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Influence of geological structure and geomorphological features on landslides in the Pokut Carpathians

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SUMMARY

The article presents the results of field expeditionary research, which identified and analyzed landslides in the Pokut Carpathians. Sixteen large landslides located in both the lowland and middle midland parts of the Pokut Carpathians have been recorded. Their size, shape and time of occurrence are investigated in detail and characterized. The causes of their occurrence are identified, the main of which are geological and geomorphological features and the nature, as well as the intensity of precipitation and groundwater. It is determined that landslides are usually confined to the structural and tectonic zones of the Pokut Carpathians and Pre-Carpathians and the boundaries of natural territorial complexes of different taxonomic ranks (localities, systems, tracts). Landslide-prone areas are mainly steep slopes with the spread of clay deposits of the Carpathian flysch, mainly steep and very steep ridge slopes, steep riverbed slopes of river valleys and water catchments. The most common are landslides, where large volumes of rocks, soil and plants slide down the slope. After analyzing the results of field expeditionary research and literary and cartographic materials, the areas of localization of existing landslides and the places of occurrence of probable landslide-prone areas were determined.



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Introduction. The territory of the Pokut Carpathians is characterized by a diverse spectrum and high intensity of physical and geographical processes. From the landscape point of view, physical and geographical processes are categorized into three groups: a) hydrometeorological (heavy rains, thunderstorms, strong winds, floods, etc.); b) geomorphological (landslides, erosion, mudslides, karst, etc.); c) biotic (forest pathological phenomena, windbreaks, windbreaks) (*Melnyk, 1999*). Often due to the impact of physical and geographical processes on living conditions and human economic activity, they are called negative. Due to geological conditions, geomorphological features and other natural factors, geomorphological processes, the most common of which are landslides, often appear in the study area.

Theory and methods. Landslide is the displacement of rocks on the slope, which is dominated by sliding on the existing surface or the emerging surface (*Sirenko, 2003*). Mostly landslides occur on slopes with a steepness of 15–20° (*Bairak, 2018*). Most often landslides occur where the soil or rocks on the slope lose stability, when the slope is covered with clay. One of the main conditions for landslides is the presence of water. They often occur in spring or during intense summer rains. The main factors of occurrence, activation and propagation of landslides are the following: 1) geomorphological conditions, geological, during rains, meteorological, anthropogenic (*Bairak, 2018; Sirenko, 2003*); The surface landslides (less than 1 m) and small (less than 5 m) landslides are mainly common in terms of the depth of the slip surface in the Pokut Carpathians. Due to the time of occurrence in the area of study the following landslides are common: old, fresh, active. According the shape, the landslides are characterized as follows: circus-like, frontal, landslide flows (*Bairak, 2018*).

The authors' research was carried out in three stages. During the first *preparatory period*, the general program of researches is concluded: borders of the investigated region are outlined; published works related to the study area and materials from the funds of geological services, National Nature Park "Hutsulshchyna", space images from *SAS Planet* and *Google Earth*, time topographic maps, etc., developed works of theoretical and methodological plan and methods of research processes are collected and analyzed (*Hostiuk, 2021; Kravchuk, 2005; Paliienko et. al., 2005; Vashchenko et. al., 2003; Zakhidukrgeologiya..., 1968-1985*).

Field period is the time of expeditionary research, which is the most time-consuming and difficult to perform and is the basis of the final in-house work. During this period, we directly investigated the landslides. The following cartographic materials basic materials were used for the study of landslides: 1) topographic maps at a scale of 1:50 000 and 1:25 000 (*Main Department of Geodesy and ..., 1947-1960; Zakhidukrgeologiya..., 1968-1985*); 2) geological maps - pre-quaternal and quaternary deposits and geomorphological map at a scale of 1:50 000 (*Zakhidukrgeologiya..., 1968-1985*); 3) SRTM Digital Terrain Model (archive of the United States Geological Survey – Landsat (United States Geological Survey)) and created on its basis maps of exposure and steepness of the earth's surface, as well as space images from *SAS Planet* and *Google Earth*. G.P. Miller's method was used for researches (*Miller, 1996*) which provides studying of external signs of dynamics of natural territorial complexes. Using a landscape map and work sheets of form No. 4 (structure and dynamics under G.P. Miller's tracts, 1996) with their own additions of collected data on the distribution of physical and geographical processes and their nature of manifestation.

In the *final stage*, all the information collected during the two previous stages of research was systematized and analyzed. All the obtained field data were processed in the ArcGIS 10.0 software and a digital database was created, on the basis of which cartographic materials were compiled and the results of all researches were systematized.

Results. The geological structure of the Pokut Carpathians is represented by sedimentary deposits (sandstones, siltstones, argillites, gravelstones, limestones, marls, clays) of the Cretaceous, Paleogene and Neogene periods (Figure 1) (*Vashchenko et. al., 2003; Zakhidukrgeologiya..., 1968-1985*).

Cretaceous deposits are represented by the Middle and Upper Stryi series, which dominate due to the area in the area of study (*Zakhidukrgeologiya..., 1968-1985*). In particular, the ridges and ridge parts of



the highest ridges, namely, Igrets ridge, the upper parts of Gregit, Rotylo, Gaboryanska, Medvezhyk slopes - in the midland part of the Pokut Carpathians, the ridges of the Karmatura-Khomynskiy, Sokil'skiy-Brusnyi, Bukovets-Ritskiy-Ploskiy ridges - in the lowland, are composed chalk deposits (Vashchenko et al., 2003; Zakhidukrgeologiya..., 1968-1985).

Sediments of the Paleogene period are represented by the Yamna, Manyav, Vyhoda, Bystrytsia, Lower and Middle Menilithic, Golovets and Lower Verkhovyna series (Figure 1) (Zakhidukrgeologiya..., 1968-1985). The sediments of this age form the southwestern and northeastern middle parts of the slopes, the valley slopes of the above-mentioned ridges and peaks in midland and lowland.

Neogene sediments are represented by the Polyanytsia, Nizhnevrotyshche, Sloboda, and Nizhnedobrotvir series. They are distributed only in lowlands, forming synclinal depressions in which river valleys are laid.

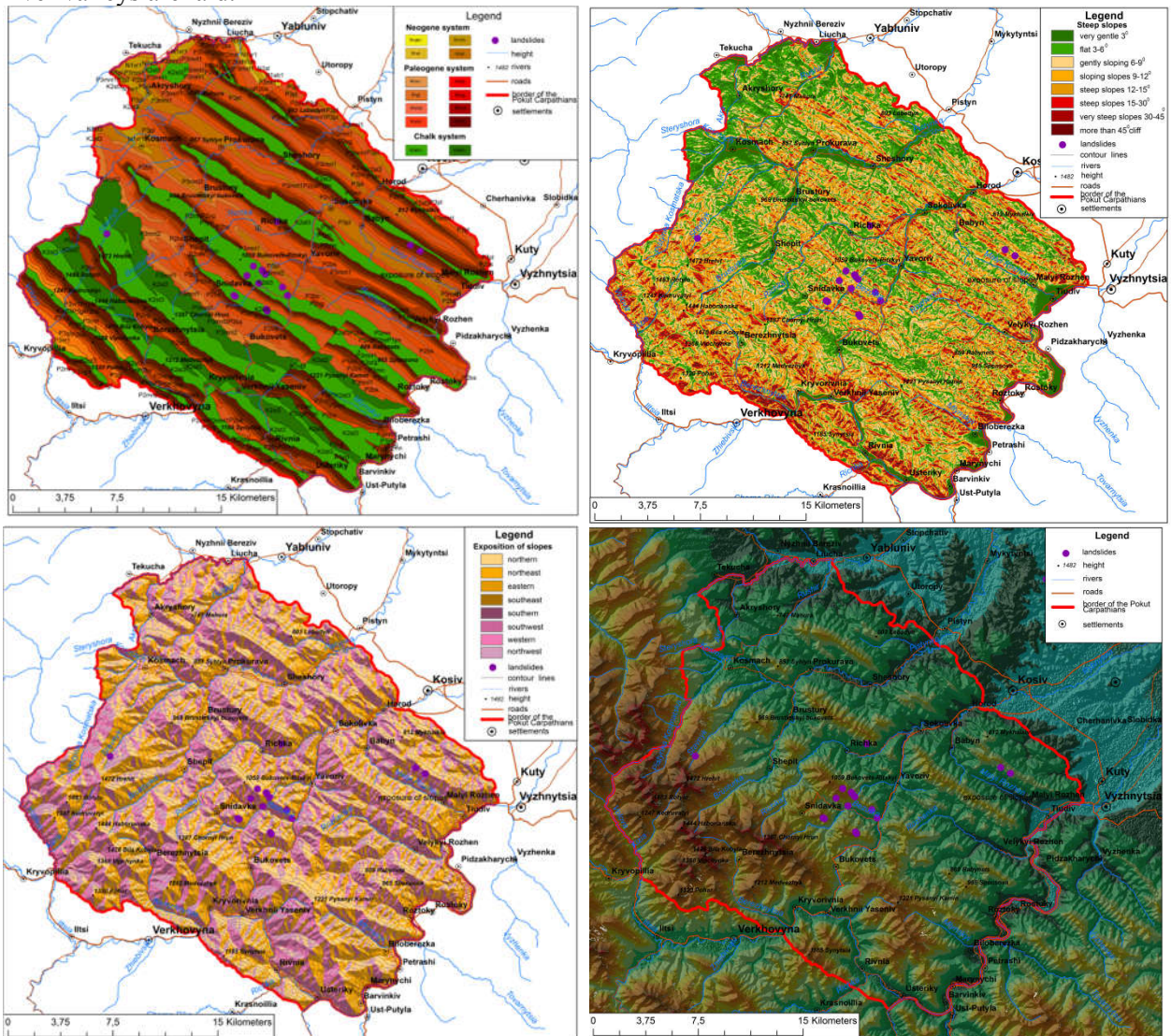


Figure 1 Geological and geomorphological features of the Pokut Carpathians.

According to the geomorphological regionalization of the Skibov Carpathians, the Pokut Carpathians belong to the subregion of Pokutsk-Bukovynian Carpathians, combining areas of the low mountain terrain of Pokutsk-Bukovynian Carpathians and the area of the middle mountain terrain of Skibov Pokutsk-Bukovynska Carpathians on the left bank of Cheremosh, ie two subregions - Pokutsk low mountain terrain and Pokutsk middle mountain terrain (Kravchuk, 2005).



The relief of the sub-area of the Pokutsk midland is formed on the Skibov cover, which is divided into morphostructures of the second order (Orivska and Parashka cuts) (Kravchuk and Ivanyk, 2006). The Pokutsk midlands are characterized by asymmetry of mountain ranges (steep northeastern and flattened southwestern slopes), significant vertical and horizontal dissection of the terrain, the predominance of narrow and deep river valleys, the presence of large collective funnels at the riverheads (Figure 1). (Main Department of Geodesy and ..., 1947-1960; Zakhidukrgeologiya..., 1968-1985).

The relief of the sub-region of Pokut lowlands is formed on Boryslav-Pokut cover of Inner Zone of Pre-Carpathian Depression (Herenchuk et. al., 1964; Kravchuk, 2005) The Pokut lowlands are symmetrical ridges with wide wedges, steep and flattened slopes that stretch from northwest to southeast and are divided by relatively wide river valleys. The ridges are characterized by absolute heights of 700–1000 m above sea level (Figure 1).

Analyzing the steepness map of the slopes of Pokut Carpathians, it was found that the largest area is occupied by slightly sloping, sloping, strongly sloping slopes - 42% and very aslope, aslope - 37%, much less - steep and very steep slopes - 18%, and the smallest areas have steep slopes. - 3% (Figure 1). Since Pokut Carpathians stretch from northwest to southeast in the form of anticline folds and cuts, the slopes of northeastern and southwestern macroexpositions are mainly common here. The northern and northeastern slopes predominate, and the eastern and southeastern slopes are much smaller. As for the slopes of the south-western macroexposure, the southern and western slopes predominate, insignificant areas are occupied by the north-western slopes (Figure 1) (Hostiuk, 2021).

During 2020 and 2021, field expeditions were carried out within the Pokut Carpathians and more than ten major landslides were recorded (Figure 1). Landslide-prone areas are mainly steep slopes with the spread of clay deposits of Carpathian flysch, mainly steep and very steep ridge slopes, steep riverbed slopes of river valleys and collective funnels. The most common are landslides, where large volumes of rocks, soil and plants slide down the slope (Sirenko, 2003; Bairak, 2018; Kravchuk, 2005).

Landslides on Bukovets-Ritskyi ridge and on Ryzhyi ridge were examined and described in detail during their own field expeditions (Figure 1). Eight landslides were recorded on Bukovets-Ritskyi ridge, six of which are located on the north-eastern macroslope, and two - on the south-western one (Figure 1). All landslides in the depth of capture are superficial and small (height of the detachable wall is up to 5 meters). At the time of occurrence, all landslides are fresh and of various shapes (Figure 1, Table 1). We would like to present the characteristics of one of the landslides on the northeastern slope of Bukovets-Ritskyi ridge (Table 1) (Hostiuk, 2021).

Table 1 Characteristics of landslides of Pokut Carpathians (north-eastern slope of Bukovets-Ritskyi ridge and north-eastern slope of Rizha ridge)

Physical and geographical location	North-eastern slope of Bukovets-Ritskyi ridge (Pokut lowlands)	North-eastern slope of Rizha ridge (Pokut midlands)
Position in microrelief	upper part of the slope	lower part of the slope
Landslide type	consistent	sequential
Landslide shape	slandslide-flow	circus-like
Length	700 m	200 m
Width	40 m	100 m
The height of the detachable wall	1,8 cm	2-3 m
Type of vegetation	meadow vegetation, mainly mudwort	young beech-fir-spruce forest
The composition of the sliding mass	mostly clay, occasionally - small fragments of rocks	clays, sandstones, argillites, siltstones, marls, limestones of the Upper Stryi series. Deluvium which accumulated in the lower part of the slope over a long period was the main landslide
Causes of occurrence	steep slope, Stryi series composed of hard rocks and heavy rains for a whole month on the eve of the landslide	steep slope, Stryi series composed of hard rocks and heavy rains for a whole month on the eve of the landslide



A large landslide was recorded in the lower part of the north-eastern slope of the Ryzhyi ridge in the basin of the Stavnyk River, in the midlands in young beech-fir-spruce forest (Figure 1, Table 1). The landslide was formed on the deposits of the Upper Stryi series (fine and medium-rhythmic flysch), which is composed of sandstones, argillites, siltstones, marls, and limestones. In addition to soil, the displacement material was also deluvium deposits.

Conclusions. The presence of certain geological and geomorphological features caused a variety of landslides in the area of study. After analyzing the results of field expeditionary research and literary and cartographic materials, the areas of localization of existing landslides and the places of occurrence of probable landslide-prone areas were determined. The specific causes of landslides were determined and it was found that in addition to geological and geomorphological features of landslides during 2020 and 2021, the amount and intensity of precipitation in spring and summer, on the eve of landslides, played a significant role. During the research, sixteen large landslides of different shape, size and time of occurrence, were identified and investigated. Landslides are usually confined to the structural and tectonic zones of the boundaries of the Pokut Carpathians and Pre-Carpathians and the boundaries of natural territorial complexes of different taxonomic ranks (localities, systems, tracts). Landslide-prone areas are mainly steep slopes with the spread of clay deposits of the Carpathian flysch, mainly steep and very steep ridge slopes, steep riverbed slopes of river valleys and water catchments.

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