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CHARACTERISTIC TYPES OF LANDSLIDES IN THE DURMITOR FLYSCH COMPLEX AREA

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ABSTRACT

The term "Durmitor flysch" was first introduced into the geological literature in 1948. Under this term, he refers to a powerful geological formation, formed at the transition from the Upper Cretaceous to the Paleogene. Its distribution begins from the northern Albanian table and the so-called Cukali zone in the south, through the central part of Montenegro and northeastern Herzegovina, and extends to central Bosnia and Mount Vlašić. It is named after the highly noticeable and extensive development of the southwest slopes of Mount Durmitor, while the best gradation of this formation and all modern geodynamic processes can be most clearly observed in the area of the Čemerno mountain pass in northeastern Herzegovina. The specific characteristics of this part of the Durmitor flysch complex will be the subject of this paper.

Keywords: *Durmitor flysch complex, instability, landslides, lithological formation*

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1. INTRODUCTION

The term "Durmitor flysch" was first introduced into the geological literature in 1948 [1]. Under this term, he refers to a powerful geological formation, formed at the transition from the Upper Cretaceous to the Paleogene. Its distribution begins from the northern Albanian table and the so-called Cukali zone in the south, through the central part of Montenegro and northeastern Herzegovina, and extends to central Bosnia and Mount Vlašić [1]. It is named after the highly noticeable and extensive development of the southwest slopes of Mount Durmitor, while the best gradation of this formation and all modern geodynamic processes can be most clearly observed in the area of the Čemerno mountain pass in northeastern Herzegovina. The specific characteristics of this part of the Durmitor flysch complex will be the subject of this paper.

The flysch sediments are characterized by a complex lithological composition, consisting of basal limestone breccias and conglomerates, limestones, aleurolites, marly limestones, clays, and mudstones, of various thicknesses and spatial orientations, which are distinguished in five superposed packages in this area.

These rock masses are characterized by specific engineering-geological properties, which are conditioned by the specific lithological composition. Therefore, this formation is distinguished by heterogeneous and anisotropic geotechnical properties, which depend on the prevailing lithological components in the complex, as well as the spatial position of the layer packages.

The formation of these sediments is associated with the Upper Cretaceous, specifically the Senonian stage (K_2^3), as presented on the OGK SFRJ map, publication Gacko [2], while this formation in the area of Montenegro is distinguished as Upper Cretaceous-Paleogene (K_2, Pg).

These lithological components were deposited under special sedimentary conditions and, as a result, occur as layers of varying thickness. Layers of different lithological composition are grouped into five superposed packages, in which the lithological components alternate rhythmically. These rhythms differ in composition, as well as in spatial distribution, which is the result of the geological composition of the basin area, the climatic conditions that prevailed during the sedimentary cycle, but also post-genetic, primarily tectonic, conditions in which these terrains were located.

Post-genetic tectonic activity caused the folding and faulting of these sediments, and intensified the process of thrusting Triassic limestones over the flysch formation. This further complicates the definition of the physical-mechanical parameters of these environments, as well as the engineering-geological conditions for the construction of road infrastructure and other building structures. In this context, the issue of ground stability, that is, the occurrence and type of instability, is extremely complex.

The specific climatic conditions that prevailed during the Pleistocene and Quaternary periods led to the formation of numerous glaciers in the studied area. Their melting during interglacial periods caused extremely intense erosion. Typical glacial landforms, such as cirques, waves, and moraines, were formed. The erosion process continued, resulting in the formation of numerous river valleys, including the Piva, Tara, Drina, Morača, Neretva, Sutjeska, and others, characterized by multiple levels of fluvioglacial terraces and accompanying erosional landforms.

Sedimentary conditions, as well as tectonic and erosional activity in this area, have led to the formation of various terrain structures [3].

Terrain construction represents a certain arrangement of natural environments, which can be characterized by different mechanical properties, but behave as a whole from a static point of view. The ultimate result of these processes has also led to the occurrence of various forms of instability [5]:

- In the superficial parts of the terrain, landslides of the consequent type are predominantly present. The sliding surfaces are generally formed at the contact between the weathered surface layer and the underlying rock (bedrock).
- During periods of intense precipitation (for example, in the Čemerno area, where the average annual precipitation is 1650 mm, often exceeding 2000 mm/m²), debris flows form, which are specific instability phenomena in the deluvial slope zone.
- On valley slopes, depending on the spatial position of the layers in the flysch packages, conditions are created for the formation of landslides. Their sliding surfaces are predisposed along interlayer surfaces, and these landslides are classified as consequent landslides according to F. P. Savarenski or extrusion landslides.
- Instabilities in the form of rockfalls are most often the result of anthropogenic activities, such as the creation of steep slopes during road construction, but can also occur later during exploitation. They are much less frequently caused by erosion or natural geological processes.

This study will focus on the impact of terrain construction types on the occurrence, types, and fundamental characteristics of ground instability. This is of exceptional importance not only during engineering-geological and geotechnical investigations for the purpose of stabilizing instability, but also in the context of preventive measures to prevent such occurrences during the construction of various structures.

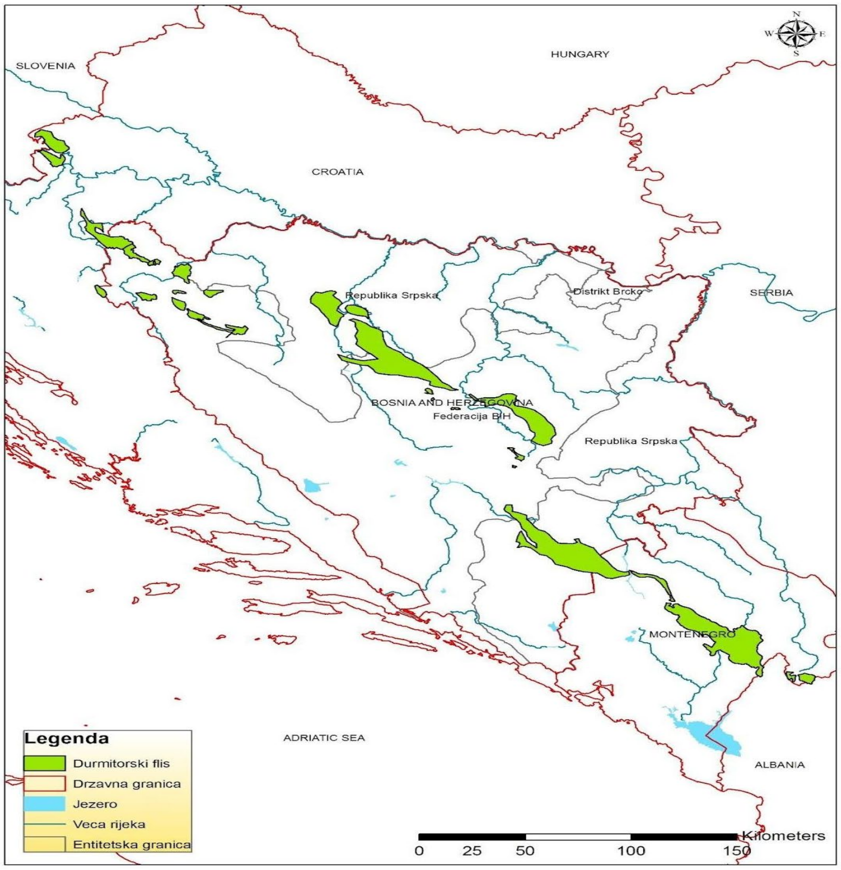

Figure 1. Distribution of the Durmitor Flysch Complex [4]

2. RESEARCH METHODOLOGY

During field research conducted for various construction purposes—primarily for the construction of the M-20 main road section from Vrba to Trnova Luka—state-of-the-art methods were applied both in the field and in laboratory conditions. Based on the results, a synthesis was conducted, and characteristic types of instability were identified.

Detailed engineering-geological mapping of the terrain was carried out, based on which numerous investigative works were located, both for the design of the M-20 road section and for the remediation of certain instabilities on the existing old part of this roadway, as well as additional investigations during the construction phase of the section itself.

A series of boreholes, test pits, and excavation works were conducted in the area of the "Čemersko Osoje" landslide. Additionally, a large number of boreholes were drilled for the installation of piles, which also served as investigative works. Certain geophysical investigations were conducted, along with a significant number of laboratory geomechanical, mineralogical, and petrological tests, as well as a series of engineering-geological and hydrogeological maps of specific localities where this formation is present—all with the aim of defining the conditions for potential activation of sliding processes or the formation of landslides.

A detailed analysis of precipitation data was also conducted, obtained from the "Čemerno" rain gauge station.

During the 1980s, extensive regional geological research was carried out, the final result of which was the Gacko map sheet of the Basic Geological Map (OGK) of the former SFRY, along with other OGK sheets covering this specific lithological formation in the territories of Montenegro and Bosnia and Herzegovina. This work resolved all uncertainties regarding the position and character of the superpositional units of this lithological formation, as well as their specific features in relation to the geodynamic activity of certain terrain segments.

3. GEOLOGICAL STRUCTURE OF THE AREA

3.1. LITHOLOGICAL COMPOSITION

The flysch complex was formed under conditions of mutual interaction between a terrestrial regime and the presence of a sedimentary basin. Surface flows and erosion of rocky masses in the terrestrial zone transport eroded material into the sedimentary basin, where the quantity and coarseness (granulometric composition) of the deposits depend on the precipitation regime. This is one of the reasons that contributed to the formation of lithologically heterogeneous rock masses, including the rhythmic alternation of breccia, conglomerates, limestone layers, aleurolites, marly limestones, mudstones, and clays. In [6], it is considered that three facies can be distinguished in the Durmitor flysch complex: carbonate, siliciclastic, and mixed. The siliciclastic facies is characteristic of the area covered by the OGK SFRJ sheet Gacko. During the creation of the OGK SFRJ sheet Gacko [2], this lithological formation was classified into five superposed packages (subunits) within the Senonian stage of the Upper Cretaceous (K_2^3):

1. **Basal limestone breccias and conglomerates ($^1K_2^3$)** have the largest distribution and thickness. The composition of the breccias and conglomerates depends on the underlying bedrock. They are most commonly composed of fragments and pebbles of Lower Cretaceous limestones. The diameter of the pieces, or fragments of limestone in the breccias and conglomerates, can reach up to 0.7 meters, and the binding material is carbonate [7].
2. **Layered breccias and limestones ($^2K_2^3$)** are distinguished as the second package, primarily composed of carbonate sediments. Coarse-grained limestone conglomerates and breccias appear in layers ranging from 2 to 5 meters thick. The binding material is marly and carbonate. The conglomerates in the geological column transition to medium-grained, and these to fine-grained layered limestone breccias. The breccias are made up of fragments of limestone, cherts, and marls [7].
3. **Breccias, limestones, and marls ($^3K_2^3$)** occupy the largest part of the space within this lithological formation. They appear in a wide belt conforming to the Dinaric trend (northwest-southeast). Limestone breccias occur in banks and layers. Their thickness varies, ranging from 0.5 to 10 meters. Over the breccias lie sandy limestones with layer thicknesses ranging from 0.25 to 0.5 meters. In the geological column, the sandy limestones grade into sandy marls, which in turn transition into grey-green to brownish, platy marls [7].
4. **The sandy marl series of the flysch ($^4K_2^3$)** is composed of microconglomerates, greywackes, aleurolites, and marls. This superposed package of the Durmitor flysch complex is characterized by very thin layers of individual components, which alternate and repeat multiple times within the geological column. It is marked by pronounced folds. The dimensions of the folds range from micro (centimeter-sized) to several hundred meters in length (macro). If a slope is made up of this package, landslides or

debris flows are most commonly formed, and such slopes should be treated as unstable or conditionally stable [7].

5. **Breccias, limestones, and marls ($^5K_2^3$)** represent the last, fifth package of the Durmitor flysch complex. It is predominantly composed of carbonate sediments. Within this package, there are coarse-grained limestone conglomerates and breccias, limestone breccias, marly limestones, and marls with lenses of cherts [7].

3.2. TECTONIC PROPERTIES OF THE AREA

Intensive tectonic processes occurred in this area in the geological past, primarily manifested through the thrusting of Middle Triassic massive limestones (T_2^1) over the Durmitor flysch complex [6]. In the studied area, the angle of thrusting ranges from 30° to 35°. The southern and southwestern margins of the Durmitor flysch exhibit erosional discordance.

- **Basal breccias and conglomerates ($^1K_2^3$ - 1 package)** are weakly stratified and have a general dip direction toward the northeast.
- **Breccias, limestones, and marly limestones ($^2K_2^3$ - 2 package)** also have a general dip direction toward the northeast. They are undisturbed, i.e., no folding process has been observed, and fault structures are represented by transverse and diagonal decameter-scale faults.
- **The package of layered stratified breccias, limestones, and marls** contains numerous meter-scale, decameter-scale, and hectometer-scale upright, inclined, and overturned folds, with limb lengths ranging from several meters to 500 meters. In some parts, the folds are upright, while in others, they are inclined. The axial planes are both upright and inclined. The vergence is southwestward, and the angle of vergence reaches up to 10°.
- Within the package ($^4K_2^3$) of conglomerates, aleurolites, marls, and clays, and the package ($^5K_2^3$) of intercalated breccias, limestones, and marls, numerous meter- and decameter-scale upright, inclined, overturned, and reclined folds have developed. The limb lengths range from 1 to approximately 10 meters. The terrain constructed by this package is largely covered with vegetation and deluvial deposits, so its development can be observed in streambeds and road cuts [4].

3.3. HYDROLOGICAL AND HYDROGEOLOGICAL PROPERTIES OF THE AREA

3.3.1. Hydrological properties

The area formed by the Durmitor flysch series in the studied part of the terrain is characterized by exceptionally high precipitation and significant temperature fluctuations throughout the year. The amount of precipitation and temperature variations represent key exogenous agents in the process of landscape formation. Moreover, these factors have a significant impact on the occurrence of terrain instability.

As an illustration of this impact, Table 1 presents the average annual precipitation recorded at the Čemerno rain gauge station, expressed in millimeters. ***Table 1****: Average Monthly Precipitation at the Čemerno Rain Gauge Station (Period according to the Meteorological and Hydrological Institute of Bosnia and Herzegovina)*

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	god
	125	130	160	170	130	100	70	70	125	180	220	170	1650

Temperature fluctuations are enormous both throughout the year and within a single day. The lowest recorded temperatures are around -40°C, while the highest are around 35°C. Such temperature ranges increase the intensity of surface weathering, significantly contributing to the mechanical disintegration of solid rock masses, which is crucial for terrain stability.

3.3.2. Hydrogeological properties

In hydrogeological terms, Quaternary eluvial-deluvial deposits, degraded aleurolites, clays, sandstones, and thinly laminated marls, which form during periods of heavy rainfall, represent a water-saturated environment. Under such conditions, physically bound water reduces the shear resistance parameters, adds additional load to the slope, and thus contributes to the activation of sliding processes. Free groundwater in the fracture aggregates of the pores contributes to pressure and circulation, leading to physical-chemical weathering and degradation of the underlying rock mass [8].

The sediments of the Durmitor flysch are mostly poorly permeable to impermeable rock masses. In the flysch sediments, the groundwater level lies within the zone of surface weathering (the eluvial–deluvial part), whereas in the Quaternary sediments overlying the flysch formation (alluvial plains and river terraces), it is directly connected to the water level in the watercourse.

According to the type of porosity, hydrogeological function, and position within the terrain, as well as the hydrogeological conditions of formation, the following categories of rock masses can be distinguished in the field:

- Hydrogeological collectors with intergranular porosity are composed of Quaternary sediment (Q), specifically alluvial, proluvial, and deluvial deposits.
- Relative hydrogeological collectors represent basal limestone breccias and conglomerates (${}^{1}K_2^3$), layered breccias, and limestones (${}^{2}K_2^3$). Depending on their spatial position in the terrain, they function as relative hydrogeological collectors of fissure porosity. These sedimentary packages do not contain large fractures with significant continuity.
- Rocks with combined fissure-intergranular porosity are represented partially by sediments from the third and fifth superimposed packages (${}^{3}K_2^3$, ${}^{5}K_2^3$), breccias, and limestones, while the clayey component of this package serves as a classic hydrogeological insulator.

Hydrogeological insulators, or impermeable rocks, are represented by the fourth superimposed package (${}^{4}K_2^3$), where the clayey component dominates. Upon contact with water, this component becomes saturated, and depending on its position within the structure, mass movement may occur along the slope.

4. CAUSES OF LANDSLIDES

Sliding is a complex slope movement process, most commonly involving disintegrated and weakly bound rock masses, along a clearly defined shear surface, known as the sliding surface. A portion of the rock masses that, due to various factors, move by shearing down the slope without detaching from the underlying material is called a landslide, or the body of the landslide [8].

According to [3], the most widespread criterion for determining landslides is the lithological criterion, which involves defining geological environments [8].

Terrain sliding can be a natural process, but it can also be a process aided by anthropogenic activities. The natural process occurs when a landslide is activated under entirely natural conditions.

Main causes of landsliding:

- Slope of the terrain
- Disintegration of rock masses and saturation of the surface layer with atmospheric water during heavy precipitation or snowmelt.
- Increase in the hydraulic gradient of groundwater due to a sudden drop in water levels in a nearby river course.
- Undermining and removal of the lower parts of the slope due to river erosion or the action of waves from standing waters (lakes and seas).
- Seismic activity.

Anthropogenic influence occurs when certain construction works disrupt the primary geostatic conditions of the terrain [9].

5. MAIN TYPES OF LANDSLIDES IN THE DURMITOR FLYSCH

The Durmitor flysch complex in the area of Bosnia and Herzegovina consists of five superimposed packages of flysch sediments, which differ from each other in terms of lithological composition, hydrogeological, and geomechanical properties. Within each package, individual sequences also show variations in these characteristics.

The most typical development of this geological formation is found in the area of the Čemerno mountain pass, on the southeastern slopes of Zelengora. The sliding process is particularly pronounced in the fourth and fifth superimposed packages (${}^{4}K_2^3$ and ${}^{5}K_2^3$).

6. LANDSLIDES CAUSED BY THE CONTACT BETWEEN DELUVIAL DEPOSITS AND BEDROCK

The fundamental prerequisites for the formation of this type of landslide include the presence of thicker layers of deluvial formations, a greater amount of atmospheric water, and the slope of the terrain.

A typical example of this type of landslide is the Mušnica landslide [4].

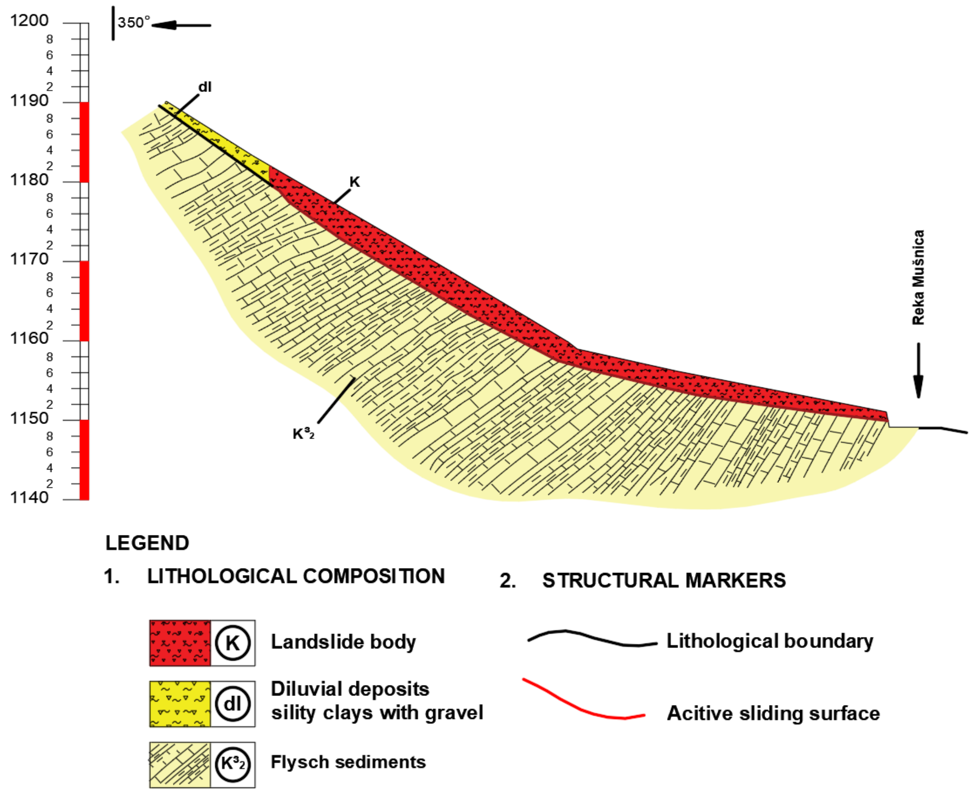

Figure 2. Cross-section of the terrain at the Mušnica landslide [4]

6.1. LANDSLIDES CAUSED BY UNFAVORABLE STRUCTURAL POSITION OF THE ROCK MASS

Flysch sediments have been subjected to continuous tectonic movements throughout geological history to the present day, resulting in pronounced folding of sediments, often accompanied by microfolds and frequent changes in their structure.

As a result, on the same slope, parts of the terrain exposed to the active landslide process can coexist with completely stable areas. Typical examples of such phenomena are the Ždralov Potok landslide [10] and the Čemersko Osoje landslide.

If the position of the interlayer surfaces is parallel to the slope, the sliding plane forms precisely along the interlayer surface, with the clayey sequence of the flysch formation most often serving as the sliding zone. On the other hand, if the layers are tilted in the opposite direction to the slope, those areas remain stable and are not susceptible to the landslide process.

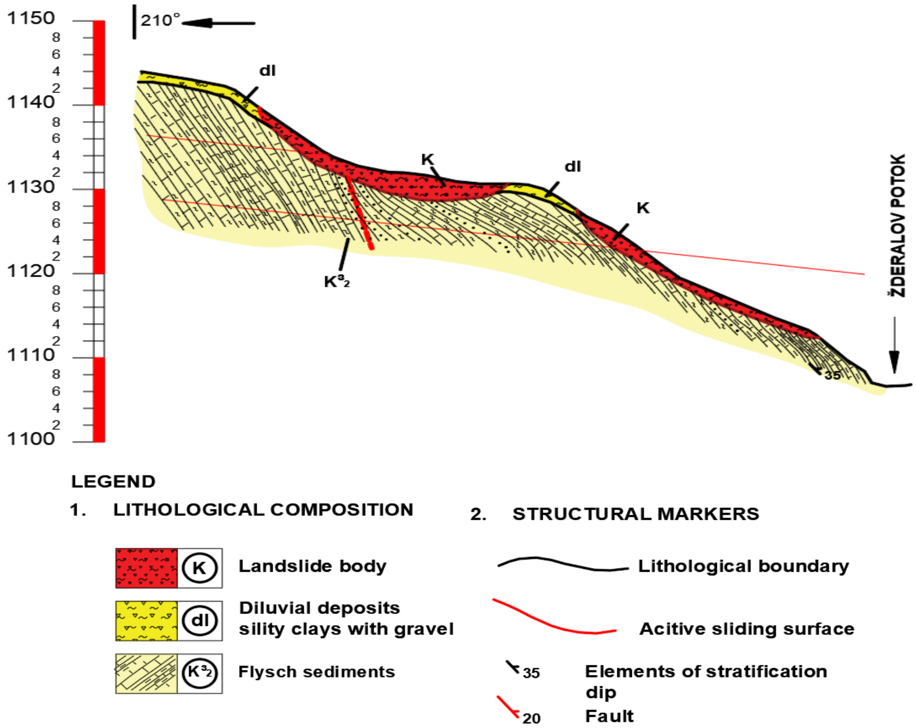

Figure 3. Cross-section of the terrain at the Ždralov Potok landslide [4]

7. DISCUSSION

This paper presents two characteristic types of landslides, with clearly defined conditions of their formation. The causes of landslide formation or activation can be categorized into geological, geomorphological, physical, and anthropogenic factors.

The geological conditions for landslide formation are inherent in the rock masses themselves, in the manner and conditions of their formation, and in their physical-mechanical properties, which reflect their ability to react more quickly or slowly to external destructive agents.

The first type of landslide occurs along the contact between Quaternary deposits and the underlying rock mass, whereas the second type of landslide develops so that the sliding surface follows the structure of the rock mass. Flysch, a highly heterogeneous and plastic medium, is characterized by alternating thin layers of siltstone, limestone, and marl, formed in a shallow lacustrine sedimentary basin. Therefore, each marly component, depending on the structural position, can be a potential sliding plane.

Geomorphological conditions are related to the morphogenetic development of the slope, that is, the shaping of the relief under the influence of current exogenous processes.

Physical or climatic conditions are associated with the amount of precipitation and with the sudden freezing and melting of snow.

Anthropogenic activity—or human activity—is the most common cause of landslide activation. In addition to their frequent occurrence, these landslides are characterized by the rapid and uncontrolled development of the process, which often leads to serious consequences for residential and infrastructural structures.

8. CONCLUSION

The Durmitor flysch complex, as a lithological formation, is most clearly developed in the area of the Čemerno mountain pass, specifically on the southeastern slopes of Zelengora, and further extends northwestward towards the central parts of Bosnia and Herzegovina.

Within this lithological formation, a large number of landslides have developed, mostly in areas built up by the fourth superimposed package ($^{4}K_2^{3}$), while the fifth package ($^{5}K_2^{3}$) is represented to a lesser extent. The natural predisposition of these sediments to activate contemporary geodynamic processes, combined with anthropogenic influences, creates "ideal" conditions for the initiation of landslide processes.

In the previous chapters of this paper, all key prerequisites for landslide formation have been described, and two characteristic types that dominate in this formation have been identified. A thick weathering crust, an unfavorable structural position (where the layers' dip is parallel to the slope), and the influence of anthropogenic processes (such as road construction) lead to the activation of slope processes, i.e., the movement of rock masses down the slope.

The dynamics and direction of the movement of these masses depend on the slope's inclination, its shape, the amount of mass mobilized, and the hydrological conditions.

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КАРАКТЕРИСТИЧНИ ТИПОВИ КЛИЗИШТА У ПОДРУЧЈУ ДУРМИТОРСКОГ ФЛИШНОГ КОМПЛЕКСА

Сажетак: Термин „Дурмиторски флиш“ први пут је у геолошку литературу уведен 1948. године. Под овим термином исти подразумева снажну геолошку формацију, насталу на прелазу из горње креде у палеоген. Њена распрострањеност почиње од сјеверне Албанске плоче и такозване Чукалијеве зоне на југу, преко централног дијела Црне Горе и сјевероисточне Херцеговине, и протеже се до централне Босне и планине Влашић. Име је добила по веома уочљивом и опсежном развоју југозападних падина планине Дурмитор, док се најбоља градација ове формације и сви савремени геодинамички процеси најјасније могу уочити у подручју планинског превоја Чемерно у сјевероисточној Херцеговини. Специфичности овог дијела Дурмиторског флишног комплекса јесте предмет овог рада.

Кључне ријечи: дурмиторски флишни комплекс, нестабилност, клизишта, литолошка формација