Reinterpretation of morphometry of headwater areas using LiDAR data in homoclinal flysch mountain ridge modelled by landslides. Case study of the Babia Góra Mt., the Western Carpathians

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Abstract—**Basing on the data of Airborne Laser Scanning (LiDAR) the reinterpretation of relief and morphometry of headwater areas in Babia Góra homoclinal flysch mountain ridge (1725 m a.s.l.) modelled by landslides was made. The newest information source made it possible to determine the distribution of gentle relief landforms indicating the former and/or present directions of transport of colluvia. Four ways of changes in relief of headwater areas followed by changes in their morphometry were analysed. Deposition of huge volume of colluvial material in the bottoms of headwater areas increases the hazard of valley landslide movement. The development of landslides on the slopes of headwater areas is connected with headward erosion in the areas and includes – unlike other areas in the flysch Carpathians – wide range of Babia Góra ridge slope hight. This insures an extremely large load of colluvial deposits which re-model the relief of slopes and bottoms of headwater areas. The data from LiDAR made it possible to distinguish such elements of relief of headwater areas which so far have been neglected in the Polish geomorphological literature.**

I. Introduction

The aim of the paper is reinterpretation of morphometry of headwater areas at the slopes of the Babia Góra ridge (the flysch Western Carpathians) modelled by deep-seated landslides basing on the data of Airborne Laser Scanning (LiDAR) carried out in September 2012. The basis of investigations was a geomorphological map at the scale 1:5000 made in the period 1997-2007. The range and configuration of landslide tongues and lobes of various size entering the headwater areas from the higher located parts of the ridge slopes were analysed. The newest information source applied in these investigations made it possible to determine precisely the distribution of gentle relief landforms indicating the former (or present) directions of transport of colluvia. The airborne laser scanning was conducted with the accuracy of 6 points per 1 m^2 to the order of the Management of Babiogórski National Park and then available for the Authors. Basing on this information source provided by ESRI ArcGIS 9.3 software, a Digital Terrain Model was generated with resolution 1x1 m as well as a map of slope inclinations and a hillshade model map.

II. Results

Babia Góra (1725 m a.s.l.) is the highest mountain ridge in the flysch Western Carpathians formed as a homoclinal asymmetric ridge 10 km long showing W-E orientation and reaching 1100 m of relative altitude. The main ridge is joined with some lower lateral

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ridges. The part of the ridge located above 1000 m a.s.l. is built of Magura sandstone layers dipping towards the south whereas the lower part is built of folded and less resistant sub-Magura layers. Within the northern and southern parts of the slopes, much below the ridge axis, up to 300 m deep headwater areas occur. In the northern slope the headwater areas are located below a steep cuesta of average inclination 40º (locally 70º) usually at the height 1100 m a.s.l. (locally 1400 m a.s.l.). In the southern slope inclined at 20º most of the headwater areas occur at the height of 1300-1400 m a.s.l. The inclination of the headwater areas is in the range of 30º-40º and the inclination of their bottoms accounts to 10º-20º. Below the headwater areas, 150-300 m deep valleys occur which cut the mountain ridge foot.

As a result of large energy of the relief of Babia Góra and relatively poorly resistant flysch bedrock, numerous large deep-seated landslides developed which result from gravitational tectonics of highly uplifted ridge. The deep-seated landslides model the slopes of the upper part of the mountain ridge built of thick layers of Magura sandstones. The landslides represent Holocene forms of Pleistocene foundations which contemporarily do not show any activity (with some minor exceptions). The development of these landslides is controlled by the distribution of fissures in the massif of the directions NW-SE and SW-NE. The elements of landforms which commonly occur within the deep-seated landslides include ridge and slope trenches, and below, within the escarpment slopes there are rock walls and rock recesses. Below these forms the slopes are covered by thick layer of debris and block colluvia locally reaching 30 m of thickness. In such places, ramparts and irregular hummocks occur which are distributed similarly to contour-lines. Apart of them there are tongues and wide lobes distributed perpendicularly to the latter ones which go down to headwater areas. The landslide lobes in the further course of valley headwater sections function as valley landslides.

The headwater areas developed at the contact of sub-Magura layers and Magura sandstones and are located in highly located ridge slopes. These forms are present at the height where the intensity of groundwater outflow to the surface is the highest (large number of springs). Therefore in the whole area of Babia Góra ridge, the density of watercourses is the highest in the headwater areas. Slow movement of colluvia deposits in the higher located fragments of the ridge slopes as well as deepening of channels of watercourses in the bottoms of headwater areas cause local activation of landslides on the slopes of headwater areas. At present debris colluvial mantles of small thickness (about 2 m) are the most mobile, whereas thicker colluvial mantles do not show clear mobility. Morphology of landslide lobes and valley landslides, despite their contemporary dynamics, is differentiated which may indicate young age of these forms and also large hazard of landslide movements in the spring headwater sections of the valleys. There is no however any evidence which would confirm these fears apart of large landslides in two headwater areas which have activated since the 1860s.

Changes of morphology of headwater areas followed by changes in their morphometry occur as a result of dislocation of colluvial deposits in the following way:

(a) formation of narrow landslide tongues on the slopes of headwater areas → filling the bottom of headwater areas with colluvial deposits → development of narrow valley landslides → change of V-shaped cross-section of headwater areas into the cross-section of convex bottom → large hazard of further dislocation of colluvial deposits,

(b) formation of wider landslide tongues on the slopes of headwater areas → filling the fragments of bottoms of large headwater areas with colluvial deposits → development of valley landslides →

change of V-shaped cross-section of headwater areas into a cross-section of convex bottom → smaller than in (a) hazard of further dislocation of colluvial deposits,

(c) formation of wide landslide lobes on the slope of headwater areas visible as a system of connected smaller tongues → filling the entire bottom of headwater areas with colluvial deposits → development of valley landslides visible as connected landslide lobes → formation of cross-section of headwater areas with convex bottom → smaller than in (a) and (b) hazard of further dislocation of colluvial deposits,

(d) formation of two landslide tongues going down to the bottom of headwater areas from the opposite slopes → blocking up the outflow from headwater areas and filling them with slope wash deposits → cutting the landslide barrier and removing the deposited material → transport of material to further distances → formation of valley landslide → change of V-shaped cross-section of headwater area into a cross-section of flat bottom above the landslide barrier and of convex bottom below this barrier → lack of hazard of further dislocation of slope wash masses to further distances.

Only in situation (a) the landslide headwalls retreating up the hill cross the timberline, which makes the limit of snow avalanches larger and activate debris flows in large area. Deposition of material in the bottoms of headwater areas increases therefore the hazard of landslide movements in the further course of valleys. Basing on different sources of information, the process of changes in morphology of headwater areas was reconstructed.

The mechanism of development of landslides in headwater areas of Babia Góra ridge reflected in their morphology is typical for landslides from other areas described from the flysch Carpathians and other mountains. The development of landslides on the slopes of Babia Góra ridge is connected with headward erosion in headwater areas. Because of the fact that headwater areas in this ridge are located much lower than the upper range of slopes, the development of landslides includes – unlike other areas in the flysch Carpathians – wide range of slope height. This ensures an extremely large load of colluvial deposits which re-model the relief of bottoms of headwater areas. This feature of the relief of Babia Góra emphasises a unique morphology of this ridge in the flysch Western Carpathians. The data from LiDAR in the analysis of morphology and morphometry of headwater areas made it possible to distinguish such elements of the relief of headwater areas, which so far have been neglected in geomorphological literature.

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