root damage followed by scar formation was dated in 33% of all samples. Absolute values of the number of erosive events in individual years are given in Table 2.

Year	Growth suppression	Growth release	Reaction wood	TRD	Scar	Total	Trees
2008		1				**1**	1
2005				1		**1**	1
2002	4		1	1		**6**	4
2000	2					**2**	2
1996	2					**2**	1
1993	5	3				**8**	7
1988	3			1		**4**	2
1982	3				1	**4**	3
1977		1	3		1	**5**	5
1975	1		1			**2**	1
1974			1			**1**	1
1972			1	4	3	**8**	3
1970	1		3	1	2	**7**	4
total	21	5	10	8	7		

Tab. 1: Number of identified growth disturbances and affected trees in individual years in the accumulation area on the alluvial fan.

Year	Root exposure	Scar	Total
2008	2	2	**4**
2005	1	1	**2**
2002	1	1	**2**
1996	3	1	**3**
1993	1	1	**2**
1977	2		**2**
1972	2		**2**
total	12	6	

Tab. 2: Number of identified growth disturbances caused by erosive processes on roots in a gully

Reconstructed accumulation events

Assessment of a minimum number of trees showing growth disturbances within the same year enabled reconstruction of a total of 13 accumulation events on the lowest alluvial fan in the last 45 years (Fig. 4a). According to the criteria we adopted, eight of these events can be considered 'real', while five events can be considered 'probable'. Intensive accumulation-based evolution of the alluvial fan falls within the period of 1970–1977 within which five events were dated. Sporadic events characterize the period of 1978–1999 when only four events took place. The second period of marked accumulation activity started in 2000, continued up to 2008 and comprised four events.

The position of all sampled tress was indicated on a geomorphological map (Fig. 5). Positions of trees that experienced a growth disturbance within a single year made it possible to reconstruct the spatial extent of accumulation events on the active part of the alluvial fan. The spatial extent of four major events was reconstructed based on four affected trees. The oldest event, affecting four trees on the central part of the fan, took place in 1970. The maximum reach of accumulation sediments was ~20 m from the gully mouth. A different behaviour pattern was identified in connection with the 1977 event reconstructed from the positions of five trees. Similar to the 1970 event, only trees in the central part of the alluvial fan were affected. However, the accumulation itself changed direction heading towards the northern end of the fan. The 1993 event affected the highest number of trees (seven) within the dating period. The accumulation parted into two branches, each occupying the opposite margin of the active zone. The northern branch is almost 30 m long and the southern branch is 10 m long. The last reconstructed event, which occurred in 2002, affected four trees and its course resembled the character of the 1993 northern branch.

Reconstructed erosive events

Similar to accumulation events, the determination of erosive event years is based on the minimum number of samples recording growth disturbance. The studied period revealed seven events, which caused deepening in part of the gully (Fig. 4b). All the events can be considered 'real' since they are replicated on the required number of samples. At the same time, all dated erosive events correspond to real or at least probable accumulation events. The oldest events date back to 1972 and 1977 followed by a long break of 15 years void of erosive activities. In the period between 1993 and 2008, five events occurred (1993, 1996, 2002, 2005, and 2008).

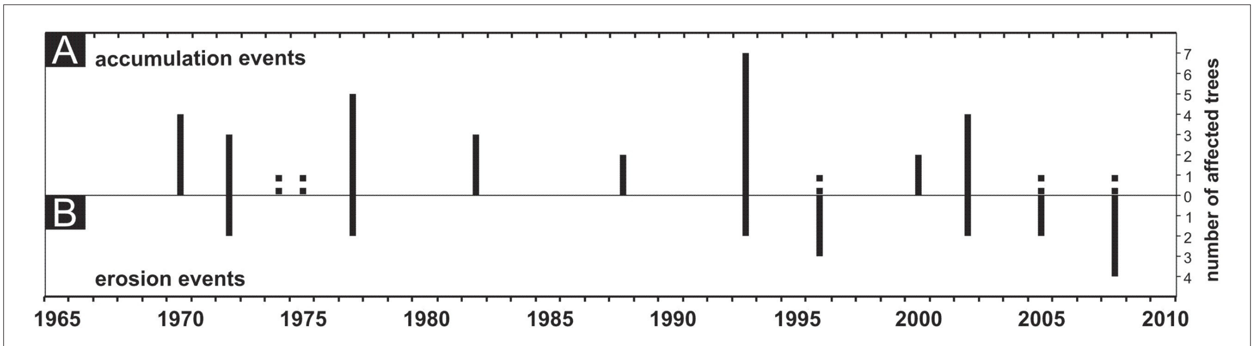

Fig. 4: Accumulation (A) and erosive (B) events confirmed by dendrogeomorphological study with regard to the number of affected trees. Continuous line = guaranteed event, dashed line = probable event (reconstruction based on the dating of a single sample)

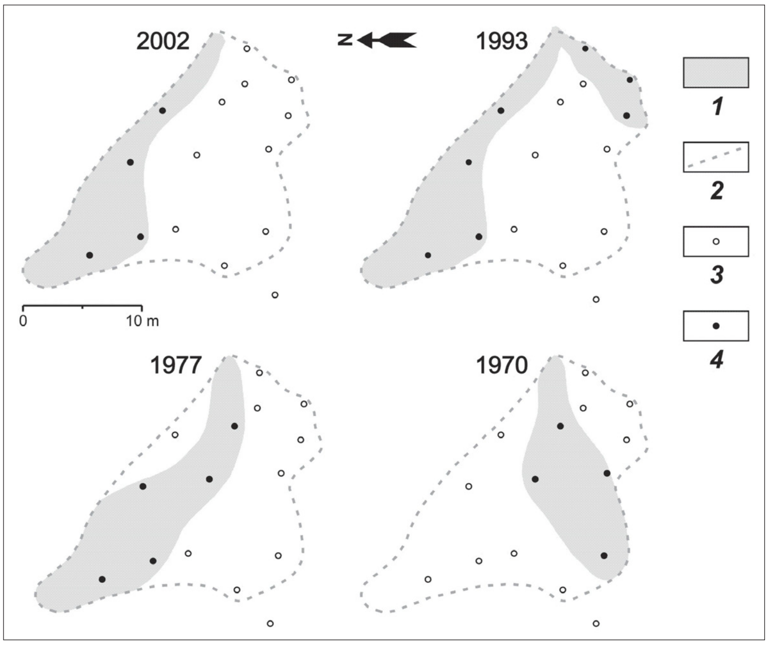

Fig. 5: Spatial reconstruction of the largest accumulation dendrogeomorphologically confirmed events (1 – accumulation-affected area, 2 – active zone boundary defining the youngest formation period of the alluvial fan, 3 – sampled tree, 4 – sampled tree displaying growth disturbance in a given year)

A careful record of the positions of sampled roots enabled reconstruction of the evolution of the depth and length of both gullies (Fig. 6). Initial deepening in the upper end of the longer gully confirmed dendrogeomorphically took place in 1972. Subsequently, the deepening continued progressively into lower parts of the gully. Samples taken in the upper part of the gully helped to date several erosive events that further damaged exposed roots. Similar evolution was identified in the shorter gully where the deepening started at its upper end and progressed to its mouth.

Sedimentological analysis of material

Granulometric analysis was carried out using four samples taken from the most active part of the lowest alluvial fan and two samples taken from an

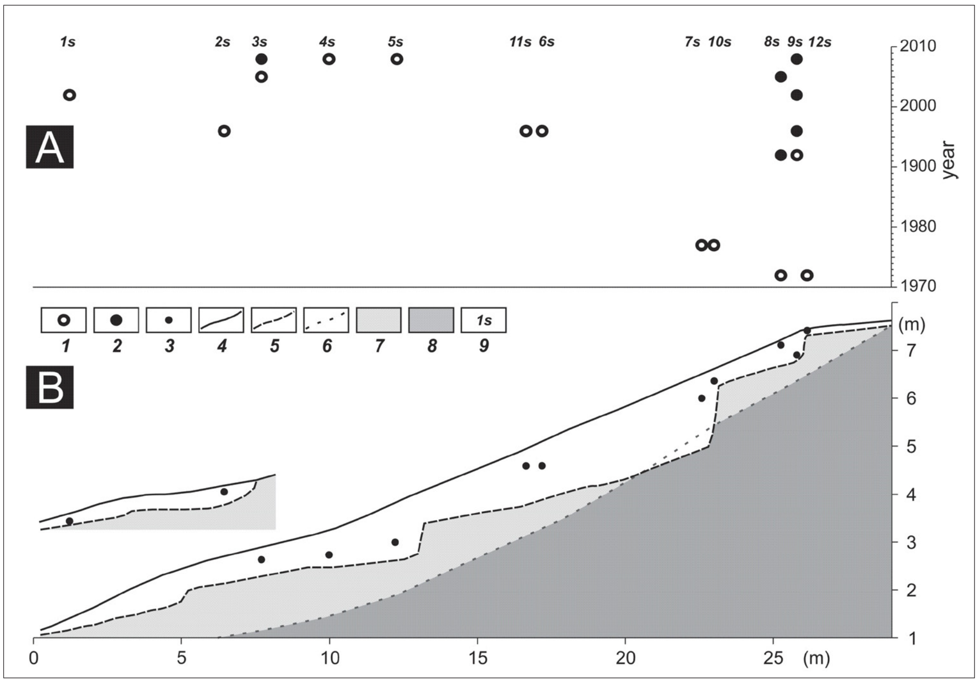

Fig. 6: A – Spatio-temporal evolution of longitudinal and vertical gully deepening, B – longitudinal profile of gullies including the position of samples (1 – root exposure, 2 – root damage, 3 – root position within gullies, 4 – current surface of the alluvial fan, 5 – gully bottoms, 6 – assumed boundary between alluvial fan material and bedrock, 7 – alluvial fan material, 8 – bedrock, 9 – root sample indication)

outcrop at the highest fan. The results are presented in Fig. 7a; they show a clear difference between the two groups of samples. The material of contemporary accumulation processes is constituted predominantly of slightly sorted sand and gravel in a matrix of mud. The well-sorted material from the older alluvial fan is characterized by equal amounts of gravel, mud, and sand. Clast shape and roundness analysis was performed based on a maximum representative sample of the material of the highest and lowest alluvial fan formations. Fig. 7b shows that the clast shape of the two samples is similar. A more significant difference is found with respect to clast roundness since the material of contemporary accumulation processes is approximately twice as rounded as the material from the highest alluvial fan. There are greater differences between material sorting and medium-size grains of the two types of clast (Tab. 3).

	RA	C_{40}	M_G	s_G
old fan	36	74	112	15.6
young fan	18	69	386	6.1

Tab. 3: Average values of roundness (RA), shape (C_{40}), medium size (M_G) and sorting (σ_G) of the material from the oldest and youngest alluvial fans

The analysis of meteorological events, potentially triggering processes on the alluvial fan (Fig. 8), focused on maximum total amounts of daily precipitation (mm/24h), maximum height (cm) of snow cover at the end of spring (March, April) and thawing index (°C) defined as the difference between average April and May temperatures (Zielonka et al., 2008). Two groups of processes can be distinguished. The first group involves processes caused by extreme short-term precipitation events (more than 100 mm/24h), based on the results, these took place in 1970, 1972, 1974, 1982, 1996, 2000 and 2002. The other group, defined as years in which the potential causative mechanism was sudden thawing of large quantities of snow, includes the years 1977, 1988, 1993 or 1996.

5. Discussion

Using dendrogeomorphological methods, accumulation and erosive activities of geomorphic processes were analyzed on a selected alluvial fans complex at the foot of the northern slope of Mt Kozubová. A total of 30 increment cores from 15 *Picea abies* trees were used to reconstruct 13 accumulation events that had taken place on the fan (five of them considered as probable events). The analysis of 12 cross-sections of exposed roots growing across a deepened gully revealed seven erosive events. It is important to observe that dendrogeomorphological analyses inform only of episodes that occurred, but it is not possible to reconstruct which of the episodes was more energetic and extreme. For this reason, it is necessary that all dated events are considered only as events confirmed by the dendrogeomorphological study.

Some of the events (15) showed on one tree only and therefore can be considered as probable. Moreover, some events may not have been detected at all owing to an insufficient number of trees. This is a common problem in many dendrogeomorphological studies (Gottesfeld and Gottesfeld, 1990; Strunk, 1997; Bollschweiler

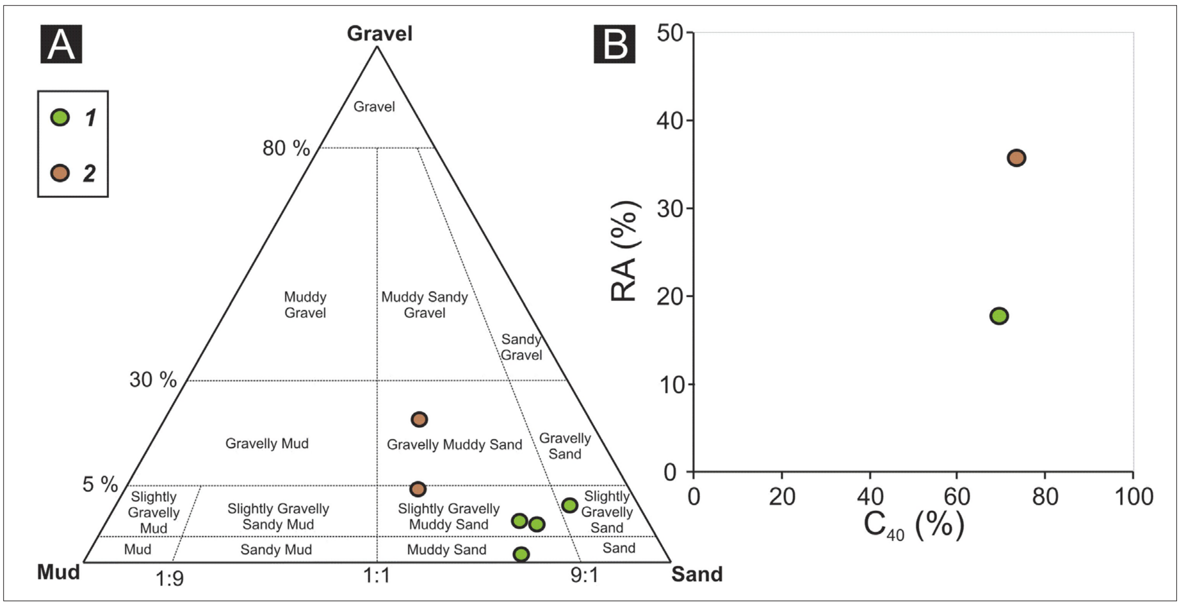

Fig. 7: Sedimentological characteristics of the material of the lowest (1) and the highest alluvial fan (2) A – results of grain-size analysis, B – relation between class roundness (RA) and clast shape (C40)

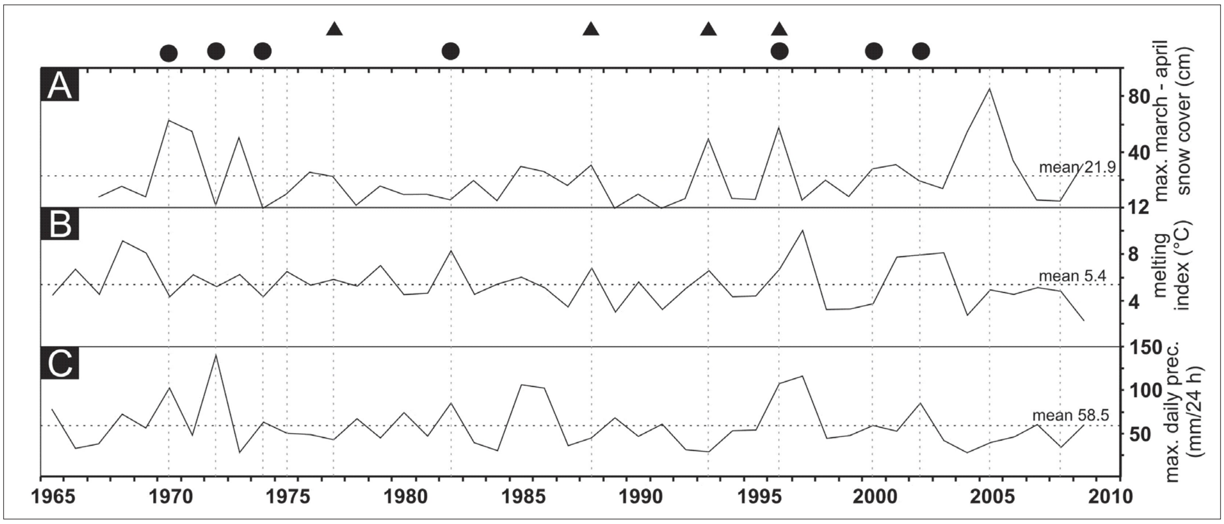

Fig. 8: Comparison of the occurrence of dated processes using selected meteorological indices. A – maximum snow cover thickness in March and April, B – melting index (difference between average temperatures in April and May, Zielonka et al., 2008), C – maximum daily total precipitation amount per year (black spots – event years with above-average daily precipitation occurrence; black triangles – event years with above-average melting index combined with snow cover occurrence)

et al., 2008; Stoffel and Bollschweiler, 2008, 2009; Zielonka et al., 2008; Szymczak et al., 2010). As a result, the number of reconstructed accumulation events can only be considered as a minimum value (Stoffel and Bollschweiler, 2009). Likewise, some of the erosion-based gully-deepening events may not have been detected owing to the insufficient root coverage of the gully.

The results show that 41% of 51 dated tree-growth disturbances in the accumulation area are represented by the sharp narrowing of rings. This finding corresponds to a typical response of trees whose base has been partially buried (Schweingruber, 1996; Stoffel and Bollschweiler, 2008). All dated growth suppressions were strong (min. 55%) and significantly differed from reference chronology fluctuations. Dated growth disturbances in increment cores could therefore have originated as a consequence of accumulation processes. Moreover, other processes (rockfall or snow avalanches) were not identified in the study area. The scarcity of scars and abrupt widening of rings (only 14 cases or 10% of the sample) may have been due to low flow activity resulting in insignificant or no damage to trees. No signs of forest measures were observed in the surroundings of the studied locality that could have been a potential cause to the suppressed growth.

What is interesting is the temporal occurrence of reaction wood. All trees (except one) containing reaction wood were tilted in 1977 at the latest. There are two possible explanations: one is that older accumulation processes were of a magnitude big enough to tilt some of the trees; this hypothesis is supported by the spatial distribution of affected trees; the other and more likely explanation is that the volume of the accumulated material differed only negligibly from younger events but trees there growing were smaller and lesser force was sufficient to tilt the trees (Schweingruber, 1996).

Gully-root analysis suggests progressive deepening from the upper to the lower end of the gully. Similar findings were recorded by Malik (2008) concerning several gullies. In a number of cases, however, the chosen analyzed roots were at a variable vertical distance below the alluvial fan surface. Therefore, the deepening may not have propagated in a downhill direction but could have occurred evenly throughout the whole gully. This would also explain the later exposure of roots in the lower part of the gully (e.g. samples 4s and 5s; Fig. 6a) in comparison with the upper gully roots growing relatively deeply below the alluvial fan's surface. The present gully bottom has a very uneven profile with several steps. These could have originated as a consequence of backward erosion induced by a series of base level occurrences at the bottom of the gully. Currently, the base level is formed by boulders (> 20 cm), which accumulated at the gully bottom after fine particle fractions had been washed out.

In the case of meteorological events such as precipitation or snow-thaw it is impossible to determine which factor prevailed since both of them occurred at above-average intensity. The year in question is 1996. On the other hand, for some years, neither precipitation nor spring thawing may be implicated (e.g. 1975 and 2008) since, due to the meteorological station's distance from the fans and differing geographical conditions, these factors should only be considered as possible agents, as suggested by e.g. Szymczak et al. (2010). If this is the case, the causative factor could have been an event that the meteorological station failed to record.

The moderate character of the accumulation processes indicated by the identified growth disturbances was verified by sedimentological analyses. Medium grain size (M_G = 3.8 mm), material sorting (σ_G = 6.1) and maximum clast size (~40 mm) indicate that the accumulation processes occurring on the alluvial fan are not debris flows but single fluvial accumulations of fine particle material. On the other hand, unsorted and gently round material containing larger clasts (< 30 cm) from the material of the older alluvial fan points to the accumulation activity on the debris flows.

Based on these analyses, we propose that the evolution of the alluvial fan has been the result of a wide number of processes. The highest alluvial fan most likely originated as a result of accumulation due to debris flow activity, the question remains when? The present morphology of the alluvial fan surface shows no traces of fresh debris flow activity and the dating of alluvial fan material using absolute dating was impossible. Nevertheless, one isolated alluvial fan of a similar extent has been dated in the Moravian-Silesian Beskids Mts. to the Atlantic period (Šilhán and Pánek, 2009). So, one of tentative possibilities is that this alluvial fan is of a similar age. However, it can originate from or just after the "little ice age" maximum as well.

The change in processes on the alluvial fan (fluctuating from degradation to aggradation and back) is most likely connected to a change in environmental conditions of the source basin. At present, the basin is fully covered by forest and therefore is not a locality for potential debris flows with contemporary erosion and accumulation processes on the fan driven by flowing water often related to extreme precipitation events. Under such conditions debris flows still originate in the Moravian-Silesian Beskids Mts. (e.g. 1972, 1996 and 2002) (Šilhán and Pánek, 2010), but almost exclusively in morphometrically more extreme areas.

6. Conclusion

Alluvial fans are landforms whose origin and evolution are affected by a wide range of processes. Where archival records are lacking, dendrogeomorphological methods represent the most accurate dating methods for processes that may be hundreds of years old. Use of a dendrogeomorphological approach helped us reconstruct processes on an alluvial fan in the eastern part of the Moravian-Silesian Beskids Mts. A total of 13 accumulation events were identified by means of growth disturbance analysis performed on 30 increment cores. In addition, analysis of anatomical changes in exposed roots revealed seven erosive events in a gully crossing the fan. A combination of the dated accumulation events and analysis of tree positions enabled spatial reconstruction of accumulation events with these showing four basic accumulation patterns on an active part of the fan.

The different types of growth disturbance identified from the increment cores and sedimentological analysis of the fan material show that present processes on the fan are a combination of fluvial erosive and accumulation processes.

Analysis of data from the nearest meteorological station indicated two basic factors influencing the origin of the modelling processes on the fan's surface: the first factor - total short-term precipitation amounts including values over 100 mm/24h – occurred in events during 1972 or 1996; the second factor – sudden thawing of high snow cover in spring months – was connected to events in 1977 and 1993.

The trees on the lowest alluvial fan provide a natural record of a marked change in geomorphological processes that took place on the fan in the past and prove that its contemporary evolution is exclusively related to extreme meteorological events.

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References:

BLOTT, J. S., PYE, K. (2001): Gradistat: a grain size distribution and statistics package for the analysis of uncosolidated sediments. Earth Surface Processes and Landforms, Vol. 25, p. 1473–1477.

BOLLSCHWEILER, M., STOFFEL, M., SCHNEUWLY, D. M. (2008): Dynamics in debris-flow activity on a forested cone — A case study using different dendroecological approaches. Catena, Vol. 72, p. 67–78.

BOLLSCHWEILER, M., STOFFEL, M. (2010): Tree rings and debris flows: recent developments, future directions. Progress in Physical Geography, Vol. 34, p. 625–645.

COOK, E. R., KAIRIUKSTIS, L. A. (1990): Methods of dendrochronology. Kluwer Academic Publisher Dordrecht, 408 pp.

ČERMÁK, P., RYBNÍČEK, M., ŽID, T., KOLÁŘ, T., BOČKOVÁ, H., PŘEMYSLOVSKÁ, E. (2010): The effects of climatic factors on radial growth of Norway spruce Picea abies in the Silesian Beskids. The Beskids Bulletin, No. 3, p. 9–18.

GÄRTNER, H. (2007): Tree roots – Methodological review and new development in dating and quantifying erosive processes. Geomorphology, Vol. 86, p. 243–251.

GOTTESFELD, A. S., GOTTESFELD, L. M. J. (1990): Floodplain dynamics of a wandering river, dendrochronology of the Morice River, British Columbia, Canada. Geomorphology, Vol. 3, p. 159–179.

HARVEY, A. M., MATHER, A. E., STOKES, M. (2005): Alluvial fans: geomorphology, sedimentology, dynamics. Geological society of London, 256 pp.

JACKSON, L. E., KOSTASCHUK, R. A., MACDONALD, G. M. (1987): Identification of debris flow hazard on alluvial fans in the Canadian Rocky Mountains. Reviews in Engineering Geology, Vol.7, p. 115–124.

KOSTASCHUK, R. A., MACDONALD, G. M., PUTNAM, P. E. (1986): Depositional processes and alluvial fan-drainage basin morphometric relationships near Banff, Alberta, Canada. Earth Surface Processes and Landforms, Vol. 11, p. 471–484.

KRUMBEIN, W. C. (1941): Measurement and geological significance of shape and roundness of sedimentary particles. Journal of Sedimentary Petrology, Vol. 11, p. 64–72.

MALIK, I. (2008): Dating of small gully formation and establishing erosion rates in old gullies under forest by means of anatomical changes in exposed tree roots (Southern Poland). Geomorphology Vol. 93, p. 421–436.

MENČÍK, E. et al. (1983): Geologie Moravskoslezských Beskyd a Podbeskydské pahorkatiny. Nakladatelství ČSAV Praha, 307 pp.

POWERS, M. C. (1953): A new roundness scale for sedimentary particles. Journal of Sedimentary Petrology, Vol. 23, p. 117–119.

SHRODER, J. F. (1978): Dendrogeomorphological analysis of mass movement on Table Cliffs Plateau, Utah. Quaternary Research, Vol. 9, p. 168–185.

SHRODER, J. F. (1980): Dendrogeomorphology: review and new techniques of tree-ring dating. Progress in Physical Geography, Vol. 9, p. 161–88.

SCHWEINGRUBER, F. H., ECKSTEIN, D., SERRE-BACHET, F., BRAKER, O. U. (1990): Identification, presentation and interpretation of event years and pointer years in dendrochronology. Dendrochronologia, Vol. 8, p. 9–38.

SCHWEINGRUBER, F. H. (1996): Tree rings and environment, dendroecology. Haupt Verlag Wien, 609 pp.

SNEED, E. D., FOLK, R. L. (1958): Pebbles in the lower Colorado River, Texas, a study of particle morphogenesis. Journal of Geology, Vol. 66, p. 114–150.

STOFFEL, M., BOLLSCHWEILER, M. (2008): Tree-ring analysis in natural hazards research – an overview. Natural hazards and earth system sciences, Vol. 8, p. 187–202.

STOFFEL, M., BOLLSCHWEILER, M. (2009): Tree-ring reconstruction of past debris flows based on a small number of samples – possibilities and limitations. Landslides, Vol. 6, p. 225–230.

STRUNK, H. (1997): Dating of geomorphological processes using dendrogeomorphological methods. Catena, Vol. 31, p. 37–151.

SZYMCZAK, S., BOLLSCHWEILER, M., STOFFEL, M., DIKAU, R. (2010): Debris-flow activity and snow avalanches in a steep watershed of the Valais Alps (Switzerland): Dendrogeomorphic event reconstruction and identification of triggers. Geomorphology, Vol. 116, p. 107–114.

ŠILHÁN, K. (2009): Geneze vnitrohorských kuželů v Moravskoslezských Beskydech – morfometrické předpoklady. In: Herber, V. [ed.]: Fyzická geografie a krajinná ekologie, Brno, p. 24–27

ŠILHÁN, K., PÁNEK, T. (2009): Aluviální kužel v údolí Černé Ostravice. Geologické výzkumy na Moravě a ve Slezsku, Vol. 16, p. 28–29.

ŠILHÁN, K., PÁNEK, T. (2010): Fossil and recent debris flows in medium-high mountains (Moravskoslezské Beskydy Mts, Czech Republic). Geomorphology, Vol. 124, p. 238–249.

V.I.A.S., Vienna Institute of Archaeological Science (2005): Time Table. Installation and instruction manual. Ver. 2.1, Vienna.

VANDEKERCKHOVE, L., MUYS, B., POESEN, J., DE WEERDT, B., COPE, N. (2001): A method for dendrochronological assessment of medium-term gully erosion rates. Catena, Vol. 45, p. 123–161.

ZIELONKA, T., HOLEKSA, J., CIAPAŁA, S. (2008): A reconstruction of flood events using scarred trees in the Tatra Mountains, Poland. Dendrochronologia, Vol. 26, p. 173–183.

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