EVALUATION OF RELATIONSHIP BETWEEN LANDSLIDES AND GEOLOGIC CHARACTERISTICS IN CENTRAL PART OF THE REPUBLIC OF MOLDOVA

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Abstarct *The article is dedicated to studying landslide distribution patterns and to assessing landslide development using fine-resolution remote sensing data and GIS technologies. There were obtained digital models of geological structure of the study area and key sectors. There were shown up dependency of the landslide development on geological conditions of the territory.*

Keywords: *landslides, geological conditions, GIS, Codri Hills, Republic of Moldova*

1. Introduction

Landslides in the Republic of Moldova are very common. They generally occur more frequently in the plateau and hilly regions of the country. For example, in the Central Region of the Republic of Moldova, known as Codri Hills or Bîc Hills, landslides annually cause damage to property, destroy houses, roads, industrial objects, agricultural lands, and so forth. In the Republic of Moldova, in the period of 1970 and 2005, annual growth of landslide area reached up to 1000 ha; in this time period Bîc heights had the highest frequency of landslides: 40-50 landslides/100 km^2.

Present work is elaborated within the project “Landslide susceptibility assessment in Central Part of Republic of Moldova”, supported by NATO within Science for Peace and Security Programme (Award No: SfP-983287) (launched on March 25, 2009), which is being realized at the Institute of Ecology and Geography MAS within Landscape Science and Dynamic Geomorphology labs, in collaboration with Geological Engineering Department of Hacettepe University, Ankara, Turkey. The project’s general objectives are the following:

- Elaboration of the methodology of landscape studying, using remote sensing and geoinformation technology methods;
- Landslide inventory and description;
- Landslide causes assessment;
- Elaboration of landslide susceptibility map of the Bîc heights, using various methodologies, and assessment of their performance;

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- Providing information for the Project's end-user (Civil Protection and Emergency Situations Service) with the purpose of taking decisions and proposing recommendations on diminishing landslide impact on economy, environment and human lives [5].

In present work we will analyze the way how geological characteristics influence appearance and evolution of landslides with the aid of simple GIS principles.

2. Object of study and methods

Central part of the Republic of Moldova, mainly including Codri Hills or Bîc's Codri Hills, was selected as the study area (fig. 1). It is the country's biggest heights unit, where maximal altitude reaches 429 m (Bălăneşti Hill). This geomorphologic unit has the highest relief energy, which exceeds 250-300 m, having in such a way an aspect of low mountains. Intense fragmentation, against predominance of the slopes with angles of about 7°-8° and constituted of the clayey-sandy rocks with acquifer complexes, contribute to development of the extremely large landslides, which cover considerable areas. Frequently, landslides affect settlements, industrial objects, agricultural lands, roads and railways, etc.

Landslide distribution assessment can be performed in different ways. There are known many classification schemas with regard to landslide causes. For example, U.S. Department of the Interior U.S. Geological Survey (Fact Sheet 2004-3072, July 2004) groups them into three categories:

1. Geological;
2. Morphological;
3. Human causes.

On Moldova's territory, first assessments of landslide distribution depending on geological factors were made in the early XXth century by O.K. Lange (1916) and F.S. Poruchik (1917). In 1960-1970 there appear a set of published works [28, 29, 26, 35] in which there were analyzed ways how geological structure and hydrogeological particularities influence on landslide emergence and evolution.

The specificity of geological structure was analyzed on the basis of medium-scale geological map, bibliographical sources and field research. For assessing the role of disjunctive tectonics in the appearance and dynamics of various landslide categories, there were analyzed geological map, landslide distribution map and tectonic map.

The objective of this study consists in the assessment of distribution pattern of the landslides depending on geological characteristics of the Codri Hills.

Geological causes include:

A. Weak or sensitive materials

B. Weathered materials

C. Sheared, jointed, or fissured materials

D. Adversely oriented discontinuity (bedding, schistosity, fault, unconformity, contact, and so forth),

E. Physical characteristics such as permeability, stiffness of the materials

F. Earthquakes.

In this work we show some preliminary GIS-related results of our work. Using of geoinformation technologies has allowed us developing spatial model of geological structure of the study area (Figure 1). We used 1:200 000 geological map of the Republic of Moldova, elaborated by “Moldavgeologia” in 1988 (Ob’yasnitel’naya zapiska, 1988) as reference material. Tectonic map by A. Drumea et al. (1978) was used for creation of spatial model of tectonic structure of the study area.

3. Results

If overlaid landslide locations and the lithologic units in GIS environment, it reveal that the landslides in central part of the Republic of Moldova develope in Neogene and Pleistocene rocks. In general, the territory between Dniester and Prut rivers (Figure 1) has in its geologic structure, mainly, platform features, except for a small area in the south, where northern slope of Dobrogea folded construction can be identified [21]. Ryphean, Paleozoic, Mesozoic and Cenozoic rocks contribute to geological composition of national territory; they have different completeness and are represented unevenly within the country’s territory.

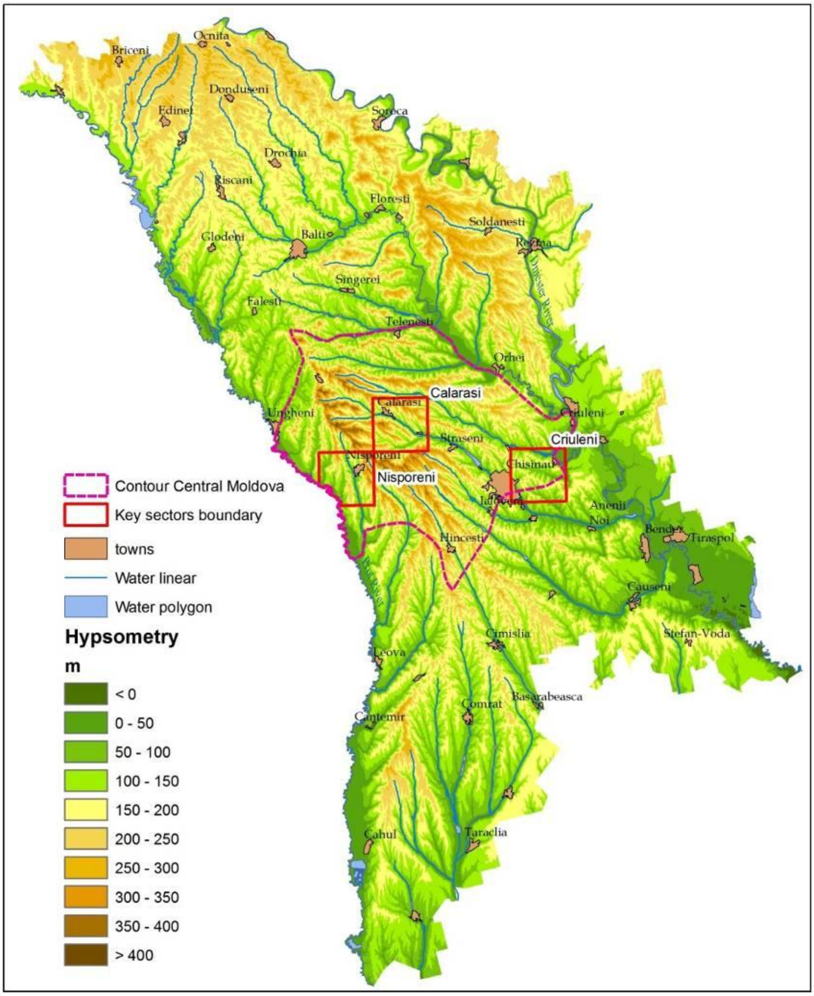

Figure 1. Region of the study and key areas location

In the north-eastern part of the country, such crystalline rock outcrops as gneisses, gabbros, and various granitoids exist. To the south-west, the foundation is covered by progressively increasing strata of sedimentary rocks of various compositions and ages. Their thickness reaches 4000 m in the south, on northern slope of Pre-Dobrogean depression [21]. Bedding depth of foundation rocks within study area is about 1300 m.

Ryphean-Paleozoic and Mesozoic deposits outcrop just in the northern part of the country and do not contribute to landslide occurrence.

Neogene deposits have the most significant role in landslide development; they are outcropped by erosion network. Neogene rocks are represented by various facieses, ranging from marine to continental. They are divided in two series: Miocene and Pliocene. These rocks are transgressively bedded on the Cretaceous, Jurassic and Paleogene deposits, burying to south-west. The thickness of these deposits constitutes 400 m in the northern part of the study area and about 600 m in the south.

Miocene deposits are represented by various limestones, clays, marls, sands, sandstones, aleurites, and are divided into middle and upper subseries.

Middle Miocene subseries are represented by the deposits of ***Badenian regional stage***. According to the numerous investigations performed through drilling, grey clayey limestones, volcanogenic sandy clays, quartz sandstones, limestones and gypsum with subordinated intercalations of clays bed on Upper Cretaceous sandstones. In the study area, these deposits do not outcrop and do not contribute to landslide occurrence.

Upper Miocene subseries are represented by marine Sarmatian and Meotian rocks, as well as by their continental analogues.

Sarmatian deposits represent polyfacial strata. Their thickness increases from north-east to south-west, where it reaches 380 m. These deposits are divided into three substages: *Volhinian* (N_1s_1)*, Bessarabian* (N_1s_2) *and Khersonian* (N_1s_3).

Volhinian deposits consist of various limestones and, partly, marls, clays, sands and sandstones; their thickness varies from 20 to 50 m and increases under the reefs up to 110 m [27, 24]. They outcrop along the Dniester and Prut valleys, as well as in all its tributaries from extreme north southwards until the latitude of Orhei town. To the south, these deposits are bedded under the erosion base level. Clays are represented by light-grey, dark-grey, rarely by brown thinly laminated differences of aleurite-pelite and pelite structure. Stratification is conditioned by the intercalation of clayey and sandy materials.

	Index	Erathem	System	Series	Subseries	Stage	Substage
	N2ak	Cenozoic	Neogene	Pliocene	Upper	Akchagylian	
	N2k+ak	Cenozoic	Neogene	Pliocene	Middle-Upper	Kimmerian-Akchagylian	
	N2k	Cenozoic	Neogene	Pliocene	Middle	Kimmerian	
	N1h-m	Cenozoic	Neogene	Miocene	Upper		
	N1h	Cenozoic	Neogene	Miocene	Upper	Sarmatian	Khersonian
	N1bs2	Cenozoic	Neogene	Miocene	Middle	Sarmatian	Bessarabian
	N1bs1	Cenozoic	Neogene	Miocene	Middle	Sarmatian	Bessarabian
	Landslides						

Figure 2. Geological structure of the study area
(Note: Akchagylian=Romanian, Kimmerian=Dacian)

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Bessarabian deposits are spread out on the entire country's territory. They are represented by clays, aleurites, sands, limestones. Their thickness increases from east to west, achieving maximal values of 360-370 m. Clays are represented by yellowish-grey, steel-blue, dark-grey differences with thinly and latently laminated texture and pelite, aleurite-pelite structure

Bioherm rock masses along the line Camenca-Orhei-Chişinău-Ialoveni were formed by a barrier reef in Early Bessarabian; they divide study area in two structural-facial zones: eastern and western [33]. To the east of the barrier reef belt (Orhei-Chişinău-Ialoveni), the role of the limestones in the geological section increases. Bessarabian rocks compose valley slopes in central part of the country. To the south from the line Cărpineni-Hînceşti-Bender, they plunge below the erosion base level.

Depending on the character of Bessarabian deposits, there are two rock masses, which correspond to two marine transgressions in Early and Late Bessarabian [33].

Khersonian deposits are spread in central part of the country and are attributed to different facieses: shallow marine, delta-front and continental [34]. Marine facieses are composed of clays, aleurites and sands with subordinated layers of limestones; delta-front facieses are predominantly constituted of sands, frequently with oblique stratification; lacustrine and lagoonal facieses are dominated by cloddy clays with rare intercalations of sands and aleurites and thin intercalations of brown coal. The clays are yellow and greenish-brown. Upper Sarmatian deposits constitute valley slopes on the territory limited to the north by the latitude line passing northwards from Chişinău municipality. They form certain slope parts of the Bîc valley around Vatra town, slopes of the Hulbocica stream, upper slope parts and interfluves in the lower course of Bîc, Ichel and Dniester rivers.

Khersonian rocks form quite abundant aquifers, discovered in Prut River valley southwards from Ungheni town, in Dniester River valley between Soroca and Dubăsari towns and from Bender city to the mouth, as well as in river valleys of Dniester tributaries Bîc and Botna.

Meotian deposits have been reliably determined in the south-western part of the country. They are represented by grey and greenish-grey clays and aleurites with greenish-grey and rust-brown spots, clays with intercalations of aleurites and sands. Meotian deposits are bedded almost everywhere below the modern erosion base level, and, therefore, they neither participate in slope composition, nor in exogenous slope processes.

In central and, partly, southern part of the Republic of Moldova, alluvial deposits of Balta suite are widely spread; they form a rhythmic rock mass of sands with oblique stratification and lenses of sandstones and cloddy clays [22]. Rhythm's thickness varies from 5 m to 25 m; genetically, each rhythm represents a complete alluvial cycle. There are up to eight such rhythms. The rocks of Balta suite, dated to *Upper Bessarabian substage – Meotian stage*, are up to 150 m thick, sometimes up to 190 m, and play significant role in slope composition; therefore, they constitute the environment for development of the majority of exogenous geologic processes.

Upper Sarmatian-Meotian aquifer is confined to the deposits of this stage; its main reserves are located in the Prut River valley southwards of the Ungheni town.

Pliocene series are represented by various facieses of the Upper Pliocene subseries: lacustrine-fluvial and subaerial formations. Lacustrine-fluvial formations are spread out more largely and are represented by Pliocene terraces of the Danube, Prut and Dniester rivers. Their thickness is about 60 m.

In the study area, Pliocene cross-section is represented by alluvial formations of the upper terraces of the Prut, Dniester and Răut rivers. Total thickness of Pliocene deposits reaches up to 200 m.

These series' rocks form the Middle-Upper Pliocene aquifer, whose main reserves are contained in the Prut valley southwards of Ungheni town.

Quaternary deposits are spread out, practically, on the entire country's territory. They are bedded on uneven surface of older deposits. These rocks are represented by alluvium (pebblestones, gravel, sands, clays) of *Eopleistocene* terraces and *Holocene* deposits in floodplains and cover deposits (loams, loess-type loams, sandy loams, in some areas with fossils, slack, detritus, landslide accumulations). Cover formations interlap interfluves, slopes and river terraces alluvium in the form of mantle. Their area and thickness have an increasing north-south trend. However, in the regions with positive neotectonic movements, thickness of these formations is low. In the areas with negative vertical movements their thickness reaches up to 30 m.

Distribution of various lithologies in the study area is given in Figure 3.

In order to assess region's landslide susceptibility, three key sectors were selected: Nisporeni, Călăraşi and Criuleni with total surface of 1019 sq. km, situated in different, but characteristic to the entire study area, geological and geomorphologic conditions [5].

Geologic structure of the Nisporeni sector

Prut River's floodplain, lower and middle part of the slopes, floodplains and slopes of the first, second and third Prut's tributaries, floodplain and lower slope parts of Nîrnova River are composed of *lower Bessarabian rocks*, in which three rock bundles are evidenced. The lower bundle is mainly clayey, the middle one is represented by intercalations of clays, sands and aleurites, the upper one is sandy. Deposits' thickness largely varies between 30 and 190 m. It is worthy of mentioning that third bundle's deposits remain just within Codri Hills, and their thickness can achieve 40-45 m [25, 27]. The upper boundary of these deposits is located at the altitudes of 150-175 m.

Middle and upper slope parts of the Nîrnova River, certain slope parts of the Prut's tributaries are represented by *upper Bessarabian rocks* composed of sands, aleurites and clays with thin intercalations of oolitic and shell limestones. Their thickness sometimes reaches up to 80 m.

Upper slope parts and interfluves between Nîrnova and Lăpuşniţa rivers, upper parts of the interfluves between Nîrnova River and small Prut River's tributaries are represented by rhythmically composed sandy-clayey rocks of *nonsegmented Khersonian-Meotian strata*. Each rhythm starts with medium-grained quartz sand, which is progressively replaced by fine-grained one. The sand is crossbedded and contains sometimes limestone lenses. Upwards the cross-section it passes into fine-grained clayey sand and aleurite. The rhythm's top is formed of cloddy clay.

The highest interfluves between Nîrnova and Lăpuşniţa rivers in the north eastern part of the sector are represented by alluvial deposits of *lower Middle Cimmerian strata*. They are represented by Mileşti horizon (XVIth Pra-Prut terrace above the floodplain) – intercalations of sands, clays and aleurites. Thickness of the intercalations varies between 2 and 15 m [13]. This horizon is represented by two facieses: in-stream and floodplain. Sands are fine- and medium-grained with lenses of various-grained ones, incorporating rare grains of Carpathian jasper; the sands are loose, rarely semiconsolidated. Clays are compact, aleuritic, with many sliding surfaces. Clayey aleuritic sands are also present. Aleurites are clayey, compacted; sometimes they represent intercalations of up to 3-4 m thick. Average altitude of the deposits' base constitutes 360-375 m.

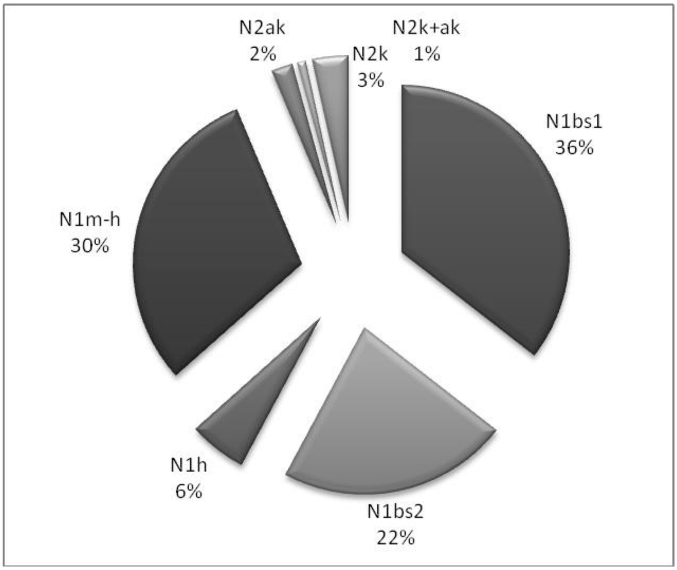

Figure 3. Distribution of different lithologies within the study region

Lower parts of the interfluve between Nîrnova and Lăpuşniţa rivers, the highest part of the interfluves between Nîrnova River and Prut River tributary are composed of the deposits of *upper Middle Cimmerian strata*. They are represented by Floriţoaia Nouă horizon (XVth Pra-Prut terrace above the floodplain) and are composed of sandy-gravel-pebble deposits, which include 0.1-0.5 cm pebbles of Carpathian jasper, Vendian sandstone and aleurolites, Cenomanian flints, metamorphic and intrusive rocks [25, 15]. Altitudes of the base vary between 270-280 m.

On the interfluves between Nîrnova River and the third Prut River tributary there are located alluvial deposits of the *nonsegmented Upper Cimmerian-Lower Akchagylian deposits* (XIIIth (Musait) Pra-Prut's terrace), which are represented by intercalations of sands and clays 2-13 m thick [15]. Total thickness of these deposits exceeds 60 m. Sands have various fineness with grains of jasper and aleurite intercalations. Sometimes sands are water-bearing. Clays are plastic, thinly laminated, in fissures. Altitudes of the base constitute 220-235 m.

Interfluves of Prut and Nîrnova tributaries represent alluvial terraces attributed to *Akchagylian regiostage*, divided in three regiosubstages.

Lower Akchagylian is composed of alluvial and subaerial deposits of *Cîşliţa-Prut horizon* (XIIth Pra-Prut's terrace above the floodplain) [2, 13, 12]. Seven bundles of intercalations of sands, pebble stones and clays are determined in these deposits. Thickness of sand layers, predominantly fine-grained, varies between 1.5 and 10 m, thickness of sandy, cloddy clays is 0.5-3.0 m; total thickness of the deposits constitutes 36 m [32]. Altitudes of the base vary between 200 and 220 m.

Interfluves of the Prut River tributaries are composed of *Buciumeni horizon* deposits with alluvial and subaerial formations attributed to XIth Pra-Prut's terrace above the floodplain [25, 13, 20]. These strata are predominantly composed of sandy-gravel deposits, fine-grained sands, floodplain aleurites, sandy clays. Sand strata's thickness varies between 1 and 4 m, clays are 1 m thick. Total thickness of this horizon is about 10 m.

Deposits of the Xth Pra-Prut's terrace above the floodplain (*Manta horizon*) are attributed to *Upper Akchagylian regiosubstage* and compose southern parts of the Prut River tributaries. They are separated from the lower terrace by a shoulder 15-20 m high. Terrace deposits are presented by medium- and fine-grained sand with gravel and pebbles of Carpathians jasper, Vendian sandstones and aleurolites [27]. They are bedded on the Upper Sarmatian rocks, whose altitude constitutes 125-130 m.

Geologic structure of Criuleni sector

Dniester and Ichel rivers floodplains are composed of *lower Bessarabian deposits*, represented by pelitomorphic, oolitic and foraminiferal limestones. Their thickness does not exceed 10 m. Limestone and silica clay rocks, are intercalated by limestones, marls and clays. Thickness of these deposits reaches up to 15 m. [16, 11]

Bottom parts of valleys, floodplains and lower parts of slopes of Dniester River tributaries are composed mainly of limestones with intercalations of sand and clay of *upper Bessarabian deposits*, 40 m thick.

Middle and upper slope parts of Bîc and Ichel interfluves are represented by *Khersonian deposits*: mainly sandy-clayey rocks with intercalations and lenses of shell limestones. Thickness of these deposits sometimes achieves 100 m.

Interfluves are composed of sandy-clayey *nonsegmented Khersonian-Meotian deposits*. Each rhythm starts with medium-grained quartz sands, which are progressively replaced upwards by fine-grained ones. Sands are cross-bedded and contain sometimes limestone lenses. Upwards within cross-section they pass into fine-grained clayey sands and aleurites. There are up to 8 such rhythms.

Interfluves of the sectors, neighboring Dniester River, represent alluvial terraces. They are attributed to *Middle Akchagylian regiosubstage* and form *Bălţata horizon* with alluvial and subaerial deposits of XI^{th} terrace above floodplain [27]. Mainly, they are sandy-gravel deposits with separate boulders of Vendian sandstones of 5-10 cm in size, bluish-gray fine-grained sands, pale-yellow floodplain aleurites. Total thickness is about 20 m.

Deposits of X^{th} Dniester's terrace above floodplain (*Fîrlădeni horizon*) are attributed to Upper Akchagylian regionsubstage [18, 10]. They are separated from the below terrace by the clearly visible shoulder 15-20 m high. They are bedded on Upper Sarmatian rocks. They represent terrace deposits of fine- and medium-grained sand with gravel and pebble of Carpathians jasper, Vendian sandstones and aleurolites.

Geologic structure of Călăraşi sector

Floodplain, lower part of Bîc valley slopes and Bîc's tributaries are composed of *Lower Bessarabian deposits*, in which three bundles show up. The lower bundle is mainly clayey, the middle one represent intercalations of clay, sand and aleurites, the upper one is sandy. Thickness of these deposits varies within large limits from 30 to 190 m [1, 11, 6]. Their roof is located at the altitudes of 150-175 m.

Middle part of Bîc valley slopes and Bîc's tributaries are represented by *Upper Bessarabian deposits*, constituted of sands, aleurites and clays with thin intercalations of oolitic and shell limestones. Their thickness reaches up to 80 m.

Upper part of slopes and lower interfluve sectors are composed of rhythmical *non-segmented sandy-clayey Khersonian-Meotian deposits*. Sands are cross-bedded and contain sometimes lenses of sandstones. Upward within cross-section they pass into fine-grained clayey sands and aleurites. The rhythm ends by cloddy clays. Maximal thickness of the strata reaches 190 m.

The highest sectors are composed of *lower Middle Cimmerian alluvial deposits* [17, 11]. They are represented by *Stolniceni horizon* (XVIth Pra-Dniester's terrace above floodplain). Anisomerous sands with gravel lenses and small pebble conglomerates 3-10 m thick represent in-stream facies [14]. Floodplain clays are compact and aleuritic. Total thickness of these deposits is 30-50 m [16]. Relative height of the base constitutes 280-310 m.

Bîc-Ichel interfluves are composed of *upper Middle Cimmerian deposits*. They are represented by *Călăraşi horizon* (XVth Pra-Dniester's terrace above floodplain) and consist of in-stream sandy-gravel-pebble deposits, which includes pebbles of Carpathians jasper and black siliceous rocks, like menelite slates 4-7 m thick [13]. Floodplain facies is represented by semicompacted aleurites 2-2.5 m thick and cloddy clays 1-1.5 m thick. In the majority of cases sands outcrop and are covered just by soil. Altitudes of the surface constitutes 295-305 m.

On the sector of Răcătău-Bucovăţ interfluve, of Bîc tributaries, there were revealed *Hruşova horizon* deposits of the *Middle Akchagylian regiosubstage* with alluvial and subaerial rocks attributed to XI*th* Pra-Dniester's terrace above the floodplain. Mainly, they are represented by sandy-gravel strata, small- and fine-grained sands, floodplain aleurites, sandy clays. Sand strata thickness is 12 m, clays are up to 1 m thick. Altitude of the base varies between 160 and 170 m.

Particularities in landslide distribution within key sectors

Within Nisporeni key sector there have been identified 100 landslides of various types. The great majority (85%) of the landslides here, as well as in Călărași key sector, are formed on the slopes composed of Bessarabian rocks: 48% of landslides are located in lower Bessarabian strata, while 37% - in the upper ones. Landslides in lower strata are more numerous and have slightly bigger area (landslide's average area constitutes 19 ha), which increases their share in total landslides' area. Landslides are also mentioned in the deposits of non-segmented Khersonian-Meotian strata as well as in Akchagylian ones (Table 1).

Table 1. Association of landslides by geological complexes (Nisporeni key sector)

Geological complex	Geological index	Number of landslides	Total area, ha	Average area, ha
Lower Bessarabian strata	N_1bs_1	49	944	19
Upper Bessarabian strata	N_1bs_2	37	413	11
Nonsegmented Khersonian-Meotian strata	N_1h-m	13	121	9
Akchagylian strata	N_2ak	2	2	1

Wihin Criuleni key sector there were revealed 34 landslides of various types. Their majority (73%) is located on the slopes composed of Khersonian deposits. The number of landslides is 5 times less within upper Bessarabian strata. However, landslides in Bessarabian strata are almost 2 times bigger (average area is of 27 ha) than those in Khersonian ones (13 ha). Besides these deposits, landslides have also been identified in nonsegmented Khersonian-Meotian strata as well as in Akchagylian deposits (Table 2).

Table 2. Association of landslides by geological complexes (Criuleni key sector)

Geological complex	Geological index	Number of landslides	Total area, ha	Average area, ha
Upper Bessarabian strata	N_1bs_2	5	135	27
Khersonian deposits	N_1h	25	324	13
Nonsegmented Khersonian-Meotian strata	N_1h-m	3	15	5
Akchagylian strata	N_2ak	1	1	1

Within Călăraşi key sector there were identified 106 landslides of various types. Their majority (74%) is located on the slope sectors, composed of Bessarabian rocks: 22% of the total number of landslides is linked to lower Bessarabian strata, while 52% is located within upper ones. Comparing their size, upper strata's landslides are slightly bigger (average area is of 23 ha), which is reflected in their increased share in total landslide area. The number of landslides within non-segmented Khersonian-Meotian strata is also significant (23%). Besides these deposits, landslides in Călăraşi key sector have been identified within Cimmerian deposits (Table 3).

Table 3. Association of landslides by geological complexes (Călăraşi key sector)

Geological complex	Geological index	Number of landslides	Total area, ha	Average area, ha
Lower Bessarabian strata	N_1bs_1	23	351	15
Upper Bessarabian strata	N_1bs_2	55	1258	23
Nonsegmented Khersonian-Meotian strata	N_1h-m	25	447	18
Cimmerian strata	N_2k	3	8	3

From the viewpoint of the mechanism of movement, complex landslides of translational-earthflow type are dominating. They are usually big, reaching up to 30-40 ha in surface. Translational landslides are less frequent, as well as small earthflow ones. General data, totalizing the information within all the key sectors, are represented in Table 4.

In what follows we add some statements to the relationship between landslide and disjunctive tectonics.

Geological researches of the late XXth century have allowed detailing structural specificity of the upper part of Moldavian Platform's sedimentary mantle. Investigations show up existence of the two main systems of tectonic deformations (Figure 4): dominant system, oriented NW-SE, represented by tectonic faults parallel to East Carpathians and the system oriented NE-SW, perpendicular to Carpathians.

Table 4. Association of landslides by geological complexes within 3 key sector

Geological complex	Geological index	Number of	Total area,	Average
Lower	N_1bs_1	72	1295	18
Upper	N_1bs_2	97	1806	19
Khersonian	N_1h	25	323	13
Nonsegmented	N_1h-m	41	582	14
Akchagylian	N_2ak	3	3	1
Cimmerian	N_2k	3	8	3

Significant influence of disjunctive structure (tectonic faults and fissures) on landslide development and dynamics in the Republic of Moldova has been mentioned by many authors [3, 4, 30]. Remote sensing outcomes have allowed obtaining reliable data on the share of landslides within the areas of tectonic faults Călăraşi and Bucovăţ etc. The influence of the faults and high degree of tectonic fissuring on landslide development and dynamics is explained through clayey rock resistance to movements on the slopes; this process is being favored by considerable increase of the humidity of the landslide body.

Existence of the fissures in clayey rocks contributes to both diminishing their hardness and facilitating penetration of water into the rock mass. As a result, hydrostatic and hydrodynamic pressures of water on the rock increase; clays swell, especially montmorillonite ones, presented in Codri Hills. In the fault area, besides superficial landslides, massive landslides are present; they can be attributed to the category of rotational landslides. Thus, landslides in the Mălăeşti village area, on the left bank of Dniester River within Criuleni key sector, landslides in the area of Pocşeşti and Vorniceni villages within Călăraşi key sector are the examples of rotational landslides. Their appearance is explained by highly fissured rocks [4].

An important role in landslide development is played by seismic processes [29, 4]. The last author shows on the map (pag.124) appearance of about 40 new landslides (19 of them are located in the Central Moldova) as a result of the earthquake of 7.3 degree Richter occurred on March 4, 1977 with epicenter located in Vrancea Mountains (Romania), 200-250 km south-west from the study area.

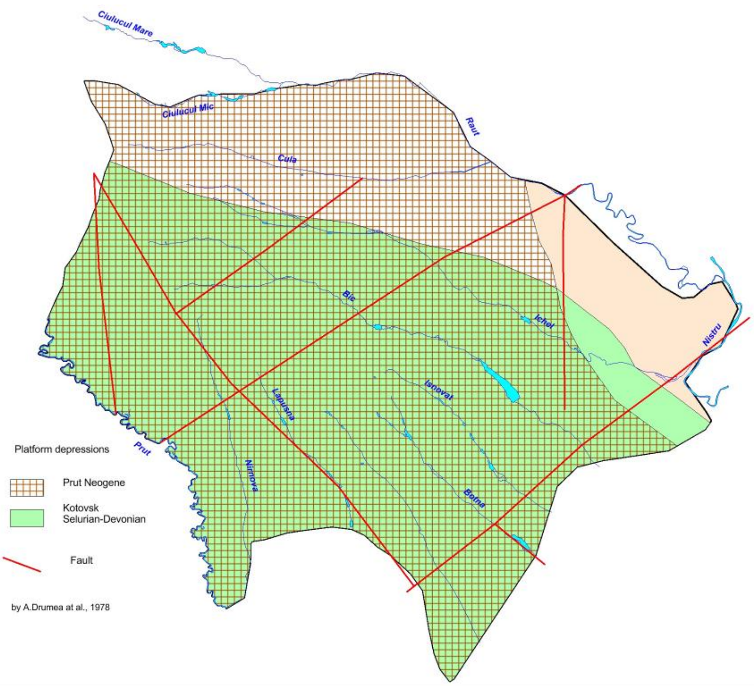

Figure 4. Tectonic map of the study area

4. Conclusions

Summarizing the results presented above, the following conclusions can be made:

1. Landslide appearance and dynamics is mainly determined by geologic factor (clayey-sandy facieses, existence of ground waters and linear disjunctive structures, highly fissured rocks etc.). However, influence of the morphological and human causes cannot be neglected neither.

2. Among the rocks, which form geological structure of the territory of study area, Miocene and Pliocene clayey-sandy deposits dominate. They are characterized by the intercalation of sands and clays of various thicknesses. Up to the geological section sand’s share increases.

3. In spite of the fact that Bessarabian deposits constitute 56% of all three key sectors, 77% of landslide areas are located in them.

4. The biggest area, as well as the most numerous landslides, has been identified within the upper strata of Bessarabian deposits. The contribution of lower Bessarabian strata is less significant due to lower share of sands in geological section. Landslide average size in these two geological complexes varies insignificantly.

5. More than one third of Codri Hills is covered by Khersonian deposits and nonsegmented Khersonian-Meotian strata. In their geological section sand’s share is higher than in older deposits; just 28% of all the landslides are located here. Landslide size is smaller than the one in Bessarabian rocks by 35%.

6. Just singular manifestations of landsliding can be identified in alluvial deposits because of the local causes.

7. Landslide distribution characteristics are comparable for Călăraşi and Nisporeni key sectors: in both sectors landslides are mainly located within Bessarabian substage. At the same time, in Criuleni key sector landslides are identified within Khersonian and non-segmented Khersonian-Meotian strata.

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