Introduction

Natural hazards are still very high in the Eastern Carpathians, despite the progresses related to the comprehension and modelling of hazardous geological processes at large scale. The sustainable development of mountainous areas and safety to the people require reliable study and modelling of hazardous processes. A major threat is induced by all types of gravity processes (e.g. landslides, debris and earth flows) which are triggered in these areas and which represent one of the most destructive natural hazards in the Carpathian region (Ivanik et al., 2019; Ivanik et al., 2017
Mass movements are dynamic systems that are complex in time and space and closely linked to both inherited and current preparatory and triggering controls. It is not yet possible to assess all factors for multi-dimensional behavior and formation of complex landslides, although considerable progress has been made in classification and choice of rheological models. Successful decision making process of landslide hazard forecasting and development of measures is impossible without full assessment of causes and determination of failure characteristics of rock complexes, which are based on a set of field measurements, paleotectonic and structural research.
The local paleogeodynamics of the Eastern Carpathians, despite the regional uniqueness of such paleotectonic movements as compression and displacement of mountains in the north-eastern direction and the formation of a system of large and small landslides remains unexplored. Despite its locality, research could give the new information not only about a small structures, but also become indicators of paleotectonic movements and, accordingly, to be informative for big tectonic structures.

Structural control of landslide hazards in the Eastern Carpathians

According to the last geological mapping the Folded Carpathians are composed of Mesozoic-Cenozoic carbonate-terrigenous formations (mainly flysch-type) which constitute several litho-tectonic zones. The Ukrainian Carpathians from the north-east to south-west the following units are distinguished over there: Bilche-Volytska zone (autochthonous outer part of Fore-Carpathian trough formed on the basement of Western-European platform); Sambirskiy and Boryslavsko-Pokutskiy thrusts of the inner part in fore-front trough; Skyboviy thrust, Krosnenska zone, Chornogorskiy, Duklyanskiy, Porkuletskiy, Rakhivskiy, Kamyanopototskiy thrusts of Outer Carpathians; Bilopototskiy, Dilovetskiy thrusts of Marmaroskiy massif; Vezhanskiy and Monastyretskiy thrusts of Marmaroska zone of Cliffs; Peninska zone and Trans-Carpathian inner trough. Hereafter, the term zone is applied to the litho-tectonic or tectonic subdivisions in general. The thrust comprises large (regional) scale geological body, displaced from its primary position over considerable distance and composed of the rocks of one, in some cases two zones. The nappe (skyba) comprises a part of thrust consisting of individual sheets and bounded by curvilinear tectonic planes. The sheet (luska) is a rock batch limited by two thrusts. The general structure of Carpathians is thrust-sheeted, with the rock mass displacement from the southwest to north-east, towards the platform. The thrusts constitute not only Carpathians but also the inner part of Fore-Carpathian trough. The thrusts are also identified in the basement of Trans-Carpathian trough. This is why the general structure of Ukrainian Carpathians is classified as the mono-vergent asymmetric mega-thrust, surrounded by the troughs and in the inner part separated by major suture zone, expressed in the rocks of Peninsko-Marmaroskiy belt and which is thought to be the Trans-Carpathian deep-seated fault (Zuchewicz, 1997). The composition of sediments, internal tectonic features, age of folding are different for the distinguished tectonic elements (Kravchenko et al. 2017).
The main goal of this research is to establish at the local level the features of the thrusts of the Chornogorski thrust and Krosnenska zone, which can be used to solve various geodynamic problems, including modern exogenous geodynamics (Andriiets et al.; 2016; Andriiets et al., 2017). The study area is located near Krasnyk village of Ivano-Frankivsk region, which in the spring of 2020 was affected by intensive landslides. This area belongs to the Chornogorski thrust and Krosnenska zone. The recent activation of landslide processes has determined the urgency of the work which comprises the allocation of local fault zones and their impact on the mass movements.

The occurrence of gravitational and erosion processes is mainly determined by the deformation nature of rocks, types of tectonites, cementation of sediments, hydrogeology, topography etc, that is the factors affecting mechanical properties of rocks and their response to stress. Strength loss can occur instantly during the process of failure, through loss of cohesion, liquefaction of granular material or remoulding of clay. Further loss of strength can occur during movement, including rock joint roughness reduction, shearing in deposits, sliding surface liquefaction, frictional heating, loss of internal coherence of the landslide body, and entrainment of water (Hungr, 2007). It is very important to study the behavior of rock complexes, in order to facilitate predictions of the existence of landslides for landslide hazard assessment.

Since the stress-strain state of the rock mass is the one of the important criteria for assessing the stability of the slope, this study is an important step to assess the formation of landslides (Ivanik et al., 2019). The solution of this problem includes several stages, covering a comparative analysis of values and indicators of strength where, according to geological data, we can expect the danger in terms of the stability of zones and contacts; detection of the formation of zones of big stresses that form near the surface of the slopes, along large cracks, etc.; determining the influence of tectonic and other cracks of different directions on the stress distribution in the rock mass; analysis of changes in stress distribution in the deposits as a result of erosion in recent times and at the ratio in the river valley.

Based on the fact that one of the favorable zones for the formation of erosive landforms are areas of the increased rate of destruction and weathering of rocks, it is expected that a significant part of regional splinters and splinters associated with the formation of thrust in the eastern Carpathians are manifested in local erosive landforms (Kravchenko et al. 2017). Therefore, we consider that their statistical processing will allow to know the regional structural paragenesis of various ranks connected with the formation of different ranks thrusts.

GIS project was created, to which SRTM images (n48_e024_1arc_v3), digital topographic maps and geological map GDP-200 (Nadvirna sheet) at a scale of 1: 200000 were added. The valleys were digitized and ranked by length, namely 0-500m, 500-1000m, 1000-1500, 1500-2000m. The azimuth of the extension was automatically set for each valley. Then it was used for construction of diagram of roses (Figure 1), because at this stage of the study we did not take into account the angle and direction of incidence of the hypothetical fault zones.

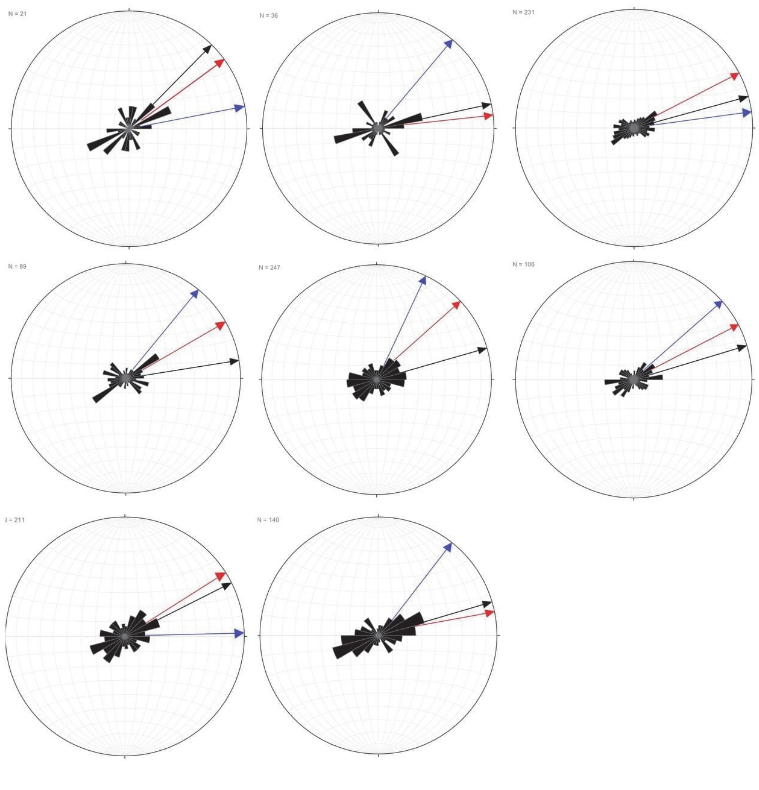

Figure 1 *Roses-diagrams and hypothetical axes of the main normal stresses of erosion forms*

In this area, more than one thousand thalwegs were digitized, which were divided into 8 areas for more detailed processing, based on the spatial affiliation to a large thrust or several thrust systems of the second order. Rose diagrams were constructed for each plot and the statistical distribution of erosion forms within its boundaries was analyzed. In the statistical distribution, erosional forms that coincided with the expansion of layered bodies were excluded from the sample, which was determined by the lithology and nature of rocks. For each rose chart using the software Stereonet (https://app.visiblegeology.com/stereonet.html) was set the main (middle) vector of the directions of erosion forms, as well as selected vectors that can theoretically relate to coalescent and non-coaxial deformations by Anderson and Riedel scheme, respectively.
Roses of diagrams show that all hypothetical axes of the main normal stresses, and including the main vector of extension of erosion forms, are oriented in one direction of northeast at an acute angle (except for some cases) to northwest directions of mapped thrusts (Figure 2).

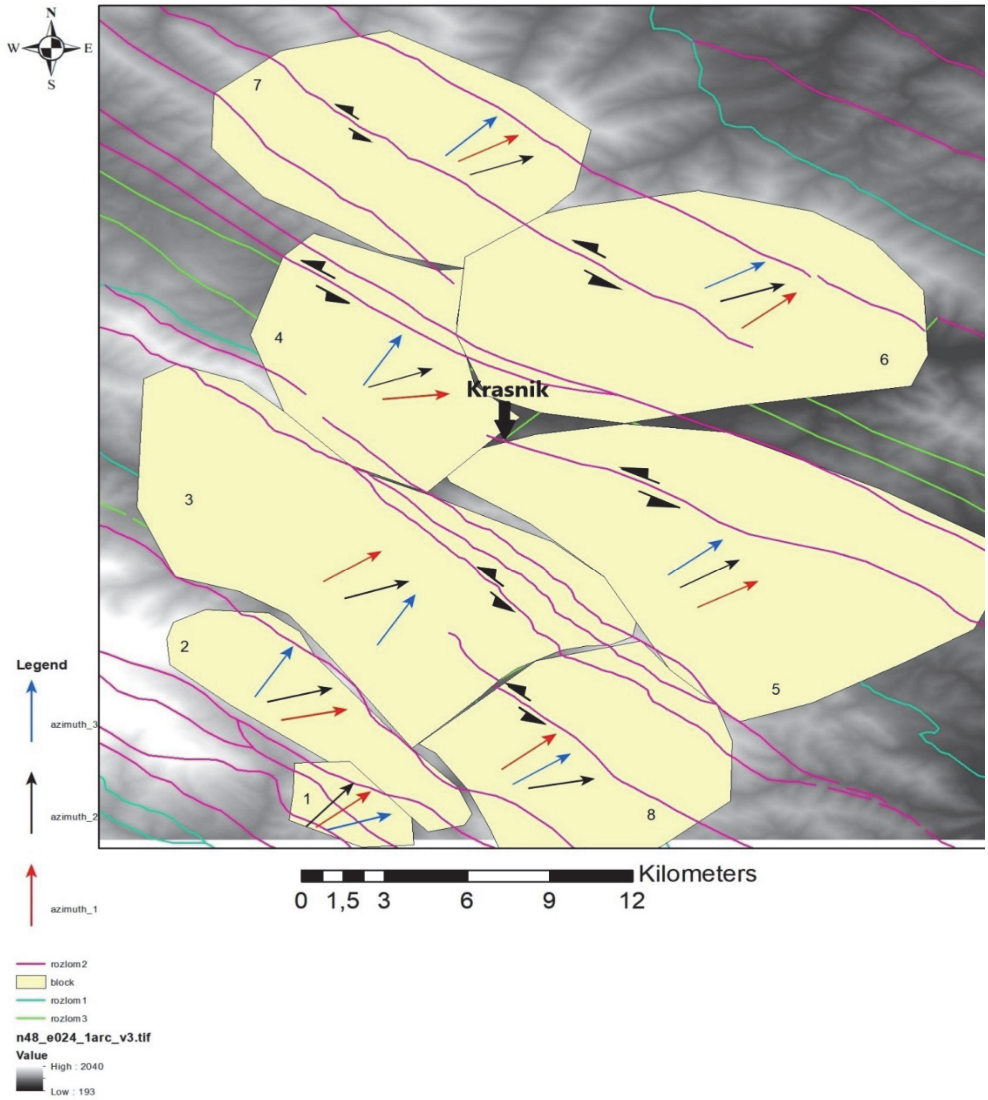

Figure 2 *Directions of hypothetical basic normal stresses of two stages of thrust formation (blue and red arrows) and orientation of the main vector of directions of erosive landforms (black arrow)*

Conclusions

Assessment of landslide hazard forecasting and development of preventive measures is impossible without full assessment of causes and determination of failure characteristics of rock complexes, which are based on a set of field measurements, paleotectonic and structural research.

One of the important criteria for assessing the slope stability is the stress-strain state of the rock mass, so to assess the landslide hazard, these studies are an important step. Integrated study of structural data with geomorphological and external factors demonstrated that the local paleogeodynamics of the Eastern Carpathians is characterized by its regional uniqueness of such paleotectonic movementsas compression and displacement of mountain ranges in the north-eastern direction and the formation of a system of large and small thrust. Therefore, in the course of our research, the angular relations between the main vector of the directions of erosion forms and the orientation of the hypothetical axes of the main normal stresses is not only vertical but also has left-sliding movements of hanging thrust blocks. The paleogeodynamic regularities could be the basis for establishing the structural paragenesis of different stages of thrust formation. These studies confirm that structural and tectonic factors play an important role in the landslide formation.

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