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Relief transformation along footpaths in the Rila, Pirin, and Western Tatra Mountains

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Abstract: High mountain areas are characterized by substantial geodiversity and different morphogenetic processes play a key role in shaping their relief. One of the most transformed landforms within the high mountain areas affected by such processes today are footpaths and tourist trails. For this reason, this issue needs to be closely examined for a variety of mountains ranges.

The main aim of the research was to characterize effects of changes in relief experienced by footpaths and their vicinity in three different high-mountain regions: the Rila Mts., the Pirin Mts, and the Western Tatra Mts. Geomorphological mapping was used to study the erosive relief in details. The comparative analysis of geomorphological effects of relief transformation along surveyed footpaths allow for the determination of regularities in landform formation.

In the Tatra Mountains, the footpaths experiencing the highest degree of physical transformation are those running along the slope gradient and across eroded rock debris zones, with little or no turf. Such paths create favourable conditions for erosion to produce deep incisions, the depth of which can reach one metre. In the case of the Rila and Pirin Mountains, the deepest incisions reach 1.8 m.

Research has shown that among the different forms of human impact the great amount of pressure on relief in high mountain areas is exerted by pastoral activity and forest management practices.

Key words: Rila Mountains, Pirin Mountains, Western Tatras Mountains, footpaths erosion, relief transformation along footpaths

Introduction

Mountain areas in Poland and throughout the world are being intensively acted upon by mass hiking tourism, skiing, forest management, and pastoral activity based on sheep, horses, cattle, and yak. A number of papers have been published on this subject including that of Watanabe (1994) on yak grazing in the Langtang Valley in Nepal, as well as a paper by Tsuyuzaki (1994) on environmental deterioration resulting from skiing in Niigata Prefecture in Japan. Other works, including a paper by Olive and Marion (2009), have examined the effects of horse grazing and hiking tourism on soil erosion in the Big South Fork National River and Recreation Area in the United States. Also the research done by Krzemień (1997, 2008) in the Monts Dore Massif area in France is a good example of detailed investigation on the development of new landforms on slopes used by hiking tourists.

Many researches have shown that various morphogenetic processes such as slope wash and deflation become accelerated in areas affected by hiking tourism and pastoral activity. While there exists a body of literature on the effects of tourist traffic in individual areas, it is also important to look at this is-

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sue from a comparative analysis standpoint. Comparative studies allow for an examination of natural processes, such as slope wash, deflation, nivation, and needle ice activity with respect to geologic structure, climate, and land use in order to assess the impact of morphogenetic processes, hiking tourism and animal grazing.

The aim of the research was to determine the effects of changes in relief along the footpaths through the study of the development of erosive landforms in selected geoecological zones, as well as an assessment of human impact on footpath morphology.

Methods

Geomorphological mapping was used to assess the effects of relief transformation within footpaths and their vicinity. The footpaths selected for analysis were divided into homogeneous segments and marked on a topographic map (scale: 1:10,000). The segments were classified based on the location of each path relative to primary landforms, such as valleys, slopes, and ridges. The path surface type was another factor used in the classification process. The following information was gathered for each path segment: elevation, types of erosive landforms present, as well as average width, maximum width, and depth of eroded incisions.

Path segments that had experienced the greatest degree of transformation were identified based on geomorphological mapping. Each research site was also photographed.

Study areas

The footpaths analyzed in this paper are located in three European high mountain ranges: Rila (Fig. 1), Pirin (Fig. 2), and the Western Tatras (Fig. 3). The Tatras are the highest mountain range in the Carpathian mountain belt and are located in its northern section. The Rila and Pirin mountain ranges are two of the most highest mountain ranges in the Balkan Peninsula; both are located in southwestern Bulgaria. The total distance of the studied footpaths were: 10 km in the Rila Mts., 12 km in the Pirin Mts., and 12 km in the Tatra Mts.

The Rila and Pirin Mountains

The Rila Mountains are the highest mountain range in the Balkan Peninsula (Mt. Mussala 2,925 m a.s.l.). The range is composed of Palaeozoic metamorphic rocks (crystalline schists, marbles) and intrusive granite. Its relief is the result of the activity of Pleistocene mountain glaciers, which has resulted in the formation of glacial relief and landforms such as cirques, numerous lakes (about 140), and different types of moraines (Mavrudčiev & Velčev, 2008; Toncov *et al.*, 2008). According to Velev (2002), the mean annual precipitation above 1,000 m a.s.l. is 800 – 1,000 mm with a maximum in June. The highest precipitation, much of it snow, reaches 2,000 mm in the 1,300–2,400 m a.s.l. zone (Toncov *et al.*, 2008).

The Rila Mountains became a national park in 1992 with a surface area of 81,046 ha.

Vegetation cover in the Rila Mountains, and to some extent in the Pirin Mountains, has been subject to human impact for a very long time. Destructive changes in natural vegetation and indications of agricultural activity and stockbreeding have been palynologically recorded in the Rila Mountains since the Late Bronze Age. Human impact has been detected across all vegetation zones since the early Sub-Atlantic. In many places, the upper tree line had been artificially lowered in order to expand high mountain pasture land. Palaeobotanical reconstructions (Toncov *et al.*, 2008) have clearly shown that livestock grazing on mountain meadows in this region is a long-standing tradition. Active pastures (mostly horses) are still quite common as high as the highest of peaks, especially in the Rila Mountains.

The Pirin Mountains are located in the southwestern part of Bulgaria and geographically belong to the Rila-Rhodopean region. The relief of the Pirin Mountains, similarly to that of the Rila Mountains, has been modelled to a substantial degree during Pleistocene glaciations. The alpine nature of the Pirin Mountains can be recognized in their relief featuring strong segmentation, steep slopes, high ridges, deep river valleys, as well as glacial cirques and lakes. The highest peak is Mt. Vihren (2,914 m. a.s.l.). Much of the Pirin Mountains area is composed of marble, limestone, granite, and gneiss. The high ridges and sharp peaks, sixty of which rise over 2,600 metres, are the remains of an old Miocene peneplain; the lateral ridges date from the Pliocene (PNPD, 2007)

Both the Pirin and Rila Mountains are located in the transitional zone between the temperate and the Mediterranean climate zones. However, the alpine zone is characterized by very restrictive climate conditions. The landscape of the two Balkan mountain areas is characterized by a vertical zone pattern, expressed as an array of distinct vertical zones. According to Mishev *et al.* (1989), four main types of mountain landscape can be distinguished in the Rila and Pirin Mountains: low mountain (from 700–900 to 1,300–1,500 m a.s.l.), middle mountain (from 1,300–1,500 to 1,900–2,100 m a.s.l.), high mountain (from 1,900–2,100 to 2,300–2,500 m a.s.l.), and alpine (above 2,300 m a.s.l.) (after Velicov & Stoyanova 2007). Mean annual temperature measured at a weather station located at 1,970 m a.s.l.

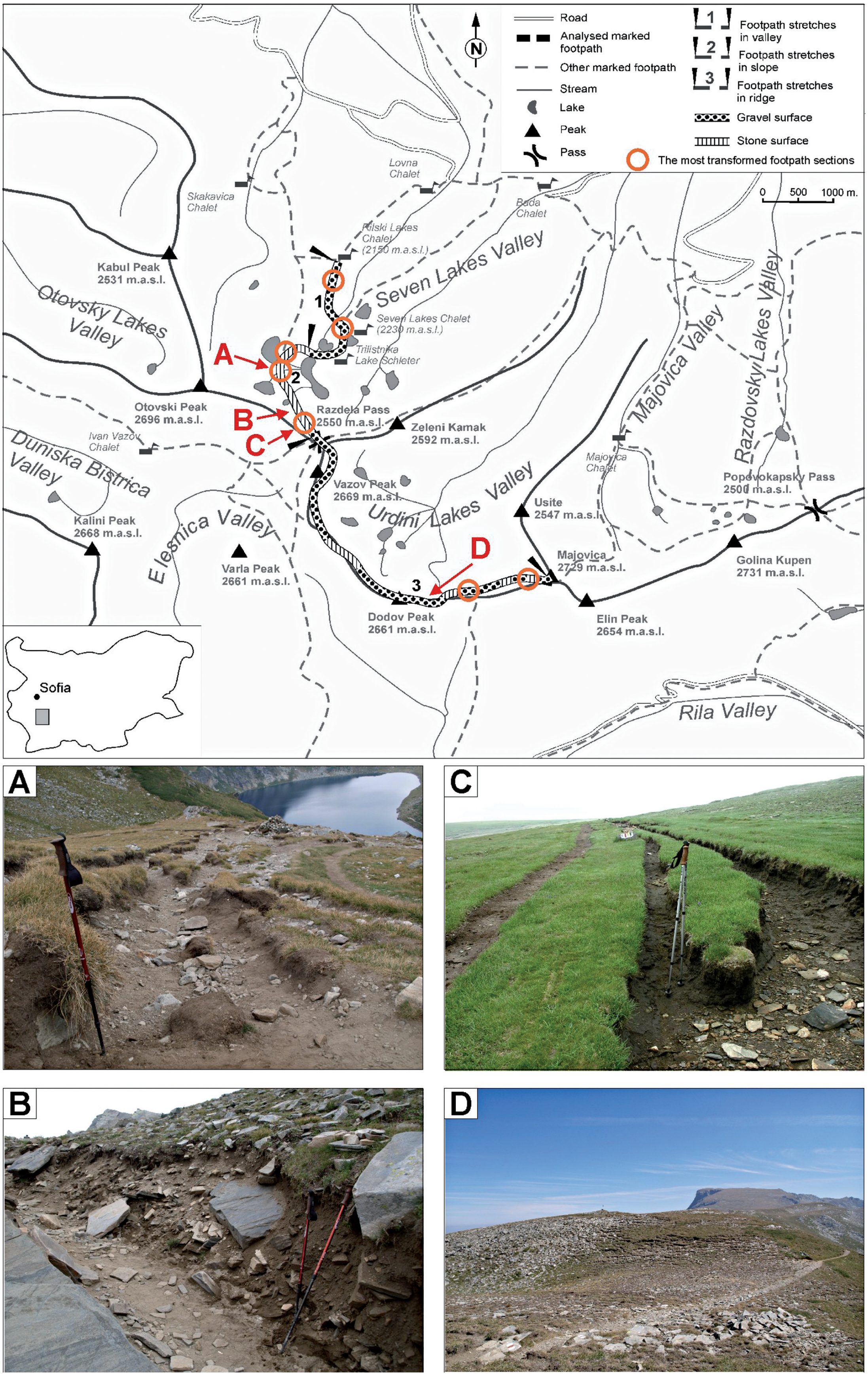

Fig. 1. Morphological location and the type of surface within the surveyed footpath in the Rila Mountains. The most common footpath morphology features are: A – turf islands and gelideflation steps formation; B – deep incisions (up to 1.8 m) along the zigzag footpath section; C – parallel paths, shaped within the plain sections of the footpath; D – formation of terraces induced by stockbreeding activity

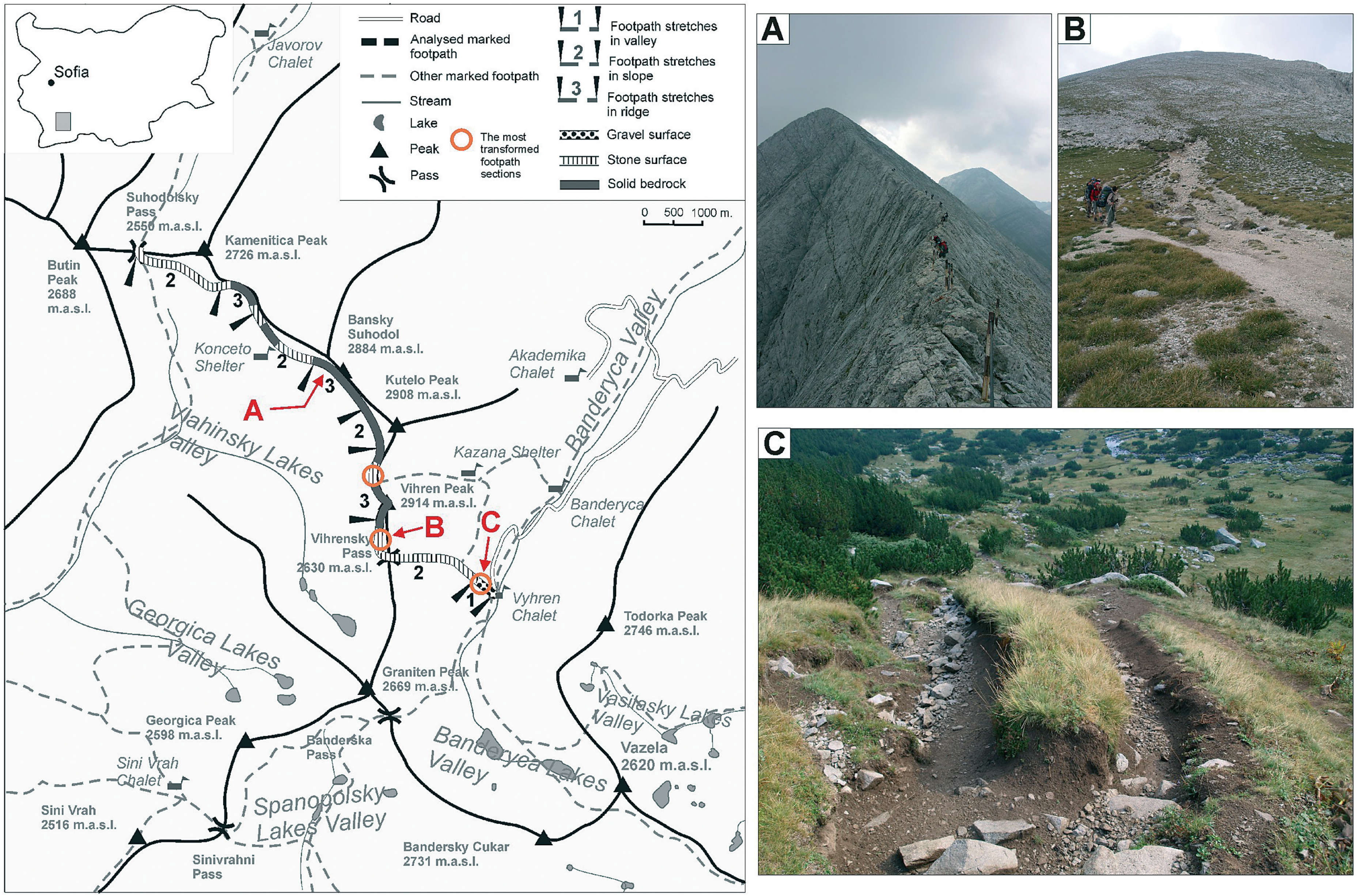

Fig. 2. Morphological location and the type of surface within the surveyed footpath in the Pirin Mountains. A – very resistant solid bedrock surface within Kutelo-Koncheto crest; B – bare surface without vegetation cover prone to deflation and trampling; C – erosive cuts within the footpath modeled by hiking tourism and pastoral activity concurrently

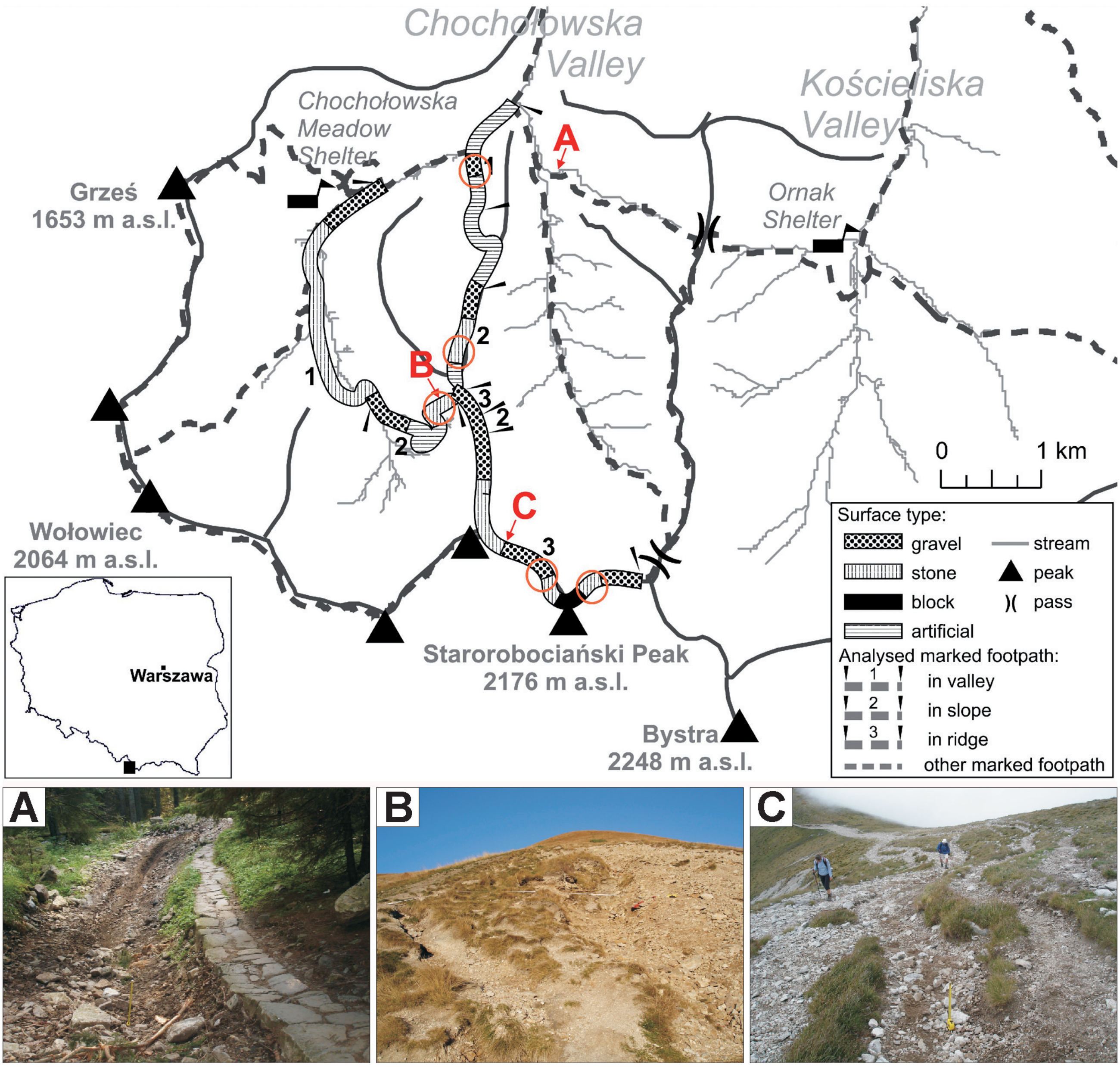

Fig. 3. Morphological location and the type of surface within the surveyed footpath in the Tatras; A – Transformed area along the footpath in the Western Tatra Mountains as an effect of forest management practices; B – The width of transformed zones can reach 20 m (Trzydniowiański Peak, the Western Tatra Mountains); C – The effects of very effective relief transformation within the footpath on the Starorobocianski Peak (the Western Tatra Mountains), due to continues trampling and an active morphogenetic processes

(Vihren) is 3.7°C, while above 2,300 m a.s.l. it is below zero. Annual precipitation is 800–1,250 mm (Velev, 1997; Atanassova & Stefanova, 2003).

Mostly skeletal soils, called rendzinas, have formed between 2,000 and 2,450 m a.s.l. and can be found along footpaths with natural surfaces. At higher elevations, only rock formations can be observed (Lässiger *et al.*, 2008).

The Pirin National Park, which is also a part of the UNESCO Man and Biosphere program, was formed in 1983, although a protected area had already been designated in 1934. The park is 40,333 ha in area. Tourist traffic in the Pirin and Rila Mountains is not limited to designated trails and hikers can use all physically available paths. The result is dispersal of tourists throughout each park, which reduces the pressure on the most popular areas, such as the Seven Lakes Valley and Maljovica Ridge in the Rila Mountains. The tourist profile in the Rila Mountains is different from that in the Tatra Mountains in that most tourists in the Rila Mountains are foreigners and are generally adapted to unguided trekking conditions.

The footpaths in the Pirin Mountains are clearly marked and are easily visible in the field. The tourist profile is somewhat different from that in the Rila

Mountains, given better road access to some valleys. Access roads have also been built to high mountain shelters such as the Vihren Chalet. This has resulted in very heavy tourist traffic starting from the Vihren Chalet to Mt. Vihren, the highest peak (2,914 m a.s.l.) in the Pirin Mountains.

Both the Pirin and Rila Mountains are very attractive tourist areas, especially in terms of hiking and trekking, however, the magnitude of these activities does not match one in the Tatra Mountains. Pastoral activity still plays an important role in both Balkan mountain ranges.

The Western Tatra Mountains

The study area in the Tatra Mountains was located in the Jarząbcza Valley and within Trzydniowiański (1,759 m a.s.l.) and Starorobociański Peak (2,176 m a.s.l.) (Fig. 3). The geologic structure of the Western Tatras is very diverse. The region is dominated by granitoids, gneisses, quartz sandstones, slates, limestones, and dolomites. The study area had been shaped by receding glaciers during the Pleistocene, as evidenced by the presence of numerous relict glacial landforms.

Annual precipitation on the northern slopes of the Tatra Mountains ranges from 1,200 mm to over 2,000 mm, while in the summer, these totals rise by another 550–700 mm (Łajczak, 2006). The area possesses three geoecological zones: forest (900–1,550 m a.s.l.), subalpine (1,550–1,670 m a.s.l.), and alpine (>1,670 m a.s.l.) (Kotarba *et al.*, 1987). Existing footpaths in the area of interest are being intensively reshaped by hiking tourism and forest management practices. Unlike in the Pirin and Rila Mountains, pastoral activity has been eliminated in this part of the Tatra Mountains and traces of such activity have become masked by new forest growth.

Effects of changes in relief along footpaths in the Rila, Pirin, and Tatra Mountains

The footpath selected for research purposes in the Rila Mountains stretches from the Rilski Lake Chalet in the Seven Lakes Valley through the Razdela Pass (2,550 m a.s.l.) to Dodov (2,661 m a.s.l.) and Maljovica Ridge (2,729 m a.s.l.) (Fig. 1). The footpath runs across glacial steps between cirques filled with seven scenic glacial lakes. While the footpath can be as wide as 4–16 metres in some places, normally it is a rather narrow footpath. This is primarily the result of the generally poor condition of the footpath at the moment when it was designated as a pastoral path. Footpaths tend to deteriorate without proper maintenance. There are no steps or drainage channels along this particular footpath. While there does not exist a clear reason to regularly maintain the footpath, its surface could be improved in a number of places in the Rila Mountains. Moreover, the poor condition of the footpath results from its being used not so much by tourists, but by passing herds of animals as well as animals that graze in the area from time to time.

The footpath selected for research purposes in the Pirin Mountains stretches from the Suhodolsky Pass (2,550 m a.s.l.) to Bansky Suhodol (2,884 m a.s.l.) and on to the Koncheto Ridge. It then runs across Kutelo (2,908 m a.s.l.), up the highest peak in the area (Mt. Vihren 2,914 m a.s.l.), and down to the Vihren Chalet (Fig. 2). This footpath possesses a fully natural surface. Unlike the footpath in the Rila Mountains, the surface of the footpath in the Pirin Mountains is formed of solid bedrock.

In the Tatra Mountains, the footpaths selected for analysis possess both natural and man-made surfaces (Fig. 3). In the case of footpaths in the Rila and Pirin Mountains, natural surfaces predominate, with most being the top layer of soil or large-grained material (Figs. 1–2). Considering natural surfaces, a key role plays the size of the dominant type of loose material. The following types of loose material have been identified in the eroded periglacial covers of the study area: gravel (<32 mm), stone (32–128 mm), and block (>128 mm) (according to Wentworth, after Mycielska-Dowigiałło & Rutkowski 1995, modiffied). A separate category was designated for footpath sections running across solid bedrock.

Surface type plays an important role in the formation of footpath relief in the Tatra, Pirin and Rila Mountains (Figs. 1–3). In the case of natural surfaces, the dominant surface type plays a key role in eroded periglacial areas. Deterioration caused by hiking tourism is markedly less substantial along man-made footpath segments. These include paths in the Tatra Mountains featuring stone surfaces.

Significant pressure on footpaths running across poorly resistant parent material results in footpaths becoming deeper and deeper. Some footpaths in the Rila Mountains are as deep as 1.8 m. Such footpaths normally run in a zigzag pattern and were formed across thick colluvial layers (Fig. 1B). Parallel paths are a type of landform commonly found along flat sections of footpaths (Fig. 1D), running perpendicular to the line of descent in ridge zones, along flat sections of the sides of ridges, and in mountain passes (Fig. 1C).

As parallel paths are used all the time, made deeper and wider thanks to natural morphogenetic processes, they change shape with time. As a result, their linear pattern is lost and becomes replaced with flat or linear-flat landforms at some locations. Progressive disintegration leads to the formation of turf islands (Fig. 1A) and gelideflation steps (Krzemień, 2008). Flat landforms featuring damaged turf surfaces are also found near the footpaths. These are usually the result of cattle trampling grassy surfaces or grazing, which eventually leads to the exposure of bare soil and formation of terraces induced by stockbreeding activity (Fig. 1D). Footpaths running atop ridges are characterized by erosion-induced incisions (up to 0.8 m).

The Pirin Mountains resemble the Tatra Mountains in terms of relief. A number of similarities also exist in the way footpaths form in the two regions. The one difference that needs to be noted is the larger number of stretches of footpaths running across solid bedrock in the Pirin Mountains (Fig. 2A) compared to the Tatra Mountains. The footpaths selected for analysis are located in three different mountain regions, however, they are affected by the same group of morphogenetic processes, although with different intensities. The most common morphogenetic processes responsible for the footpaths shaping are slope wash, nivation, deflation, needle ice activity, and gravity. The intensity of such morphogenetic processes can be determined indirectly based on the effects of particular morphogenetic processes and landform size (Table 1).

The footpaths of interest run along valley bottoms, slopes, hilltops, and ridgelines (Figs. 1–3). They zigzag down slopes, running perpendicular to the line of slope gradient or along this line. The greatest energy of morphogenetic processes can be observed on steep stretches running perpendicular to contour lines. However, the process of incision and the widening of landforms along footpaths in the Rila and Pirin Mountains can also be observed along grassy stretches in animal grazing zones. In the Tatra Mountains, the footpaths being reshaped most are those running along lines of slope gradient in rock debris zones with little or no vegetation (Fig. 3C). Deep incisions develop along such footpaths, some being as deep as 1 m. In the case of the Rila and Pirin Mountains, the deepest of incisions reach 1.8 m along footpaths that zigzag down slopes.

Table 1. The most significant landforms along researched footpaths and their morphometric parameters

Landforms along researched footpaths and their morphometric parameters	Tatra Mts.	Rila Mts.	Pirin Mts.
Max erosive cuts within [m]:			
a. slope sections	1.0	1.8	1.0
b. flat sections	0.2	0.8	0.3
Max trampled surface [m]	30	20	4
Max number of parallel paths	3	10	4

The destruction of plant cover (Fig. 2B) along footpaths favours the development of nival niches. Deflation niches also develop along footpaths located on windward slopes and in mountain passes. Other landforms found close to the footpaths analyzed are eversion hollows, as the effects of linear erosion, and small landslides, mudslides, and scarps along larger roads used by car traffic and logging trucks (in the Tatras).

The areas in question are dominated by erosive landforms, which is why they are the main subject of this paper. The incision formation process is strongly linked to local land use. In the Rila and Pirin Mountains, shallow incisions (Fig. 2C) tend to form as a result of sheep and horses grazing. In the case of the Tatra Mountains, such incisions are the result of forest management practices and mass hiking tourism (Fig. 3A). In all three cases, incisions become deeper as a result of morphogenetic processes.

Footpaths in the Tatra Mountains are normally shaped by hiking tourism. Linear landforms found along such footpaths tend to be smaller than those found along footpaths in the Rila and Pirin Mountains, where footpaths are shaped primarily by pastoral activity. The mechanical impact of hikers in the Tatra Mountains as well as sheep and horses in the Rila and Pirin Mountains is the greatest during the spring season. It is during spring that soil cover is saturated with snowmelt and tends to be most susceptible to physical pressure.

The presence of physically transformed zones in three studied areas varies based on the morphological location of the footpath. In the Tatra Mountains, the oldest of transformed zones reach over 30 m in width and are usually found in valleys where logging trucks travel back and forth. Substantial changes in relief can also be found at alpine elevations along footpaths running along slope gradient. In such cases, the width of transformed zones can reach 20 m (the area of Trzydniowiański Wierch) and is generally the result of the erosive power of rainwater and snowmelt (Fig. 3B). In the Rila Mountains, a maximum width of approximately 20 m was observed along a footpath between the Rilski Lake Chalet and the Seven Lakes Chalet (approx. at 2,200 m a.s.l.).

Conclusions

The most important factors in the development of erosive landforms along the footpaths are resistance of the parent material, surface type, and a footpaths morphologic location on a slope (Figs. 1–3). However, the land use type has also a significant influence on its condition.

The most significant changes in relief along the footpaths selected for analysis are associated with intensive pastoral activity in the Rila and Pirin Mountains. In the Tatra Mountains, on the other hand, such changes are associated with forest management practices and mass hiking tourism. The effect of differences in footpath use is the development of erosion-induced incisions, nival niches, and ruts in the Tatra Mountains. In the Rila and Pirin Mountains, the result is the presence of deeply-incised parallel paths as well as bare soil zones created by cattle grazing.

Maximum dimensions of erosion-induced incisions in the Tatra Mountains approach one metre. In the Rila and the Pirin Mountains, incisions can exceed 1.5 m deep. Surprisingly deep cuts, up to 0.8 m, can be also found along flat sections in the Rila (Table 1). The formation of such incisions is the result of pastoral activity. In the Tatra Mountains, the footpaths subject to the greatest degree of physical transformation are those running across debris-covered terrain within the sections tracked on the steep slope, with little or no vegetation. However, in the Rila and the Pirin Mountains, the significant physical changes can be observed along footpaths stretch within flattenings, covered by vegetation.

Finally, spring and autumn are seasons characterized by conditions favourable to accelerated changes in relief driven by soil instability caused by saturation with water. Saturated soil is then more susceptible to mechanical trampling by tourists and animals resulting in significant changes in footpath morphology.

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