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Morphological changes within road incision forms in the blowdown area in the Slovak Tatra Mountains after termination of intensive forest works

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Abstract: Natural environment of the Slovak High Tatra Mountains, including landforms, underwent a rapid change. On November 19, 2004, following a disastrous bora, a blowdown area was formed covering 12,600 hectares, and bearing nearly 3 million cubic metres of fallen wood. Necessary forest clearing works related to damage mitigation began in spring 2005. These consisted in cutting and taking down the wood using heavy machinery and vehicles. Intensive after-disaster works led, however, to changes in the depth and density of cart roads.

The aim of this paper is to estimate the direction and rate of changes within road dissections after intensive forest works. To achieve this task, the results of measurements of the depth of road incision along selected profiles situated at places differing by inclination and the type of exploitation were used.

The collected data point to dominant, although minor role of accumulation processes over erosive ones, the latter being important during the period of relatively not intensive road exploitation. The most important factor contributing to such a denudation balance of gently inclined (up to 20°) roads appears to be human impact, dominating over properties of natural environment. Hence, termination of intensive road exploitation and introduction of anti-erosive measures, such as steps on steeper (>15°) road segments, are most effective when preventing erosion processes within the latter in the blowdown area in the Slovak High Tatra Mountains.

Key words: cart roads, recent morphogenetic processes, forest works, blowdown area, Slovak Tatra Mountains

Introduction

High-speed winds may bring changes to different types of natural environment. These winds seldom occur in mid-latitudes, although leading to considerable damage. Winds of speed exceeding 93 km h^{-1} (26 m s^{-1}; 10° B) can break and uproot trees (blowdown areas) and destroy buildings (Niedźwiedź 2003). On November 19, 2004, wind speed exceeded 200 km h^{-1} on the southern slopes of the Tatra Mountains. Close to Lomnicke Pleso Lake (1,751 m a.s.l.), this speed attained 194 km h^{-1} (55 m s^{-1}) (Motyčka, 2005) and the highest value, 230 km h^{-1} (64 m s^{-1}), was recorded at the upper timber line (1,480 m a.s.l.) (Koreň, 2005).

The immediate consequence of this bora was a blowdown area covering 12,600 ha. The damage area was 30 km by 2–3 km in size (Motyčka, 2005), extending from the vicinity of Podbanska through Štyrbské Pleso Lake, Vyžne Hagy, Smokovce, Tatranská Lomnica to Tatranská Kotlina (Fig. 1). This zone is situated on slopes rising from 800–900 to 1,250–1,300 m a.s.l. It is estimated that nearly 3 million cubic metres of wood were uprooted.

Many components of natural environment, including relief, underwent rapid changes within the blowdown area. Some of these components have been modified owing to necessary measures undertaken to mitigate the damage as well as due to natural processes. The so-called after-disaster works were initiated already in spring 2005 and continued afterwards, particularly during the two successive years. The amount of wood obtained from this area is shown in Table 1. Cutting and taking down the wood using heavy machinery and vehicles led to

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changes within cart roads. The influence of such works on erosion and degradation of mountain soils has been dealt with, i.a. by: Laskowski (1996) and Maciaszek & Zwydak (1992). The studies of changes in the density of cart roads before and after the formation of blowdown area were initiated at a selected test area near Tatranská Polanka and Tatranské Zruby by Dąbrowska *et al*. (2008).

Aim of study

Recognition of changes in the relief of blowdown area reveals that they represent two types:
- natural – depressions produced by uprooted trees, resulting from a short-term bora event
- anthropogenic (or both anthropogenic and natural ones) – roads produced due to human activity, locally or temporally enhanced by natural morphogenetic processes.

The aim of this paper is to estimate the direction and rates of changes within road incisions, based on examples selected after intensive forest works ceased.

Area and methods

To achieve this task, a number of places for benchmark location were chosen on cart roads. Every benchmark consisted of two steel rods installed on either side of the road down to a depth of 0.5 m or 1 m, depending on the substratum. Measurements were taken by using a tape between the installed rods up to the road's surface, every 10–50 cm in different time periods. Altogether, 13 sites (profiles) were analysed. These are located in the following areas: Vyžné Hagy, Nová Polanka, Danielov dom, Tatranské Zruby, Starý Smokovec and Tatranská Lomnica (Fig. 1). Road slope and type of exploitation, lithology and annual precipitation totals in the nearest vicinity were determined at each profile. In this paper, results obtained from 5 profiles installed along the roads were used:
- within the "REF" (reference, intact forest) test area near Vyžné Hagy (2 profiles: HV1, HV2)
- within the "FIRE" (burnt forest, wood party removed, fire) test area in Tatranské Zruby (TZ)
- close to the "NEXT" (non-extracted forest, unmanaged) test area near Jamy, Tatranská Lomnica region (JA)
- in Nová Polanka (NP).

Results

During the first two years (2005 and 2006) after the blowdown area was formed, gross part of wood was already taken down (Table 1). Most of the profiles were installed in June 2007, that is after the period of intensive forest works, i.a. due to safety reasons. Therefore, the obtained results do not embrace the time span, when transformations within the

Table 1. Volume of wood obtained from the blowdown area during forest clearing works

Year	2005	2006	2007	Total
Wood obtained (in cubic metres)	1,616,485	221,664	18,881	1,857,030

Based on: Fleischer *et al*. (2007)

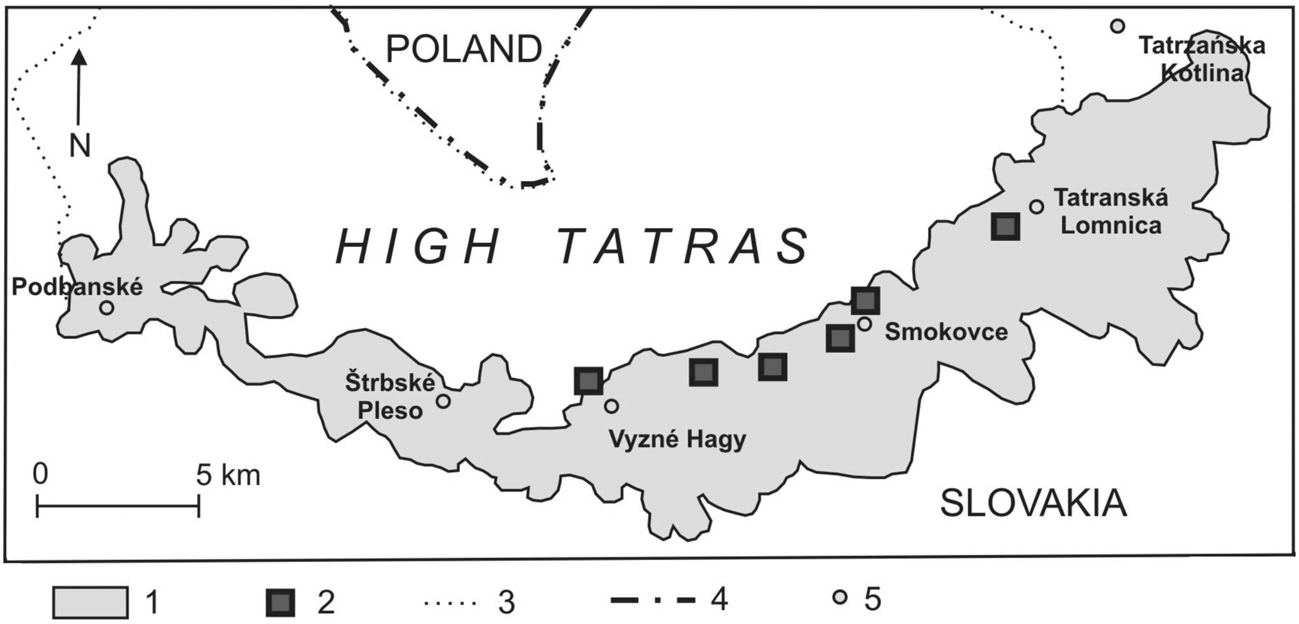

Fig. 1. Location of the blowdown area and measuring points
1 – blowdown area, 2 – benchmarks, 3 – extent of the Slovak High Tatra Mountains, 4 – state boundary, 5 – localities

roads were the greatest. Analysis of cartographic data and preliminary results of observations and field studies enable to conclude that intensive after-disaster works conducted in the blowdown area led to:

- formation of new roads
- increase in width (even twice) of the existing road segments
- dissection and deepening of road surfaces (e.g., close to Tatranská Lomnica and Vyžné Hagy, to ca. 50 cm during four months)
- permanent or temporal changes of the road function.

However, termination of management works on gently inclined roads leads to systematic decrease of their length owing to slow encroachment of vegetation (Dąbrowska *et al*., 2008).

Principal characteristics of the selected profiles and related road segments are shown in Table 2.

Profile VH1 (Table 2) was installed on a road near Vyžné Hagy. This road was intensively used for cutting and taking down the wood during the period of damage mitigation works. Its substratum was then lowered by even 50 cm, being accompanied by undermining of road scarps. During the first measuring period, the intensity of road exploitation was fairly high, then considerably diminished. The road crosses the "REF" test area, located in a forest zone that remained nearly intact after the November 19, 2004 event (Fig. 2).

During the entire observation period (25.06.07–12.08.09), the depth of the road cut changed insignificantly at site VH1 (Fig. 3), and even minor prevalence of aggradation (5.5 cm) was noted. Close to the road's axis, in turn, a small erosional incision (3.5 cm) occurred. Moreover, a certain seasonality of dominance of different processes took place: warm seasons were characterized by aggradation (6–8 cm), while the cold ones were dominated by erosion (up to 6 cm).

Profile VH2 (Table 2) was established 322 m below profile VH1 along the same road. Aggradation prevailed throughout the observation period (Fig. 4) attaining 9.5 cm within the furrow. Even in winter time, aggradation did slightly prevail (4 cm), except one site where dominating erosion (ca. 6.3 cm) was noted.

Profile NP (Table 2) is located on a road segment in Nová Polanka. This road used to be one of main roads on this area during after-disaster management works. The latter largely controlled the rate and amount of transformation within the road, being additionally enhanced by relatively high slope inclination, higher annual precipitation totals compared to those at Vyžne Hagy, and road's course concordant with slope inclination. Few tens of anti-erosive protective steps were built from tree trunks, branches, boulders, stones and earth. The mapped road segment, 308 m long, bears 19 steps spaced every 3.5 to 21.5 m (Fig. 5, 6, 7). Below step no. 5, site

Table 2. Characteristics of profiles and cart road segments

Profile	Measurement period	Profile width (cm)	Cart road inclination (°)	Lithology*	Annual precipitation totals (mm)**	Type of exploitation
VH1	25.06.07–12.08.09	543	8.5	gravels, blocks and boulders of glacial moraines	780	intensely used before and during the first measuring period; then used seasonally
VH2	26.06.07–21.04.09	599	11.5	gravels, blocks and boulders of glacial moraines	780	intensely used before and during the first measuring period; then used seasonally
NP.	25.06.07–13.08.09	689	19.5	fluvioglacial gravels and boulders (with admixture of blocks)	900	intensely used before the measuring period; then not used
TZ	25.06.07–20.04.09	545	6.0	gravels, blocks and boulders of glacial moraines	900	used only during the first measuring period; then used sporadically
JA	27.06.07–20.04.09	579	17.0	gravels, blocks and boulders of glacial moraines	1,050	sporadically used

*Based on: Geologická mapa Tatier (1994)
**Data from TANAP Research Station (2009)

Fig. 2. Cart road in Vyžne Hagy test area. Profile VH1

NP was installed purposefully on the reinforced road segment.

Changes in road's profile can be analysed in a seasonal pattern. During the first summer minor aggradation occurred (up to 7 cm), while during the first winter erosion of the bottom of the road between furrows took place (Fig. 8). During the following summer (2008), nearly the entire profile was dominated by insignificant aggradation (to 4 cm), and after the following winter the road surface was placed even 12.5 cm higher compared to the former season, while after the last summer it became lowered to 10.5 cm.

Throughout the observation period, aggradation (up to 9.5 cm) of the material took place in both ruts, accompanied by minor (up to 5 cm) erosion between them.

Profile TZ (Table 2) was placed on the road in the test area "FIRE", in Tatranské Zruby. This part of the blowdown area was affected by fires in summer 2005. The road used to be frequently exploited for taking down the wood before installing benchmarks, and then used seasonally.

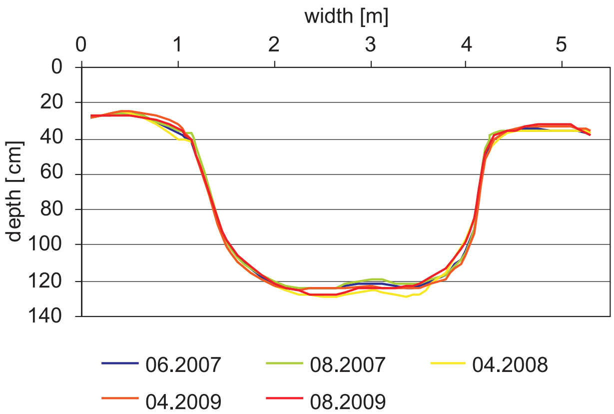

Fig. 3. Profile of cart road VH1 in Vyžne Hagy

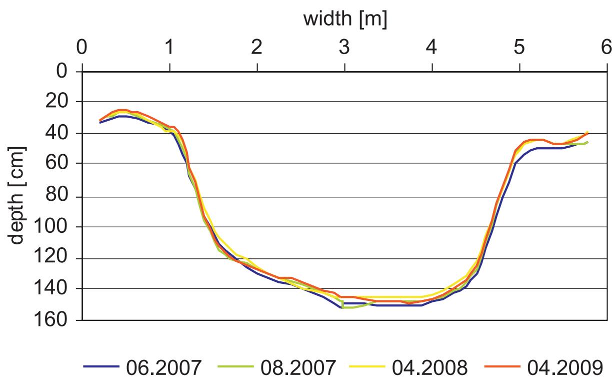

Fig. 4. Profile of cart road VH2 in Vyžne Hagy

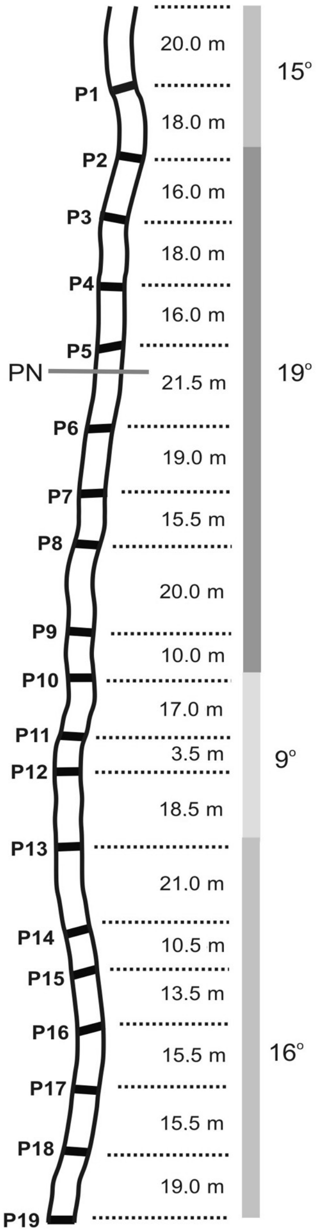

Fig. 5. A segment of cart road with anti-erosion protection steps in Nová Polanka
P1–P19 – anti-erosion steps, PN – profile line

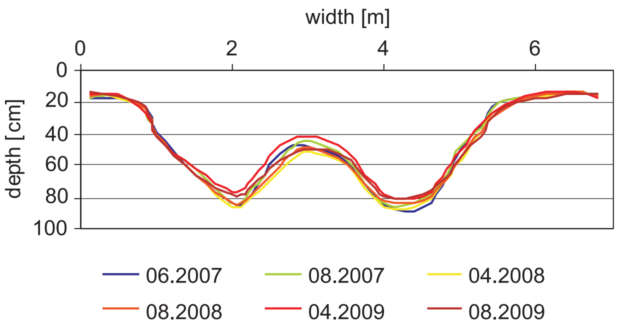

Fig. 8. Profile of cart road NP in Nová Polanka

Fig. 6. Cart road with protective steps in Nová Polanka

Fig. 7. One of anti-erosion steps on a cart road in Nová Polanka

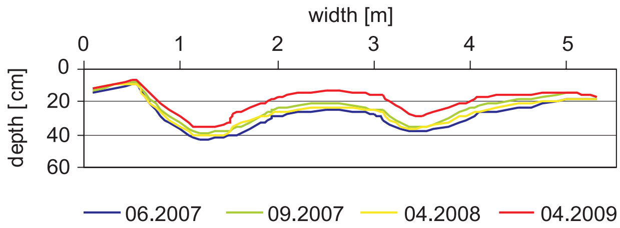

Fig. 9. Profile of cart road TZ in Tatranské Zruby

During the measuring period, distinct accumulation was recorded along the entire length of profile TZ (max. 14.5 cm). However, minor erosion (3.5 cm) was noted within ruts in the cold 2007/08 half-year (Fig. 9). Such results were probably constrained by small inclination of the road, position of the profile in the lower portion of the latter, and occasional use fostering relatively quick encroachment of vegetation.

Profile JA (Table 2) is situated on a road leading to the "NEXT" test area near Jamy, close to Tatranská Lomnica. Owing to the type of this test area, the road is infrequently used. Its fragment cuts obliquely strongly inclined slope (Fig. 10).

Throughout the first year, accumulation dominated here decisively (Fig. 11). During the cold half-year of 2007/08 the accumulated material was in part removed. In the entire observation period, distinct aggradation (up to 9.2 cm) was recorded over

Fig. 10. Cart road close to Jamy near Tatranská Lomnica. Profile JA

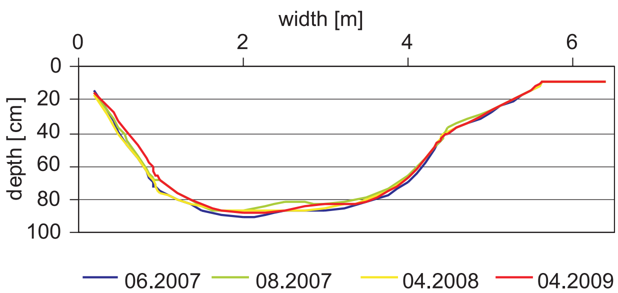

Fig. 11. Profile of cart road JA in Jamy near Tatranská Lomnica

the whole length of the profile. Position of this road segment, which is not concordant with slope inclination and placed below the slope-concordant segment, as well as occasional use contribute to positive balance of matter in this road fragment.

Summary

Papers dealing with anthropopression in the mountain environment concern mainly tourist traffic, as the most important factor initiating degradation of cart roads and footpaths, with relatively little attention being paid to land management in mountain forests. Formation of such a large blowdown area in the Slovak High Tatra Mountains and long-term forest works conducted in this area before and after the disaster motivates and even obliges one to investigate changes in the relief of such regions. Use of heavy machinery and vehicles leads to formation of frequently distinct and deeply-cut linear landforms, the persistence of which depends on numerous components of natural environment. These landforms are being further remodelled due to natural morphogenetic processes.

The obtained results of erosion-accumulation balance enable one to estimate the tendency of development of road dissections in the blowdown area already after termination of intensive forest works. The collected data point to dominant, although minor role of accumulation processes over erosive ones, the latter being important during the period of relatively not intensive road exploitation. This may be associated with, among others, geological setting of the study area. Prone to erosion upper layer of morainic and fluvioglacial sediments became completely or nearly completely eroded before the period of study, as shown by the depth of dissection and amount of debris in the lowest-situated portions of road profiles. Undoubtedly, the most important factors suitable for hampering or decreasing rate of erosion on the studied roads are termination of intensive exploitation and introduction of anti-erosive (steps) measures on strongly inclined roads. Comparable results were obtained from footpaths of the Danielovo test region within the blowdown area in the Slovak High Tatra Mountains (Dąbrowska, 2009).

The role of cart road in morphology of the lower parts of the Tatras is becoming particularly important in the light of mass destruction of forests caused by bark beetles after November 19, 2004, what implies necessity of further forest works.

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