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GEODYNAMICS AND FORECAST OF CATASTROPHIC LANDSLIDES AND MUDFLOWS IN THE CARPATHIAN REGION

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Abstract. Research of the mechanisms of the slope processes and their dynamics have been carried out on the basis on the engineering-geological, geophysical and geodetic techniques and modelling methods. The main research methods were not contact methods (air visual, interpretation of photographs), which allowed to estimate a catastrophic situation. As a result of the application of these methods, the regional classification of slope processes has been prepared which has created a basis for the landslides models and their mechanisms. It must be underlined that the character of the geological environment in the studied region was defined by different mutually related parameters (of geological, geomorphological, climatic, landscape, informational and technogenical nature) which caused feature diplacements and processes of catastrophic activation of the slopes.

Key words: slopes processes, landslides, mudflows, geological environment.

Abstrakt. Badania mechanizmu i dynamiki procesów zboczowych prowadzono metodami geologiczno-inżynierskimi, geofizycznymi, geodezyjnymi oraz z zastosowaniem modelowania. Podstawowe badania prowadzono metodami pośrednimi (obserwacje z powietrza, interpretacja fotografii itp.). Pozwalały one na szybką ocenę sytuacji w przypadku katastrof. W wyniku zastosowania tych metod, wypracowano regionalną klasyfikację procesów zboczowych, co stworzyło podstawy do opracowania modeli mechanizmów osuwiskowych. Stwierdzono, że uwarunkowania badanego środowiska były określone przez różne, powiązane ze sobą parametry, które powodowały katastrofalną aktywację procesów zboczowych. Należą do nich warunki geologiczne, geomorfologiczne, klimatyczne, krajobrazowe, technologiczne itd.

Słowa kluczowe: procesy zboczowe, osuwiska, spływy błotne, środowisko geologiczne.

GEOLOGICAL SETTING

Territory of the Carpathian region within the Ukraine borders consists of four geological environment types, according to the natural conditions of the formation of technological transformations, namely: Carpathian Backland inner caving, Carpathian folded area, Forecarpathian caving, and southwestern district of the East European platform. Dynamics of geological environment was set up by complex of the regional and local evolution regularities. These regularities were formed under the influence of natural and technological factors. The joint influence of the factors caused the development of dangerous geological processes, which has lead to modification of the mass-energetic balance of geological environment (Goshovsky, Rudko, 2004).

The Carpathian folded area is characterised by prevalence of flysch formations, which is an environment of the dangerous geological processes development: landslides, collapses and mudflows. Within this area, a system of structural zones, encompassing landslide zones, is developed, dividing Carpathians, Forecarpathian and Carpathian Backland caving. Besides, the cross-cutting and diagonal breaks have developed there, attributed by instrumental research to seismic-active type.

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LANDSLIDES OCCURRENCES IN THE CARPATHIAN REGION

The Carpathian region is characterised by intensive development of natural disasters, especially of the slope processes. Therefore, from fixed 16 thousand landslides in all the territory of Ukraine, more than 30% (about 6 thousand) were developed in limites of the Carpathian region. It is necessary to note that in the last decades sharply increased the role of technological factors in the transformation of the geological environment of the particular regions (Rudko, 1996).

In the region discussed, both, single and mass displays of the geodynamic processes have been known for a long time in the region. In 1969, there was a catastrophic activation of a landslide of 40 million m^3 volume at Verhniy Yaseniv, which created a threat to a site of a channel of river Black Scheremosh. In 1979, in the Forecarpathians, the massive activation of landslides led to destruction of 500 residential buildings, as well as several roads, electric lines and other objects. In the period of in 1998–1999, catastrophic activation of landslides and other dangerous exogenic processes were observed. Only in the city of Chernovtsy, more than 40 landslide displacements of catastrophic character took place. An activation of dangerous geological processes was the reason of evacuation and resettlement of more than 400 families (Fig. 1, 2).

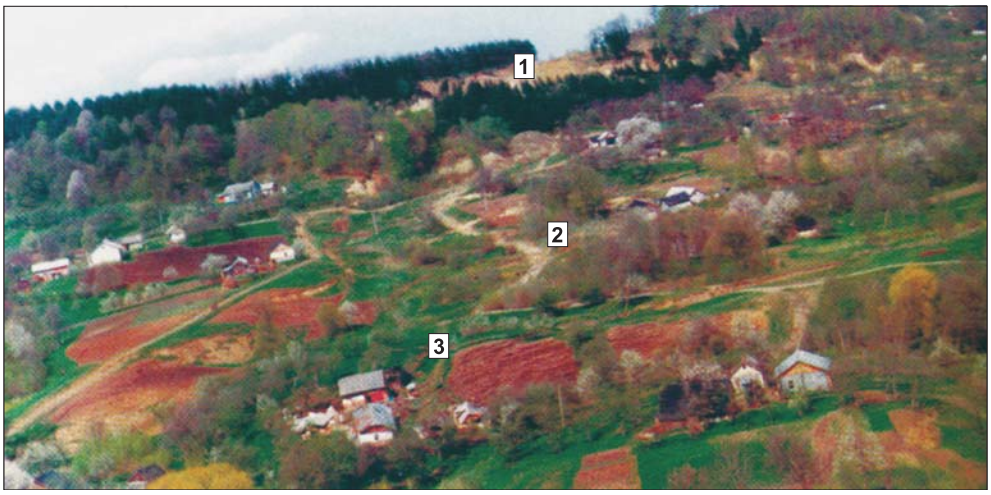

Fig. 1. Panorama of the catastrophic Kostinca landslide

In the upper part (1) a ripped off material with dislocated pines is visible; in the middle (2) and the lower (3) parts of the slope, plastic deformations developed (*photo by H.I. Rudko*)

Fig. 2. A detailed study of the lower part of the Kostinca landslide slope

Fissure zone speeded up the plastic deformations (*photo by H.I. Rudko, from helicopter*)

In the Carpathian folded area as well as in units of the dangerous crossing infringements, over 70 landslides and collapses were developed. The volume of the particular landslide masses changed from 1.0 up to 10.0 million m^3, and sometimes up to 70 million m^3. In the tectonically weakened zones, at the contacts of sandstones and argillite, the watering and a loss of density of the flysch massif has taken place. In those places clay interlayers were formed, 0.4–4.0 m wide, which constituted sliding surfaces of structural-plastic landslides. The breaks zones were characterised by the increased fissuring. Mudflows were developed there, carrying annually material in volume of 600–3,400 m^3/km^2. Within the Carpathian borders, folded area has revealed over 4,000 landslides and collapses.

DESCRIPTION OF THE RESEARCH AND ITS RESULTS

Taking into account the above described phenomena, and the necessity of urgent implementation of actions to prevent the further development of the catastrophic slope processes, we have carried out a research on their regularities, mechanisms and dynamics. The research was based on the engineering-geological, geophysical and geodetic techniques and modelling method. The main research methods were not contact methods (air visual, interpretation of photographs), which allowed to estimate a catastrophic situation.

As a result of application of these methods, the regional classification of the slope processes has been prepared, which has created a basis for development of the landslide models and their mechanisms. It must be underlined that the character of the geological environment in the studied region was defined by different mutually related parameters (of geological, geomorphological, climatic, landscape, informational and technogenical nature) which caused feature displacements and processes of catastrophic activation of the slopes.

An analysis of natural and technogenical factors of the regional geological dynamics of environment allowed to draw the following conclusions: the natural climate conditions (the mode of temperatures and precipitations) have defined the periods of the catastrophic processes of the activation of the slope, and they were also the major factors for prognoses of the plastic landslides and mudflows activation. The first have had the five-years-rhythm of activation, and the second the eleven-years-rhythm of activation.

The development of the slope processes within the Forecarpathians borders and the Carpathian Backland led to shape the molasses formation, composed of halogen, carbonate and clay deposits. Clay molasses are composed of montmorillonite-hydromica kaolin. In zones of tectonic infringements cuttings, on sites of water horizons formation, the clay formation changes its properties, as the hydromica transforms into montmorillonite, there. It provides the transition of the material condition from firm into plastic one. Depending on the depth of such transformation zones, plastic, structural-plastic and structural landslides have been developed (Fig. 3).

The molasses have acquired unlimited capacity and spatial position as the result of intensive folding. In the sites of the hydrochloric appearance, karst processes have been activated by exploitation of salt deposits. Structural-tectonic conditions of the Carpathian Backland inner caving have caused formation of the flat folds in molasses (clay molasses in which landslides were advanced).

Within the southeastern borders of the East European platform area, the terrigenous-carbonate formation displays the widest development. In this area the karst, landslides and erosion processes are present. Structural-tectonic conditions of the region are defined by the development of block and ring

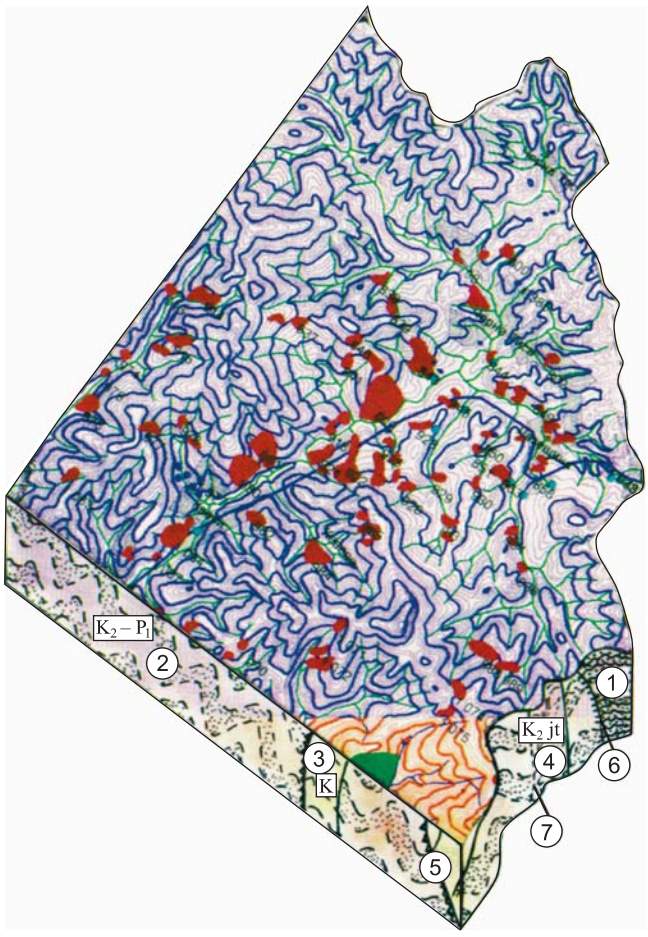

Fig. 3. The regional regularities of landslides development on the Yaseniy strip

The strip is characterised by an intensive development of stabilised and active landslides; there are many ruined engineering installations in the technological zone, there; *1* – clay's flesh, *2* — sand flesh, *3* — not parted Cretaceous deposit, *4* — red and green argillite and marl, *5* — thrust 1st order, *6* — thrust 2nd order, *7* — faults, uplifts, breaks

structures (megastructure, macrostructure, mezoblocks and microblocks). Epicentres of local earthquakes are located within the crossings of the megastructures zones. The landslides are developing in the Neogene clays. Karst phenomena are attached to sulphate and carbonate mezoblocks and microblocks.

Modern tectonic movements have been investigated on the basis on the repeated geodetic measurements. In effect it was established, that the Carpathian folded area has raised with the maximal speed (up to 3 mm/year). Towards the deflections direction, speed of the modern tectonic movements decreases to 1 mm/year, and on the platform — to 0.5 mm/year. Modern tectonic movements have influenced the hydro network development as well as the exogenic geological processes.

Seismicity of the Carpathian region territory was the major factor of the development of the geological processes. The Carpathian Backland inner caving was the most active seismic area, where the intensity of seismic processes could reach level of eight grades. A number of local earthquakes epicentres, connected with the active breaks of an earth's crust, was noted (1880, 1903 and 1937). According to our research, each seismic motion within the tectonically active territory limits caused an opportunity for insignificant displacement of temporarily stabilised landslides in the Carpathian folded area and the Forecarpathian deflection, with size from 1 up to 5 mm. It has prepared favourable conditions for activation of the landslide processes during the periods following the abnormal humidifying of the landslide slopes. For example, in 1977, there was a 6-grades earthquake, and two years later, in 1979, an abnormal humidifying (80–100 mm precipitation during the two days rain) was observed. It was followed by massive landslides activation (over 560) within the Forecarpathian deflection limits.

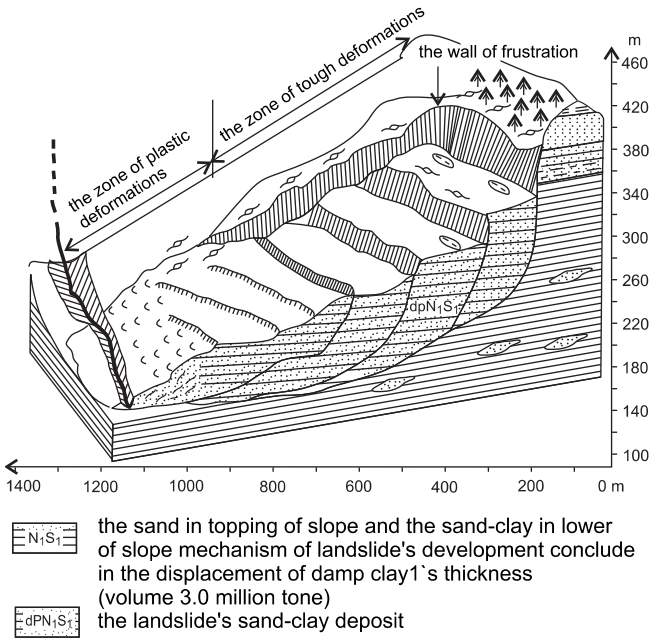

Fig. 4. The principle scheme of the structural-plastic Kostincy landslide (Chernivcy region)

Catastrophic landslide activation was in April 1999, resulted in ruining of 137 dwelling houses

The basic technogenetic factors, which influenced the intensity of development of geological processes in the investigated region, changed the subsoil water level as the result of violation of the forest exploitation technologies and of the mineral extraction works (sulphur, salt). Technogenetic activity was the major factor of the catastrophic activation of slope processes and their development which accelerated their natural course in tens of times. Character and intensity of the technogenetic activity have caused the formation of the technogenetic landscape provinces. The information on the natural and technogenetic factors is collected in a database, which is constantly updated and which allows carrying out the operative analyses of the development of the geological environment.

For maitanance of optimization of territorial information use, the autors offer a scheme of the Carpathian region division in respect to development of landslide processes within the limits of geostructural regions and engineering-geological areas. For each engineering-geological area, the risk of natural disasters has been designed, as well as for all the geostructural regions. Three models of the development of landslide processes mechanism were developed: structural-plastic, structural and plastic.

Structural-plastic landslides characterise a whole spectrums of the Carpathian region rocks, from the loose material up to the rocky one. On the slopes built of homogeneous material, landslide displacements occur on a surface close to circle-cylindrical form. In slightly inclined multilayered Carpathian folded area and in the Forecarpathian deflection, development of active landslides occurs on cracks, which slashes a slope to pieces. The volume of structural-plastic landslides changes from 40 to 0.1 million m^3. The speed of landslides movement changes from several meters a year, up to dozen of meters a day (Fig. 4).

Structural landslides are formed on slopes built of material deposited close-to-horizontal position. In the investigated territory, such landslides develop within the limits of the southwestern district of the East European platform, and in a contact zone of the platform with the Forecarpathian deflection. They are characterised by the long periods of preparation (until 70 years), insignificant speed of the initial displacement, and a fast active stage (up to 10–15 m/day). Volumes of the displaced material reach 30 million m^3.

Plastic landslides are distributed mostly in diluvium. This kind of landslides is developed as plastic deformations within all the investigated territory. The volume of plastic landslides changes from tens of thousand m^3 to 1 million m^3. The five-years-rhythm of catastrophic plastic activation of the landslides prevails.

As a result of the described research, three mechanisms of the mudflows development have been distinguished: 1) denudation, connected with aeration and displacement of its products as well as complete washout; 2) gravitation, connected with collapses, landslides, falls etc.; 3) accumulation, connected with accumulation fans, as well as with diluvium, proluvium and colluvium.

As far as phases of mudflows are concerned, the water-stone and clay-rock ones should be distinguished. Water saturation in a solid phase may reach up to 350–450 kg/m^3. In the Carpathians, there were 219 mudflow-water courses revealed. They have arisen after long rains, with downpours intensity of 0.85–1.25 mm/min. Annual removal of material by mudflow-water courses from an area exceeds 500–2400 m^3/m^2. It was revealed, that in the Carpathian region mudflows volume may reach up to 1000–25,000 m^3, and more rarely — about 100,000 m^3.

CONCLUSIONS

As a result of the described research, the methodological approach to studying natural disasters, on the base on constant working models, which reflect total conditions and factors of the development of geological environment, has been created.

Forecast of the catastrophic landslides and mudflows included several components: space, times, and a component, which defined mechanism, genesis, sizes, energy, and other peculiarities of the processes.

The spatial forecasts of the landslides and mudflows in the territories with different engineering and geological conditions have been prepared, mechanisms and dynamics of these phenomena have been analysed. The basin space forecast was based on special subdivision into engineering and geological districts, which are characterised by different parameters and scales.

Based on the complex evaluation of the development of natural disasters, an organization scheme of a regional monitoring system for the geological environment of the Carpathian region has been created.

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