THE DEVELOPMENT OF EROSIVE AND DENUDATIONAL LANDFORMS ON FOOTPATHS SECTIONS IN THE BABIA GÓRA MASSIF AND THE WESTERN TATRAS

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Agata Buchwal, Joanna Fidelus: The development of erosive and denudational landforms on footpaths sections in the Babia Góra massif and the Western Tatras. Geomorphologia Slovaca et Bohemica, 8, 2008, 2, 10 figs, 17 refs.

The most intensively used tourist regions within the Polish Carpathians are the Tatra Mountains and the Babia Góra massif. Tourist traffic within these regions contributes to the initiation and intensification of various morphogenetic processes. These processes result in numerous polygenetic landforms within footpaths.

Geomorphological mapping has been used to study the development of erosive and denudational landforms within the selected footpath sections. 23 km of footpaths in the Western Tatras have been researched and in the Babia Góra massif 15 km respectively. This paper aims to determine the regularity in development of erosive and denudational landforms within footpaths below and above the treeline. The impact of tourist traffic and forestry on development of researched landforms has also been verified. Because of differentiation of natural conditions within both researched regions, for example lithology or slope morphology, only effects of erosive and denudational processes have been compared.

The research shows, that because of higher elevation and altitude, higher slope gradient and intensive water circulation in the Tatra Mountains there are more zones with well-developed erosive and denudational landforms. These forms are also larger in size than those observed in the Babia Góra massif.

Key words: Tatra Mts., Babia Góra, trampling erosion, footpath maintenance, erosive and denudational landforms

INTRODUCTION

Intensive utilization of footpaths contributes to relief transformation within slopes. It is related to the mechanical impact of tourist traffic and intensification of morphogenetic processes, which result in development of numerous erosive and denudational landforms within footpaths. Many research projects in Poland and other mountain regions, for example: in the Tatra Mountains (MIDRIAK 1983; SKAWIŃSKI 1993; GORCZYCA and KRZEMIEŃ 2005, 2006; BARANČOK and BARANČOKOVÁ 2007), within the Pilsko massif (ŁAJCZAK 1996), in the Central Massif in France (KRZEMIEŃ 1997) and in the mountains of North America (COLE 1983, WILSON and SENEY 1994) confirm high impact of trampling on slope relief.

Because of differentiation in environmental conditions, for example intensity of tourist traffic in different mountain regions, the results of human impact can be diverse. However, despite of numerous researches related to relief transformation and tourist usage, the mountain regions require new surveys, which will allow researchers to propose methods, that can help minimize trampling impact and allow to propose an effective trail maintenance methods. The aim of this study is to determine the regularity in development of erosive and denudational landforms within footpaths below and above the treeline and also to determine the impact of tourist traffic and forestry on development of researched forms in the Western Tatras and the Babia Góra massif.

METHODS

Geomorphological mapping was used to study erosive and denudational landforms development within footpaths in the Tatras and the Babia Góra massif. In the Tatra Mts. there was 23 km of footpaths, which is 8,4 % of all footpaths length in the Tatra Mts. National Park. In the Babia Góra massif it was respectively 15 km of footpaths, which is 25 % of all footpaths in the Babia Góra National Park. The choice of the footpaths was related to high tourist utilization which is observed on those tracks.

A special questionnaire was used to gather information about the footpaths, including their morphometric parameters (average and maxi-

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mum width and trail incision, depth of erosion cuts and slope gradient), types of erosion and accumulation landforms, lithology and types of vegetation cover. The cross-sections of the footpaths and in the most cha-racteristic places their long-profiles as well were plotted.

The conducted morphometric measurements of erosive and denudational landforms within footpaths became the base of their typology. The research was complemented by photographic documentation.

STUDY AREA

The study area includes selected footpaths in the Babia Góra massif and in the Western Tatra Mts. (**Fig. 1**). The Babia Góra massif is the highest area in the flysch of the Western Carpathians. It is the highest part of the Western Beskydy Mountains, with developed periglacial relief (JAHN 1958). It consists of flysch, the Magura sandstones. Research in the Babia Góra massif was conducted within the route leading from Krowiarki (Lipnicka Pass, 1012 m a.s.l), through Sokolica (1367 m a.s.l.) to the top of Babia Góra (1725 m a.s.l.) and down to the Brona Pass (1408 m a.s.l.), the Markowe Szczawiny hut (1180 m a.s.l) and to Zawoja Markowa (about 700 m a.s.l.). It is the most often chosen way to the Babia Góra summit, which indicates a high concentration of erosive and denudational landforms within footpaths related to concentrated tourist traffic. The analyzed trail surface is mainly artificial (consists of mineral layer or sandstone slabs *in situ*) with well-developed technical provisions. The research area represents three climatic and vegetation belts, that is the lower regiel (to 1150 m a.s.l.), upper regiel (to 1390 m a.s.l), dwarf mountain pine (to 1650 m a.s.l.) and alpine belt (average from 1650 to 1725 m a.s.l.) (CELIŃSKI and WOJTERSKI 1983). The average annual precipitation rate is very different across the Babia Góra massif and values a little below 1500 mm per year at 1192 m a.s.l. altitude on the northern slope (OBRĘBSKA-STARKLOWA 2004). All of the analyzed footpaths run through the Babia Góra National Park (BgNP), which was established in 1954. It is worth mentioning, that the Tatra National Park (TNP) was established exactly at the same time.

The study area in the Western Tatra Mts. is located within the Chochołowska and Jarząbcza Valleys. The highest summit in the area is Jarząbczy Wierch (2137 m a.s.l.), while the lowest point is the estuary of Chochołowski stream (990 m a.s.l). In the Western Tatra Mts. geological settings are differentiated. The area consists mainly of granitoids, gneiss, quartz sandstone, metamorphic slates, limestone and dolomites. The precipitation rate on the northern slopes ranges from 1200 mm to 2000 mm annually and the summer rainfalls ranges from 550 to 700 mm in total (ŁAJCZAK 2006). The relief of the area was highly transformed by glaciers during the Pleistocene, which results in different glacial forms. Footpaths in the Western Tatra Mts. are located within three geoecological belts: forest (900-1500 m a.s.l.), subalpine (1550-1670 m a.s.l.), alpine (1670-2150 m a.s.) and four climatic belts: temperate cool (900-1150 m a.s.l.), cool (1150-1550 m a. s.l.), very cool (1550-1850 m a.s.l.) and temperate cold (1850-2200 m a.s.l.) (HESS 1965).

Both the Western Tatra Mts. and the Babia Góra massif are under a high intensity tourist impact. However, due to more differentiation in the natural conditions and the vicinity of the High Tatras, tourist traffic in the Western Tatra Mts. is more intensive in comparison to the Babia Góra massif. The total tourist traffic in the TNP in 2007 was above 2.5 million. The research area, the Chochołowska Valley, was visited by 175,888 tourists (data from the TNP). At the same time tourist traffic at the Babia Góra massif was about 50,000 (data

Fig. 1 Study area – the Tatra (A) and the Babia Góra National Park (B) with the selected footpaths, Southern Poland

from the BgNP). The highest concentration of tourist traffic is observed from May to September within both analyzed mountain areas. The tourist traffic is one of the main factors, which influence the development of erosive and denudational landforms within mountain footpaths.

MORPHOGENETIC PROCESSES MODELING FOOTPATHS

The course of morphogenetic processes in the research area is dependent on different factors, such as surface resistance, slopes, type of surface, meteorological conditions in individual weather seasons; type of vegetation cover in the vicinity of footpath and human impact, like magnitude and intensity of tourist traffic. The analyzed footpaths in the Western Tatra Mts. and in the Babia Góra massif are subjected to numerous transformations resulting from natural morphogenetic processes, as well as mass tourist traffic and trampling impact. Those impact are reflected in the footpath morphome-tric, such as trail incision and widths (**Fig. 2, 3**). Significantly deeper erosive cuttings are located in the Tatra Mts. They can reach 1m depth and are mostly intensively transformed during summer rainfalls. The higher slopes angles and different slope morphology makes run-off more effective.

It is worth noting that the tourist impact is limited to initiation and acceleration of processes but natural morphogenetic processes have the biggest influence on relief transformation. The main part in modeling of footpaths is attributed to linear as well as surface run-off. As the result of concentrated run-off erosion cuttings, furrows and kettles are formed. Erosion cuttings are most common landforms within the analyzed footpaths, which are present in all geoecological belts. Footpath sections within the Babia Góra massif, which are located above dwarf mountain pine belt, are an exception where due to small slopes no significant erosive landforms have been developed.

In the study area the geological settings are differentiated, which allows comparing the development of erosive and denudational landforms in different conditions. Intensive run-off, triggered by precipitation and meltwater, concentrate mainly in the areas without vegetation cover, which means exactly within bare footpath surface. This situation contributes to continuous deepening and widening of erosion cuttings and gullies, until a solid bedrock is exposed. Morphometric parameters of particular erosion gullies depend mainly on substrate re-

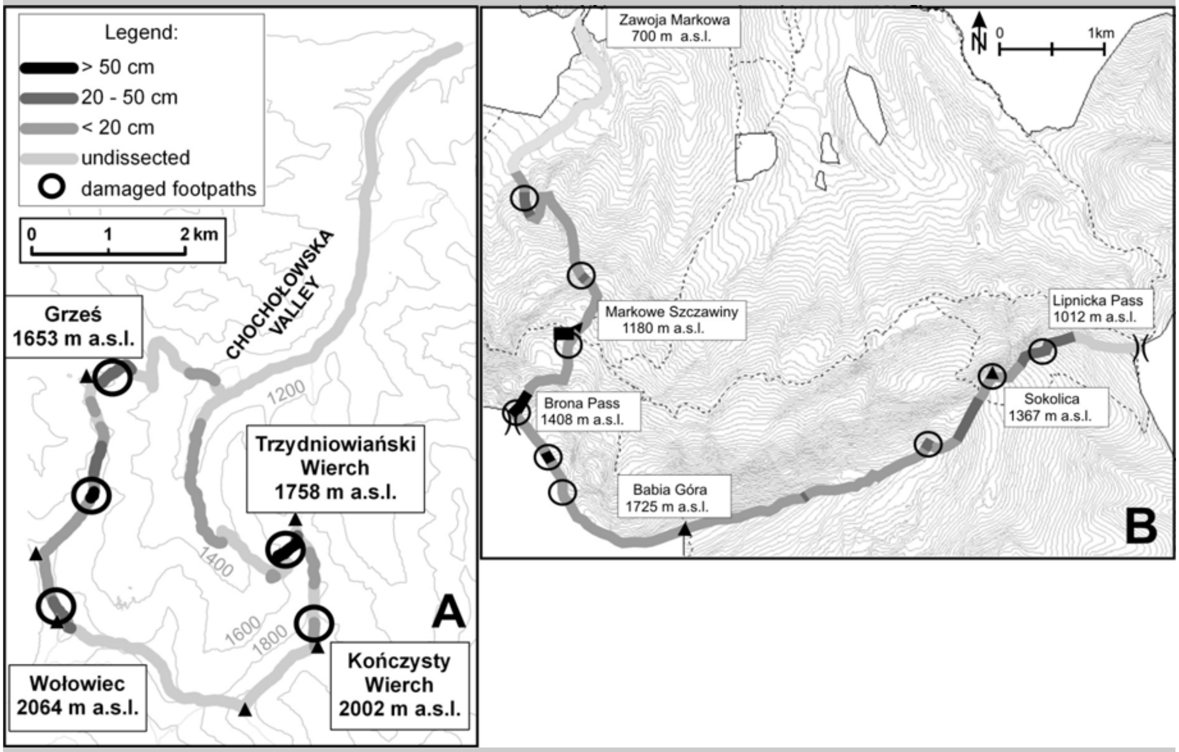

Fig. 2 Footpaths incisions within the analyzed areas in the Western Tatra Mts. (A) and the Babia Góra massif (B)

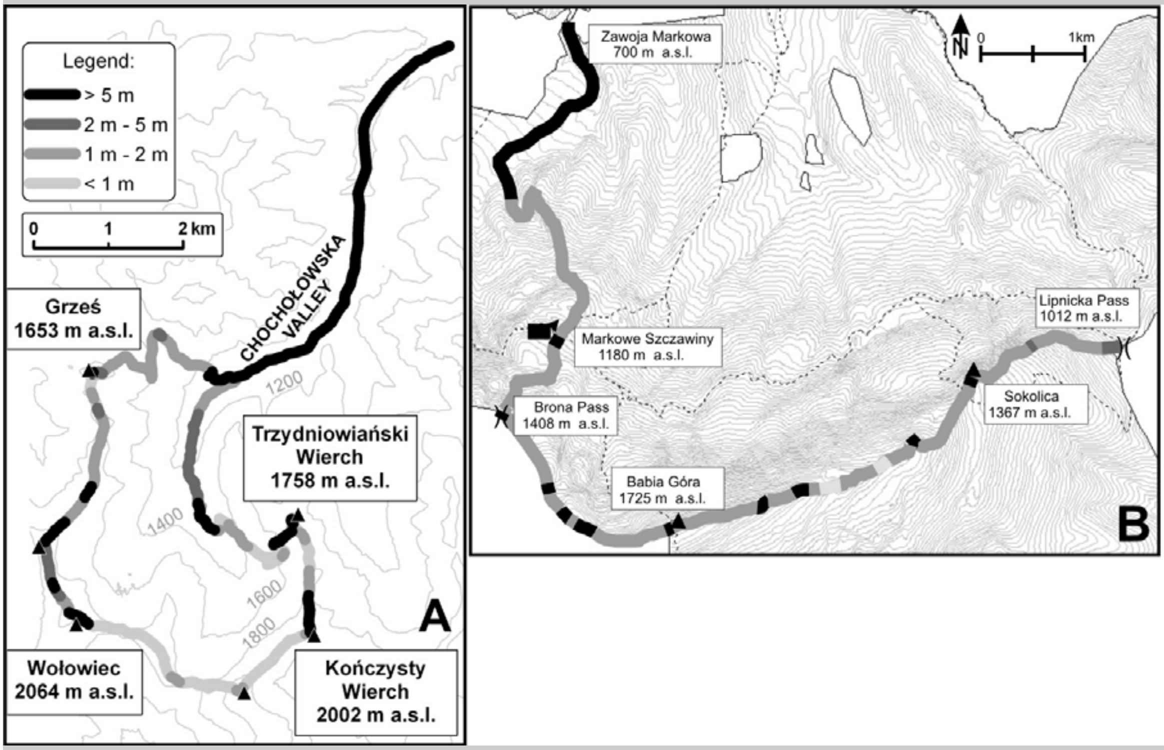

Fig. 3 Footpaths widths within research areas in the Western Tatra Mts. (A) and the Babia Góra massif (B)

sistance and slopes. Precipitation and melt-water also contribute to the initiation of mass movements, mainly landslides. These land-forms are located in every geoecological belt but the most active landslide action takes place in the forest belt, particularly within roads un-dercuttings and embankments, which are large-ly related to forestry in these areas.

Another very important process is needle ice action, which contributes to soil loss and transformation of erosive and denudational landforms. Needle ice action, as a factor contri-buting to soil creeping, plays very important role in the development of crionival niches and gelideflation steps as well. Needle ice forma-tion takes places in every geoecological belt, contributing to transportation of the material, which is later more subjected to deflation pro-cesses and run-off.

The processes that occur only above the treeline are deflation and nivation. Deflation niches are created as a result of deflation, while gelideflation steps are created as a result of co-operation between deflation and needle ice for-mation. The best developed deflation niches are localized within ridges and uppermost parts, passes and sections of windward slopes (**Fig. 4**). The development of these landforms is limited to seasons with high speed winds and takes place mainly within overdried and bare footpaths surfaces. Another type of morphoge-netic processes influencing the development of erosive and denudational landforms within footpaths is nivation, which contributes to for-mation of nival niches. The snow is gathered within concave, shaded parts of footpaths and its compaction is a result of trampling. Snow cover in these places lasts longer and nivation processes transform the footpath's surface more effectively.

Tourist utilization plays an important role in the initiation and development of new land-forms, as well as the transformation of existing ones. Trampling impacts the course of natural processes by conservation of snow cover, de-struction of footpath surface, disintegration of material on footpaths, shearing and displace-ment of turf layers, especially in spring and au-tumn, when the soil cover is saturated with wa-ter, unstable and exposed to the mechanical im-pact. The impact of tourist traffic on the foot-path surface contributes to the formation of dif-ferent landform types. In general, we can dif-ferentiate areal, linear and indirect types of those landforms, which undergo transformation as a result of different natural morphogenetic processes. The areal landforms are created mainly within quite plain parts of a slope, for example on wide ridges or sections conducted within the bottom of a valley and especially

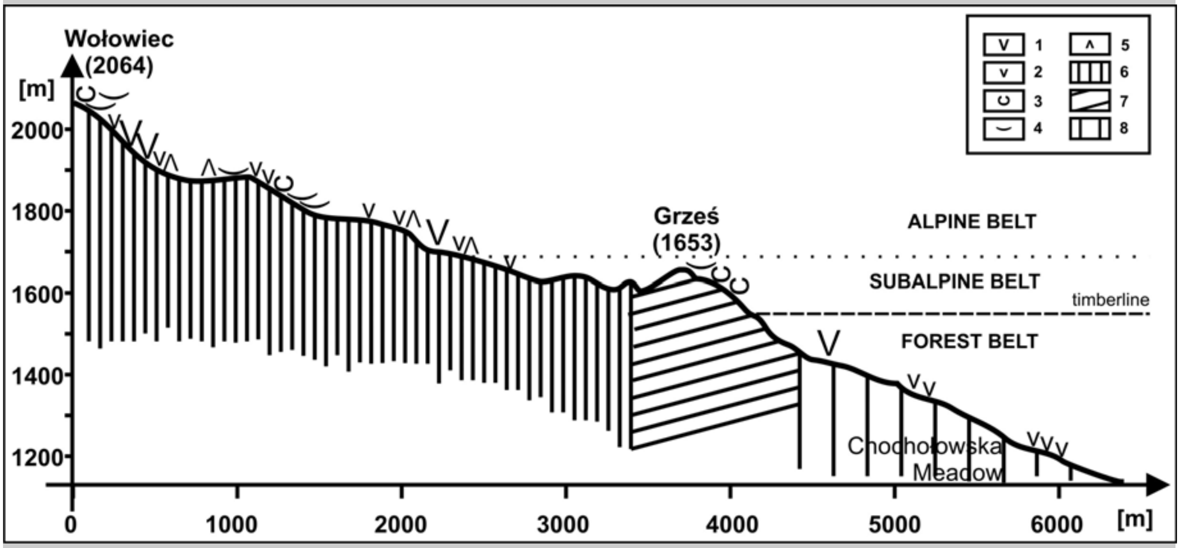

Fig. 4 A longitudinal profile with a distribution of erosive and denudational landforms in particular geoecological belts within the analyzed footpath in the Western Tatra Mts.: 1, 2—deep, shallow linear erosion cuts; 3, 4—nival, deflation niches; 5—gelideflation steps; 6—metamorphic rocks; 7—sedimentary rock; 8—slope debris

where timber harvesting and logging takes places. The linear landforms are created as the result of formation of new, parallel footpaths, for example shortcuts and social trails. The indirect landforms are created by joining surface and linear landforms types together (**Fig**. **5**).

Fig. 5 Degraded area within the footpath at the Trzydniowiański Wierch in the Tatra Mts. (an alpine belt), as a result of natural and human-induced morphogenetic processes (water erosion, needle ice action and trampling

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The differentiation of climatic conditions and vegetation cover within the vertical profile of the studied mountain areas is connected with the existence of climatic and vegetation belts, within which various geomorphic processes take places. Development of different erosive, denudational and accumulation landforms results from those processes (**Fig. 4, 6**).

This paper discusses only the regularity of development of erosive and denudational landforms. Due to small representation, the accumulation landforms were excluded from the research. Different conditions in each climatic and vegetation belt, as well as landuse changes, contribute to the differentiation of numerous erosive and denudational landforms, located above and below the treeline. In the forest belt a forestry activity has a significant impact on the condition of footpaths. Mechanical impact of logging leaves a substantial effect within the slope morphology. The change of water conditions, especially directions of water outflow

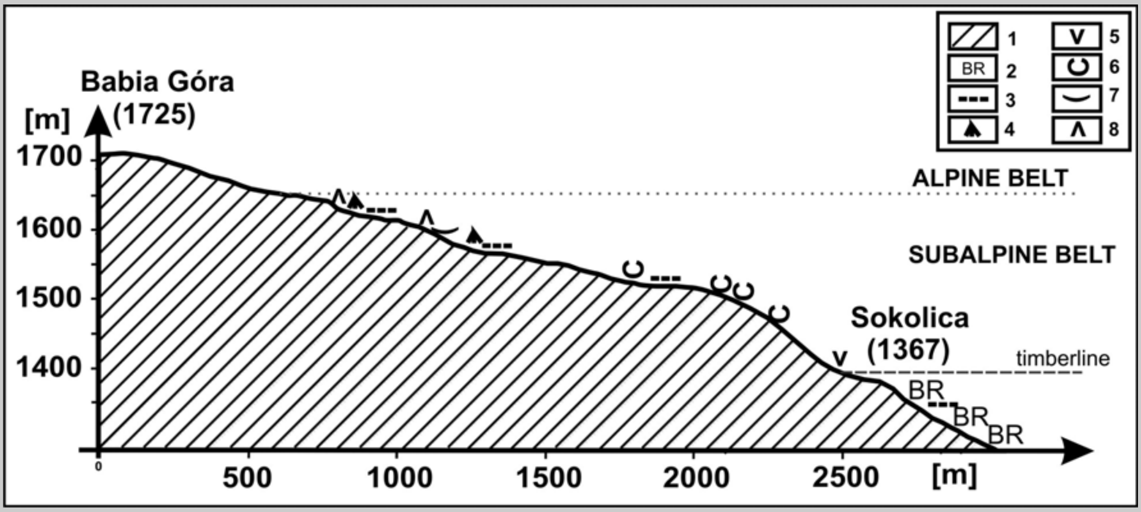

Fig. 6 A longitudinal profile with a distribution of erosive, accumulation and denudational landforms in particular geoecological belts within the analyzed footpath in the Babia Góra massif: 1—flysch conglomerates; 2—bare roots sections; 3—trampled surface; 4—small accumulation landforms, 5—shallow linear erosion cuts; 6, 7—nival, deflation niches; 8—gelideflation steps

and material displacement, is a result of slope relief changes. The conditions of water retention on a slope are also altered, which often results in a small basins development.

Logging causes a significant breach of slope stability through a mechanical attrition of the mineral layer. A common effect of logging within footpaths is the creation of deep ruts and grooves. During rainfalls the water run-off concentrates on road surface, especially in ruts which leads to systematical removal of substrate from roads surfaces and their deepening.

Continuous road utilization leads to accelerated modeling of roadcuts and embankments. Systematical displacement of material takes place within road embankments, especially in high humidity soil conditions, as well as with the co-operation of needle ice action. The displacement of material within road embanksments is most intensive during landslide processes. Compared to trampling, intensive forestry has much more significant influence on footpaths modeling over a very short time. Roads and logging tracks created in their vicinity lead to significant slope fragmentation and water run-off acceleration. Seasonal interception of water disposal on the road surface, as well as a seasonal increase of the drainage network density, can often be observed on footpaths surface.

Erosive landforms in the forest belt are the largest in size compared to other belts, especially as far as incision is concerned. Undoubtedly, erosion cuttings are the most frequently observed landforms within footpaths (**Fig. 2, Fig. 7**). Their development and deepening is accelerated by logging. Temporary water reten-

Fig. 7 Erosive cut within a footpath with natural type of surface in the forest belt in the Chochołowska Valley, the Western Tatra Mts.

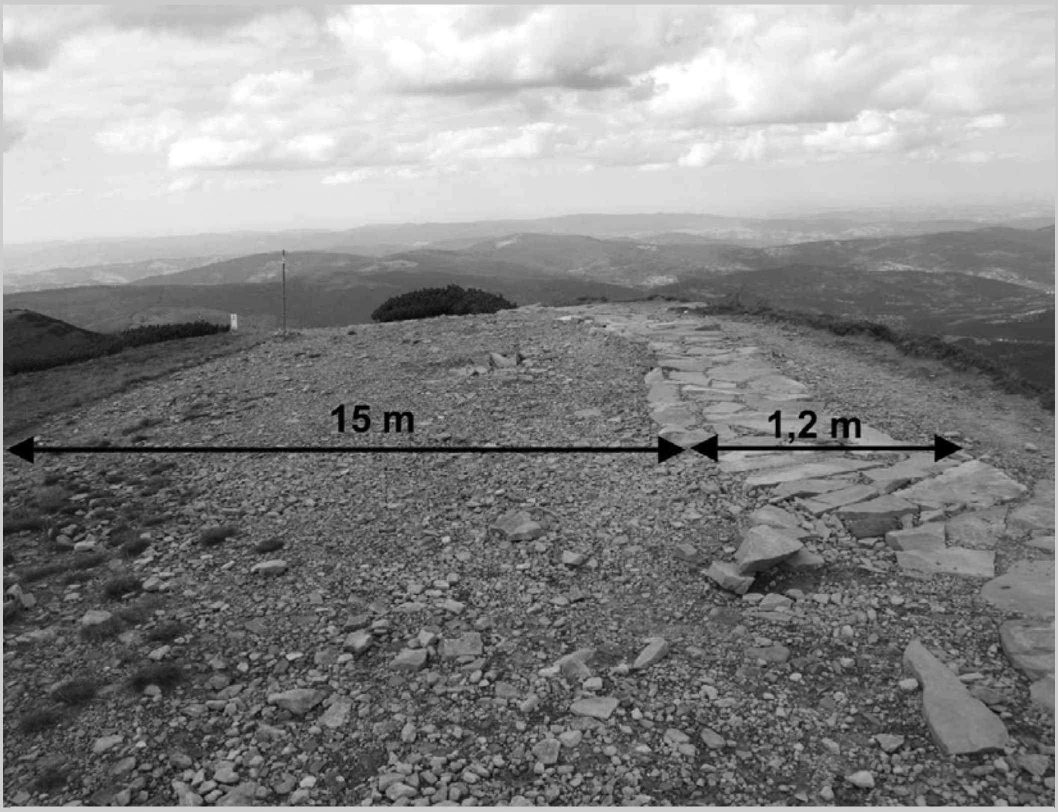

Fig. 8 Disturbed trailside along the plain section of the footpath in the Babia Gora massif marked on the krioplanation terrace in the subalpine belt. The bare trampled surface is prone to deflation and further utilization. To restoring those destructions a vegetation transplanting might be applied

tion on footpaths surfaces often leads to spontaneous rerouting and widening of a track. At the outlet of forest roads, logging tracks and within flatten segments of footpaths accumulation landforms are created. These landforms are mainly alluvial fans. After extreme events a formation of torrential debris fans is prevalence.

The footpath surface above the treeline is characterized by a larger differentiation of erosive and denudational landforms compared to the forest belt. It is related to nivation and deflation, which take place only above the treeline. Deflation niches, crionival niches, gelideflation steps and erosion cuttings are very well developed above the treeline. In the Babia Góra massif erosion cuttings above the treeline are shallower than those in the forest belt. However in the Western Tatra Mts. the deepest gullies are located above the treeline within steep parts of the slope.

The development of erosive and denudational landforms depends on local slope morphology, as well as slope gradient and aspect. Larger denivelations within footpaths in the Western Tatra Mts. cause a larger differentiation of erosive and denudational landforms in comparison with the Babia Góra massif (**Fig. 4, 6**). Footpaths sections, located in the upper part of the Babia Góra massif, are predominantly delimited within crioplanation terraces. This is the reason, that the intensity of erosion processes there is lower then it is in the Western Tatra Mts. and areal landforms, such as trampled surfaces (**Fig. 3**), are predominant over linear landforms.

EXTREME EVENTS AND LANDFORMS DEVELOPMENT WITHIN FOOTPATHS

The development of individual erosive and denudational landforms dependents on the variations of annual meteorological conditions. One of the predominant morphogenetic processes in footpath modelling is run-off. The course of this process, its intensity and duration, dependents on precipitation rates and its intensity. Therefore, the highest activity of morphogenetic processes and modelling takes place during summertime storms and snow melting in late springtime. However, extreme events have the biggest modelling impact on footpaths. The frequency of extreme events and

Fig. 9 Total destroyed section within the footpath in the Western Tatra Mts. An extreme rainfall ranging up to 104,2 mm on the 5th of June 2007 resulted in temporary footpaths closing

natural hazards has significantly increased during last years (KOTARBA 1998; MIGOŃ et al., 2002; GORCZYCA, KRZEMIEŃ 2008), hence there are playing an increasingly important role in footpath modelling. Extreme events impact on a regional scale and often only on a local scale. The results of extreme events are often catastrophic, causing temporary closings of footpaths and their exclusion from usage until surface improvements can be made. Destruction of footpaths connected to extreme events occurs most often on footpaths which are located near the streamside and correlates with increased water erosion during heavy storms.

An example of disturbances related to violent summertime rainfall of 104.2 mm is the destruction of the footpath in the Staników Gully. During this event the footpath has been completely destroyed by the Staników Stream, which resulted in formation of numerous undercuts, erosion gullies and evorsion kettles (**Fig. 4**).

TECHNICAL PROVISIONS AND DEVELOPMENT WITHIN FOOTPATHS

To minimize natural and human-induced deterioration of footpaths it is necessary to apply effective trail development techniques. The most important element in protecting footpaths against erosion is surface stabilization, which determines the footpath's resistance to mechanical impact of trampling. The most resistant surface type is a boulder pavement (**Fig. 10**). In

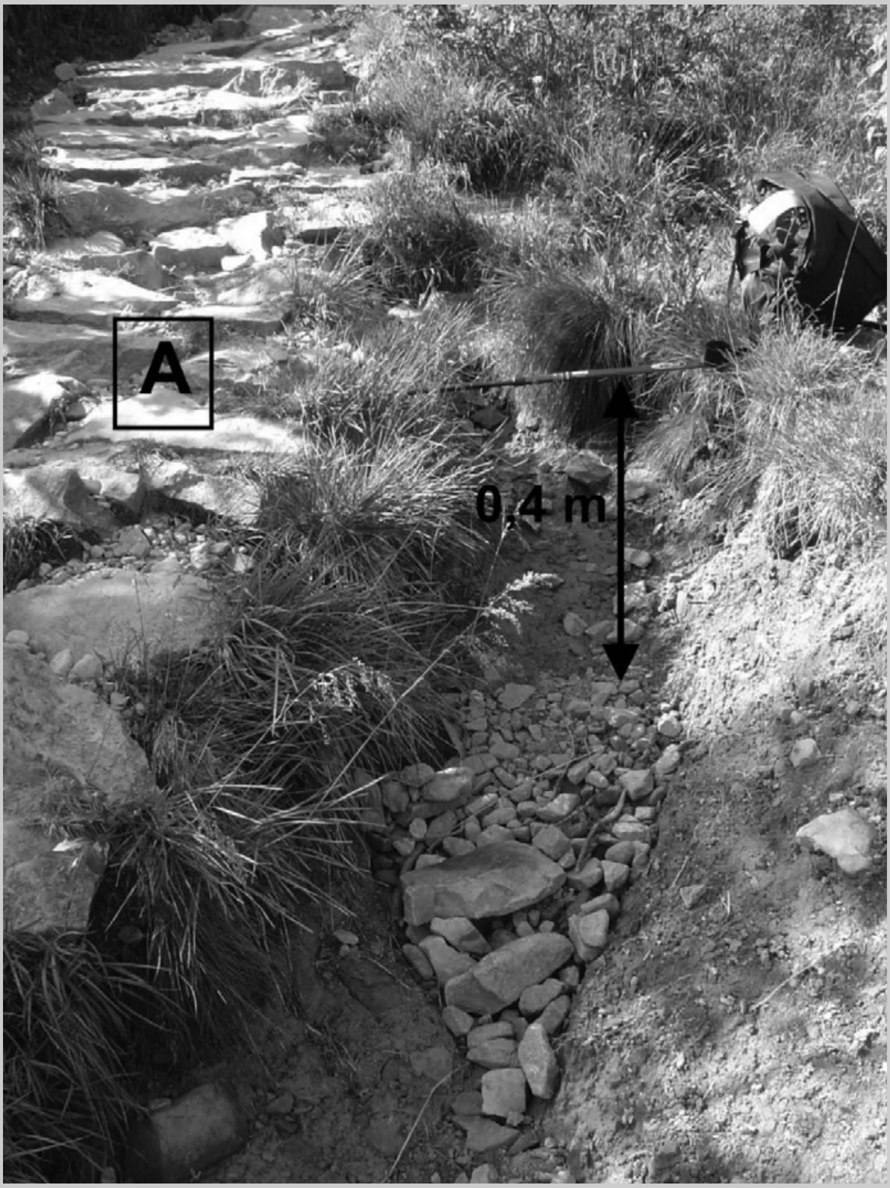

Fig. 10 An erosive cut along the trail near the Brona Pass (1408 m a. s. l.) in the Babia Gora massif with the maximum incision of 0.4 m. A boulder surface of the footpath (A) seems to be the most resistant to erosion induced both by natural and anthropogenic factors

the Babia Góra massif this type of surface, made by sandstones slabs *in situ*, dominates within the alpine and dwarf mountain pine belts. In the forest belt, there are footpaths with waste-soil surface with drainage elements (stone or wood drains), which are used to remove water from footpaths surface. Other commonly used types of footpath technical provisions method are wood curbs and wood logs.

Most of the footpaths in the study area located in the Tatra Mts. have surfaces paved with boulders. On other footpaths sections natural waste-soil surfaces, often surrounded with wood curbs is observed. Wooden or stone paved gutters are used to remove water from the footpath surface. Within footpaths with natural surfaces, especially above the treeline, within very steep sections numerous erosion cuttings and evorsion kettles can develop. It is related to removal of waste material from footpaths by run-off, triggered by heavy precipitation or snow melting. Therefore it is very important to improve technical provisions and development to protect footpath surfaces against water erosion.

The role of biological restoration in footpath sides protection in the Babia Góra massif and in the Western Tatra Mts. needs to be highlighted. A good example is a dwarf pine, a species which is very resistant to trampling and effectively limits the widening of footpaths.

SUMMARY

Numerous erosive and denudational landforms have been distinguished in the particular geoecological belts within footpaths. The morphometric characteristics of landforms within footpaths reflects the course and the rate of morphogenetic processes.

Based on this research, it can be shown that the landforms which develop within footpaths in the Western Tatra Mts. are larger in size, than these which were observed in the Babia Góra massif. Because of higher altitude, faster water circulation and steeper slopes there are more areas with well developed erosive and denudational landforms within footpaths in the Western Tatra Mts. than in the Babia Góra massif. The development of these landforms is heavily influenced by tourist utilization of the areas. The higher intensity of tourist traffic in the Western Tatra Mts. in comparison with the Babia Góra massif has a significant influence on development of new landforms and theirs transformation, for example deepening of existing landforms.

The regularities in landforms development above and below the treeline have been observed. The forest belt is dominated by linear erosion cuttings with maximum incision in the Western Tatra Mts. range up to 1 m and in the Babia Góra massif to 0.40 m. However the areas of most active development within the forest belt are erosion undercuttings and embankments, which are transformed by slope processes, creeping and needle ice action.

The development of erosion gullies and undercuttings is largely related to forestry and logging activity in the Western Tatra Mts. (in the Chocholowska Valley) as well as in the Babia Góra massif (below the Markowe Szczawiny hut). Nival, crionival and deflation niches dominate within areas above the treeline.

A comparison in the relief remodeling due to trampling in different slopes types is crucial and gives an opportunity to identification of the regularity in those transformations in the areas of various natural conditions and tourist utilization. In those comparisons it is important also to analyze, especially within the protected areas, the provisions methods and techniques in trampling damage mitigation. An effectiveness of those procedures must be considered and the best footpaths provisions techniques should be proposed.

ACKNOWLEDGEMENT

This paper details work was funded within the framework of Research Project N306 059 32/3660 and N306 290 235 financed by the Polish Ministry of Science and Higher Education.

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