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LANDSLIDE RISK AT THE BABIA GÓRA FLYSCH MASSIF (1725), WESTERN CARPATHIAN MOUNTAINS

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INTRODUCTION
Outline

In mountain ranges prone to landslides, such as flysch mountains, the development of new tourist infrastructure, as well as the assessment of the stability of existing structures, requires an assessment of the risk that they could be undermined by new or revived landslides. This assessment begins with careful study of the existing landslide morphology to detect early evidence of mass movement. In such spots radical change in the terrain morphology can occur, but its timing is difficult to predict. Laser scanning is one method that has been used to assess landslide micromorphology (Borkowski et al., 2011, Wojewoda et al., 2011, Wojciechowski et al., 2012, Migoń et al., 2013). LIDAR, also known as ALS, was first used in modern remote sensing in the 1970s and became wide spread in the late 1990s. Geomorphology makes especial use of it in the study of mountain areas where the relief is the most difficult to detect and LIDAR data are helpful in re-interpreting landforms and their patterns of evolution. With these data it is possible to recognise the subtle geomorphic signatures of landslides and their distribution on slopes (Łajczak et al., 2014).

Aim of Study

The aim of the study is to reinterpret the extent and morphology of landslide forms on the slopes of the Babia Góra massif, a popular tourist destination in the Western Carpathian Mountains, using LIDAR data. A comparison of the latest remotely sensed data with existing detailed geomorphological maps on which the extent and configuration of landslides are traced allows an assessment to be made of potential change in the microrelief that might provide an early-warning of the initiation of land sliding, especially in the vicinity of the tourist infrastructure constructed in the area.

Study Area

The Babia Góra massif (1725 m) rises 1100 m above the surrounding valleys to form the highest peak in the flysch Western Carpathian Mountains. Running along an E-W axis this 10-km long monoclinal ridge consists of a relatively soft sub-Magura base layer covered at 1000 m a.s.l. with a Magura sandstone cap with its layers dipping southwards (Łajczak, 2014). The profiles of the northern and southern slopes differ. The northern slope is of the cuesta type and features local flattenings at various altitudes, while its other sections continue with a uniform angle from the ridgeline to the valley floor. The high energy of the massif's landform and its relatively soft bed-rock are conducive to the development of deep-seated landslides which represent the number one process shaping the slopes. The massif is predominantly fractured along the NW-SE and SW-NE axes and this fracturing controls landslide development. Some of the most widespread landslide forms, found throughout the nearly all the massif, include: ridge and slope trenches with fissure caves, escarpments, rocky niches, and cliffs. Areas covered with debris or block colluvia include hummocks and isolated hillocks, ramparts running roughly along the contours and colluvia legs and broad lobes reaching down into headwater areas (Łajczak et al., 2014). Shallow waste-type landslides and debris flows are limited of the steep sections of the northern slope covered with thin waste mantle (Łajczak, Migoń, 2007).

The Babia Góra massif is criss-crossed by waymarked tourist paths and there is a tourist refuge (as well as the ruins of an old one) built on an old landslides. The ground on which these structures were built has remained stable since their erection more than 100 years ago. Landslides recorded in the 19th century, especially the youngest debris slides and debris flows, have rarely affected the tourist infrastructure constructed in the area, but remain a serious threat to many of the tourist paths. Most of the massif is part of the Babia Góra National Park, which is a biosphere reserve.

METHODS

The location and extent of landslide forms were determined using geomorphological map made by the first author in 1996-1998 at a scale of 1:5000. Reinterpretation of the massif's landslide relief was based on a LIDAR survey performed in 2012 for the Babia Góra National Park with an accuracy of 6 points per square metre. The authors used the ArcGIS 9.3 package from ESRI to generate a digital terrain model with a resolution of 1x1 m, a map of slope angles and a hillshade model, all at the same scale. These materials helped determine the extent and configuration of landslide forms. The paper only discusses the results of test areas selected to represent different slope angles and deep-seated landslides, including: two areas on the ridge top plateau with landslide trenches (a tourist path), one on the southern slope with a landslide niche (a tourist path and the ruins of the old refuge), four areas on the northern slope with a number of landslide forms like slope trenches, escarpments, rocky niches, hummocks, hillocks, ramparts, colluvia legs and broad lobes (tourist paths and refuge), and also two areas on the northern slope with shallow waste landslides and debris flows (tourist paths). A comparison of the configuration and extent of landslide forms in the two main sources of information helped to detect spots with or without a change in slope configuration. It was thus possible to identify sections of the tourist paths subject to deterioration due to land-sliding. In addition, an analysis of historic sources on the pastoral economy and early tourism within the massif added to the assessment of the past risk of land sliding in areas where the current tourist infrastructure is located.

RESULTS

General remarks

Using the latest remote-sensing data in comparison with older detailed maps the study found subtle geomorphic signatures of landslides, the dynamics of these forms and their directions of development. Local differences between deep-seated landslides were identified involving such driving variables as the dip of the sandstone layer and slope inclination, slope length, and the altitude of headwater areas. The relief of test areas reflects geomorphological phenomena widely present in the Babia Góra massif and specifically the predominant role of deep-seated landslides in the shaping of its landforms (Alexandrowicz, 1978, Łajczak, 2014, Łajczak et al., 2014). Landslides either develop in low sections of the slopes or at the top of them. In the former case the driving process is headward erosion in headwaters and as these normally occupy the lower parts of the slopes. The development of landslides generated this way does not comprise the upper located parts of the slopes. The initiation of deep-seated landslides in the top sections of the slopes and on the ridge plateau occurs as ridge or slope trenches develop along the deep fissuring present in the Magura sandstone. On the northern cuesta slope the resulting colluvia are transported over longer distances than on the less inclined southern slope that is concordant with the dip of the sandstone layers. Colluvial legs reach the valley bottoms causing major changes in their morphology.

Stability or instability of landslides vs. distribution of tourist infrastructure

Deep-seated landslides develop as a result of the massif's gravitational tectonics. In the test areas located on the ridge plateau, rock mass movement is primarily directed towards both slopes. In this area, tourist paths avoid rocky landslide trenches because of their inaccessibility. In the test area on the southern slope there is a large, but shallow, niche of a translational slide. This is where the first mountain refuge on Babia Góra was built in 1905. A waymarked tourist path crosses the area skirting an area of creeping debris covers. Landslide forms of various sizes are present in the test areas on the northern slope. In the upper sections there are deep, glacially transformed rocky niches accompanied by vast debris legs that appear to be mobile. For this reason tourist paths come close, but never onto these forms. Lower down the slope, in another test area, landslide trenches are apparently stable and this is where the current mountain refuge, built in 1906, is a focus of numerous paths. In a test area located still further down and far away from any paths is a deep rocky niche, developed in 1868, and a stabilised foot of colluvia made up of rock blocks. A test area nearby contains the mountain's largest colluvial leg, which has been stable enough to incorporate a path that has been popular for the last 130 years.

None of the deep-seated landslides with tourist infrastructure on display any apparent dynamic. Also, there is no information about any historic landslide activity from the period when these specific areas were involved in a pasture economy or from the early days of tourist exploration and the establishment of tourist infrastructure. Young deep landslide originated in 1868 is located far from waymarked tourist paths and a tourist refuge. Only in two sections of the steep northern slope, covered by thin cover of debris, are there debris slides and debris flows developed between 50 years and 12 years ago. These young forms are periodically refreshed, but popular tourist paths run close by or even over them and one of the paths suffers from regular damage from the processes.

CONCLUSIONS

1. The mechanism of landslide development on the Babia Góra was analysed using data from LIDAR surveys and was found to be similar to the mechanism known from other areas and described by eg. Hutchinson (1988, 1995), Cruden, Varnes (1996), Dikau et al. (1996), Margielewski (2006), Margielewski et al. (2008), Rączkowska et al. (2012). Landslides are initiated either low down or high up on the massif`s slopes (Łajczak, 2014). The former process is linked with headward erosion of headwater, while the latter is linked to the high-reaching undercutting effects of Quaternary glacial erosion on the northern slope. Deep-seated landslides mainly develop on the ridgetop plateau and in the top sections of the slopes and are initiated by the development of deep ridge or slope trenches along deep fissures in the sandstone bedrock followed by rocky niches and cliffs with the related accumulation forms built with colluvia.
2. It may appear paradoxical that nearly all of the flysch slopes, fragmented as they are by landslide morphology, remain stable, while any activity of this type is limited to long slopes covered with thin debris covers.

3. The most spectacular landslide forms do not involve any tourist activity, but this is not because of a threat of the landslide moving again, but due to their low accessibility. Tourists explore easily accessible sections of the slopes regardless of the landslide risk.

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