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LANDSLIDE DISTRIBUTION AND THEIR RECENT DEVELOPMENT WITHIN THE CENTRAL MOLDAVIAN PLATEAU OF ROMANIA

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Abstract: Land degradation by soil erosion, gullying and landslides has been recognized as a major environmental threat in the Moldavian Plateau of eastern Romania. Landslides are of particular concern in the Central Moldavian Plateau, both in terms of damage and affected areas. However, the spatial distribution and the very recent temporal development of the landslides require further study. Generally, the study area is an aggregate of hills and structural platforms separated by deep, frequently asymmetrical, valleys. Middle and Late Miocene (Sarmatian and Meotian) clayey-sandy layers have outcropped due to erosion. Based on thorough reconnaissance of the Central Moldavian Plateau, three representative catchments, encompassing 106,824 ha (a quarter of the total area), have been selected, namely: the Upper Bârlad upstream of Băcești, Șacovăț and Crasna. The results obtained showed that landslides, in any shape or age, cover about half of the study area and most are inactive. Two landslide indices have been used to correlate landslide areas with both hypsometry and slope. In addition, there are similarities and differences between the selected catchments, which are strongly connected with their specific characteristics.

Keywords: land degradation, landslide, landslide indices, cuesta front, cuesta back slope

1. INTRODUCTION

Land degradation has been recognized as a major environmental threat in the Moldavian Plateau, which covers ~27,000 square kilometers and occupies most of eastern Romania. Landslides are of particular concern in the Central Moldavian Plateau, both in terms of damage and affected areas, and then follow soil erosion and gully erosion. These processes are accompanied by aggradation via sedimentation along floodplains and reservoir siltation.

Investigation of landslides has been a major research focus for the national community over recent decades, mainly after the period 1968-1973 that received more precipitation. The most significant contributions include identifying controlling factors, characterizing landslide types, establishing the age of landslides, landslide susceptibility and land improvement practices.

Băcăuanu (1968) and Băcăuanu et al., (1980) distinguished eight landslide types, from which four are common, namely:

- *Mound landslides* are initiated on slopes under Quaternary fluvial terraces and Sarmatian substrata.
- *Step-like landslides* occur on slopes shaped in alternating rocks (clay-sand) with high ground water supply.
- *Wave-like landslides* sometimes result from step-like landslides after a long-term evolution stage or occur on slopes with vertical sequences of two or more aquifers.
- *Complex (mixed) landslides* comprise a combination of mounds, steps and waves.

The broad occurrence of large, ragged sandstone slabs, incorporated in loamy-sandy matrix of some deep-seated landslides, represent the evidence of relict periglacial features. Under these circumstances, the oldest landslides are regarded as being Late Pleistocene in age and the intensity of mass movements diminished during the Holocene (Băcăuanu, 1968; Barbu & Băcăuanu, 1977).

Site-specific investigations deployed by Pujină (2008) highlight the non-periodic feature of landslide reactivation over the period 1829-2007. In addition, other findings, reported by Pujina, are of interest for the period 1968-2007 in the Moldavian Plateau, such as:

- The mean amount of precipitation <590 mm yr^{-1} especially triggered slumps and shallow, local landslide reactivations.

- The mean amount of precipitation >590 mm yr^{-1} resulted in deep-seated active landslides.

- Landslides within the Bârlad Plateau are typified by a high content of montmorillonite weighing >70% of the total clay minerals.

- The mean denudation rate related to landslides was 38 mm yr^{-1} in the Central Moldavian Plateau.

Across the entire Bârlad Plateau it is estimated that total erosion usually varies between 20-30 t/ha (Moţoc, 1983).

Despite the valuable research on landslides, there is also a need to assess both the spatial distribution and the very recent temporal development of landslides. The fundamental challenge is to separate areas only covered by landslides and to estimate their proportion of cover within the study area. This work is a regional assessment and allowed us to reveal the true extent of landslides, in any shape or form, and data obtained are essential for land management.

2. STUDY AREA AND METHODS

2.1. Study area

The Moldavian Plateau is the broadest and most typical plateau of Romania (Ungureanu, 1993). The Bârlad Plateau is the most extended high unit of the Moldavian Plateau and covers >8,000 km^2. The Plateau comprises three major subunits: the Central Moldavian Plateau in the northern area, the Tutova Rolling Hills, west of Bârlad Valley and the Fălciu Hills, east of Bârlad Valley. The Central Moldavian Plateau is the most representative subunit and covers >4000 km^2 (Fig. 1).

Westwards, between Doljeşti and Cozmeşti, the Plateau is confined by the left, west-facing side of the Siret Valley. Northwards, along Coasta Iaşilor, it merges with the Jijia Rolling Plain (a subunit of the Moldavian Plain). The Prut Valley in the Ţuţora-Drînceni reach represents the eastern limit. The southern limit with the Tutova Rolling Hills is the Racova Valley, while in the south-east it merges with the Fălciu Hills and Fălciu Rolling Plain.

The distribution of land degradation processes and landforms is controlled by several factors, including geological, geomorphological, meteorological, biological and land use. Four groups of factors promoting landslides can be identified. These are: predisposing factors (for example, slope materials or geological structure), preparatory factors (e.g. climate change, neo-tectonic uplift and human activity), triggering factors (hilly landscape, intense rainstorms, prolonged period of wet weather or rapid snowmelt, slope undercutting) and sustaining factors (Glade & Crozier, 2005).

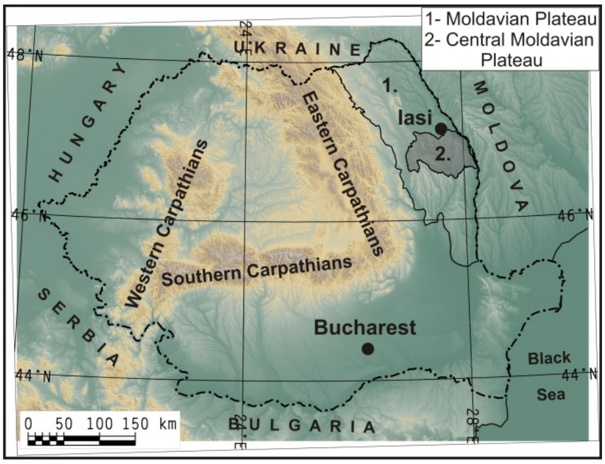

Figure 1. Location of the Central Moldavian Plateau of eastern Romania

Geo-structurally, the Central Moldavian Plateau is regarded as lying in the southern part of the Moldavian Platform (the south-western area of the East European Platform). From the stack of the Paleozoic, Mesozoic and Tertiary sedimentary strata, Middle and Late Miocene (Sarmatian and Meotian) layers have outcropped due to erosion (Jeanrenaud, 1961, 1971).

The Sarmatian (Middle/Late Miocene) outcrops in the Central Moldavian Plateau, where the layers of only two sub-stages (Bessarabian and Kersonian) occur successively by age from north to south (Fig. 2). Clays, sands and subsequently some harder and thus more erosion-resistant check layers of sandstones and oolitic limestones, accumulated during the Sarmatian. The thickness of layers varies between 800 m in the east and 2600 m in the west (Ionesi, 1994; Ionesi et al., 2005). In contrast to the subsidence during the Carpathian Orogeny, the layers that appear to date are slightly dipping, under 1^0, to the south-east, as showed by some check layers, and generally form a monocline structure (homocline) (Jeanrenaud, 1961, 1971).

Bessarabian (Middle Sarmatian) outcrops in the central and southern part of the Moldavian Platform, where lateral facies variations, similar of those from Lower Sarmatian (Volhynian), are evident. Thus, the pelitic sedimentation continues by deposition of the “*clays with Cryptomactra*” east of the Flămânzi-Tg. Frumos line, and these clayey layers

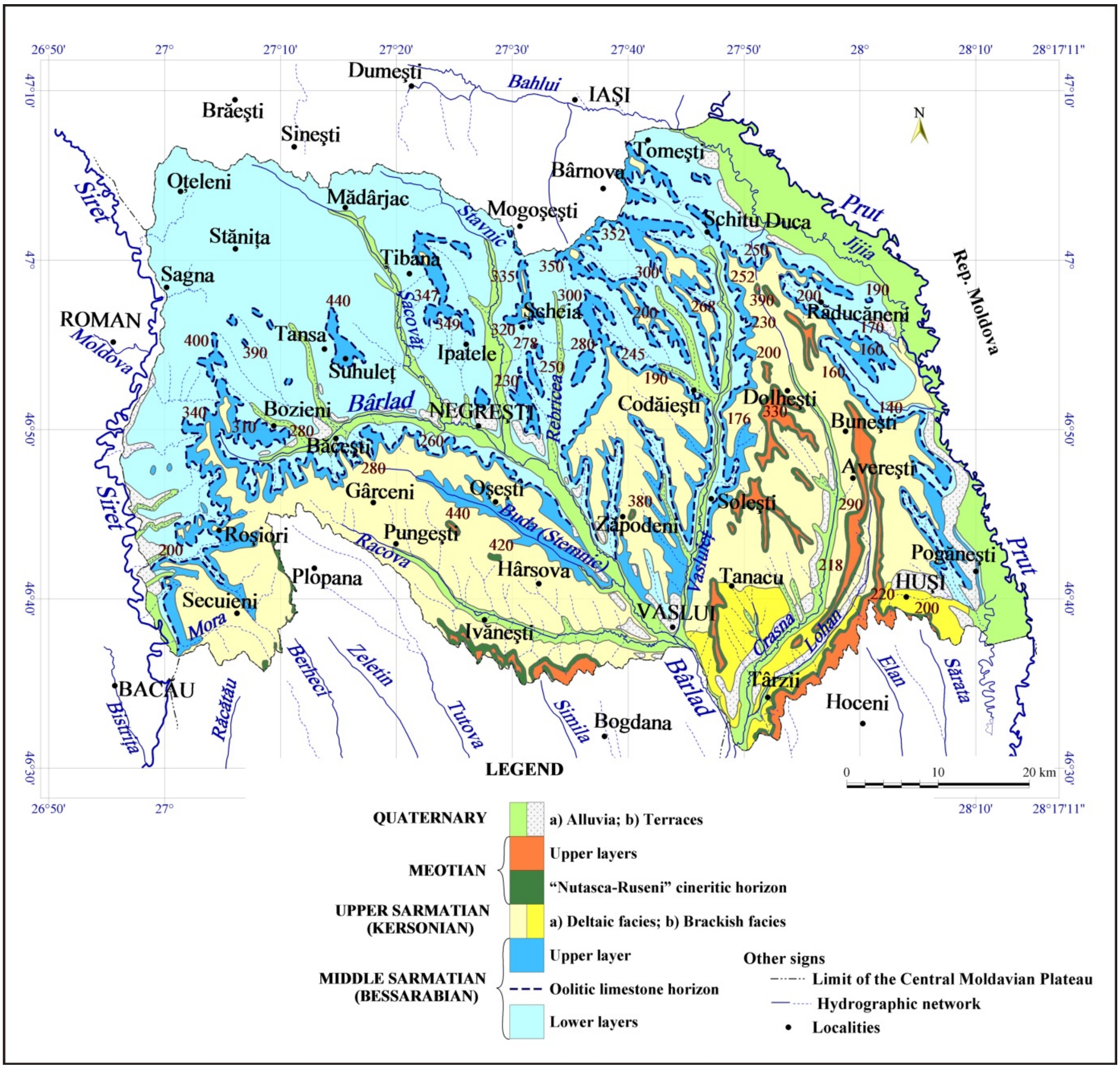

Figure 2. Geological map of the Central Moldavian Plateau (Jeanrenaud, 1971)

with thin sandy seams (intercalations) reach 400-450 m thickness. In the clayey matrix, the frequency of sands increases every 60-80 m depth, so that they form a 10-20 m thick layer called "*Bârnova sands.*" Concomitantly, as a result of decreased water salinity, the fauna was decreased to a few fresh water species, including *Mactra macarovicii* and *Congeria* (Jeanrenaud, 1961, 1971; Ionesi, 1994; Ionesi et al., 2005).

Above the Congeria strata, there is a remarkable uniformity of sedimentation. Thus, within a large area between the Siret and Prut rivers, a homogenous check layer of oolitic limestone with *Mactra podolica*, typically 3-5 m thick ("*Repedea limestone*"), has been deposited. Above this, after an alternation of sands and clays of 10 m thickness, a reference complex of rocks called "*Şcheia sands and sandstones*" follows. In this well-spread package of rocks of 10-15 thickness, sands are abundant at the bottom and lime-sandstone slabs prevail at the top. The oolitic limestone cannot be separated from Şcheia sands in the Dealul Repedea-Coasta Iaşilor and is 25 m thick (Jeanrenaud, 1961, 1971).

The Upper Sarmatian (Kersonian) outcrops south of the Păun Hill-Ţibana-Avereşti line up to the bottom of the valley-sides in the High Tutova rolling hills. Here sedimentation conditions changed in favor of two facies (Jeanrenaud, 1971):

- One of marine brine features with clays, sands and a few seams of lumachellic limestone with small Mactra;

- The other, coastal-deltaic, consisting in cross-bedded sands and clays and sandstone concretion.

In the upper Racova Catchment at Pungeşti, along the southern border of the Central Moldavian Plateau, the Kersonian consists in a package of 250 m thick strata (Jeanrenaud, 1966, 1971). Then, in sedimentation continuation, Meotian (Late Miocene) deposits follow, and three strata have been separated by Jeanrenaud (1961, 1966, 1971), namely:

- The lower 80-100 m thick layer, consisting of sands, clayey sands and clays (later this layer was attached to the Kersonian).
- The middle, cineritic layer (the *"Nuţasca-Ruseni"* reference horizon, being 30-40 m thick in the middle area of the Tutova Rolling Hills). This layer consists of slabs of andezitic cinerites with sandstone concretions, which are separated by clayey and sandy-clayey seams (intercalations).
- The upper and thickest layers (150-180 m) comprise a succession of sands, clayey sands, clays and shallow sandstone seams, and are predominantly cross-bedded.

In conclusion, by ignoring the older geological phases and the un-intercepted layers in the present-day valleys across the Central Moldavian Plateau, it appears the regressive layout of the Middle and Late Miocene (Sarmatian and Meotian) formations is evidence that the sea started to regress towards the south-east. Neotectonic uplift during the Romanian (Late Pliocene) can be correlated with the Valachian phase and it affected the whole Moldavian Plateau. These affects varied, being more pronounced in the north-west and less in the south-east. That explains the prevailing occurrence of the Bessarabian (Middle Sarmatian) layers, while the Kersonian (Upper Sarmatian) layers, initially more extended, are isolated as erosion remnants in the northern half of the study area. In turn, similarly, the Kersonian is prevalent and the Meotian (Late Miocene) occur as erosion remnants on the hilltops in the southern part of the Central Moldavian Plateau.

Generally, the Central Moldavian Plateau is an aggregate of hills and structural platforms separated by deep, frequently asymmetrical, valleys. The typical hilly topography is strongly related to both the local characteristics of the fluvio-denudational system developed on a homocline and the influence of lithology (Băcăuanu et al., 1980; Ungureanu, 1993). To the north-west of the region, the peak of the highest hills, Tansa and Milişte, is 466 m a.s.l. and the altitude declines progressively south - south-eastward to 87 m at the confluence (junction) of the Bârlad and Crasna rivers.

In the Central Moldavian Plateau, the topography is typified by a succession of cuestas. These are either north-facing, and characteristic of the subsequent valleys (Upper Bârlad, Buda-Stemnic, Racova and Coasta Iaşilor) or west-facing, developed along north-south oriented reconsequent valleys (Ionita, 2000). There are also representative typical structural platforms (plateaux) that remain as erosion remnants, such as Băneasa-Avereşti, Tansa, Ipatele, Şcheia, Repedea-Păun and Schitu-Duca (Fig. 3).

Figure 3. Şcheia structural platform bound by cliffs in Middle Sarmatian sandstone (30 October 2007)

Due to its geographical position, the study area has a temperate-continental climate, a feature emphasized by the major inter-annual fluctuations of temperature and precipitation. In average years, westerly and north-westerly circulations of air masses prevail, that carry ample, and sometimes excess, moisture (e.g. 1969-1972, 1974, 1984, 1988 and 1999). The eastern and south-eastern circulation generates insufficient precipitation (e.g. 1954, 1963, 1983, 1985-1987, 1989-1990, 1994-1995, 2003 and 2012), increases the duration of sunshine and is associated with higher daily and seasonal temperature amplitudes. These fluctuations are reflected in the oscillating character of the yields of the main crops. Climatically, the mean annual temperature varies between 7.5-10.0^{0}C and the mean July temperature rises from 17.5^{0}C on hilltops in the north and north-west to 20.1^{0}C on the Bârlad floodplain at Vaslui. The lowest mean monthly temperature is recorded in January with values ~-4/-5^{0}C. The mean annual precipitation exceeds 700 mm on hilltops in the north and north-west, but the Central Moldavian Plateau usually receives 500-630 mm per year. About 60-75% of precipitation falls during the warm season (April-September). The permanent and semi-permanent drainage net is typically of low density ($\leq$0.6 km/km^2), due to the continental climate, and rivers show a predominantly pluvial supply, where ~72% of runoff results from rainfall. In terms of the water discharge regime, flash floods, triggered by snow-melt and overlapping with certain rains during late winter and early spring, are distinguished. Floods induced by heavy rainfall during the warm season are more frequent in May and June, followed by shallow flows over autumnwinter. The peak water discharges recorded during severe floods reached 301 $m^3 s^{-1}$ on the Bârlad River, in July 1979 at Negrești and 135 $m^3 s^{-1}$ on the smaller river Vasluieț at Moara Domnească (Băcăuanu et al., 1980). The following mean discharges should be noted: 1.5 $m^3 s^{-1}$ for the River Bârlad at Negrești and 3.0 $m^3 s^{-1}$ at Vaslui, 1.0 $m^3 s^{-1}$ for the River Vasluieț at Moara Domnească and 0.45 $m^3 s^{-1}$ for the River Stavnic at Căzănești (Patriche, 2005). The natural lakes are floodplain lakes, but today the most important are the reservoirs.

Bio-pedo-geographically, the higher areas are enclosed by deciduous forest, where there is a gradual transition from the beech (*Fagus silvatica*) subtype to durmast (*Quercus petraea*). The sylvo-steppe is advancing on the Bârlad Valley, and is composed of quercine coppices and meadows consisting mainly of fescue grasses. Despite drastic changes in the natural vegetation cover, the forest still covers ~30% of the total area. Accordingly, the zonal soils in the higher districts are part of the Luvisols class (luvosols, preluvosols), and those from lower areas are within the Cernisols class (phaeozems, cambic chernozems).Under the prevailing conditions, the study area is very prone to landslides (Fig. 4).

Figure 4. Active landslide on the left valley-side of the Telejna Valley (West-facing cuesta front), Central Moldavian Plateau (07 April 2007)

2.2. Methods

Thorough reconnaissance of the study area provided more-recent information for the selection and assessment of variability within reference catchments. Repeated field surveys of landslide features involved the measurement of areas subjected to landslides and are sometimes conducted in conjunction with the collection of remotely sensed data. The full range of geomorphological criteria described in Dikau et al., (1996) was also used for landslide identification. Therefore, classical research methods (especially repeated field surveys and mapping, mathematical-statistical processing) and present-day methods based on the GIS software, have been used effectively.

Cartographic material was obtained using TNT Mips v.7.1 software and data processing was performed using Microsoft Office Excel 2010. A very important step in spatial modelling of land degradation consisted in achieving the Digital Elevation Model (DEM), by vectorizing contour lines on topographic plans at 1:5,000 scale. Then, based on DEM, different thematic maps have been obtained, such as the hypsometric, slope angle and slope aspect maps. The distribution of the landslides resulted from collating data collected during field surveys and the ones taken from the 2005 and 2009 aerial orthophotos and the topographical plans at 1:5,000 scale.

In addition, other materials and data of interest included the geological map of Central Moldavia between the Prut and Siret rivers (Jeanrenaud, 1971), climatic data released by the National Administration of Meteorology (ANM), hydrologic measurements recorded in the Bârlad Catchment by the National Administration 'Romanian Waters' (ANAR) and especially soil surveys, at 1:10,000 scale on agricultural land, carried out by O.S.P.A. Iași, Vaslui and Neamț.

3. RESULTS AND DISCUSSION

In order to achive the proposed objectives, three representative catchments, extending over 106,824 ha (a quarter of the total area), were selected for detailed study within the Upper Bârlad upstream of Băcești, Șacovăț and Crasna (Fig. 5). This area is highly susceptible to soil erosion and landslides, which damages the local landscape by depleting soil resources and decreasing agricultural productivity. Each of these catchments is described below:

● The Upper Bârlad Catchment upstream of Băcești covers 21,559 ha and is located in the western part of the Central Moldavian Plateau. The minimum altitude of 146 m is on the Bârlad floodplain, and the maximum (466 m) is the summit of Miliște Hill. Most of the land is subjected to land degradation, since three-quarters of the catchment are covered by slopes that vary between 3-15^0 (5- 27%), and 6% of the total area exceeds 15^0 (Fig. 6). This area significantly underlines the first order structural asymmetry, being divided by typical subsequent, west-east orientated valleys (e.g. Bârlad Valley, Bozieni Valley between Bozieni and Cuci) or askew (oblique) subsequent valleys, usually with intermittent flows (e.g. Bozieni Valley upstream of Bozieni and Poienari-Râş Valley).

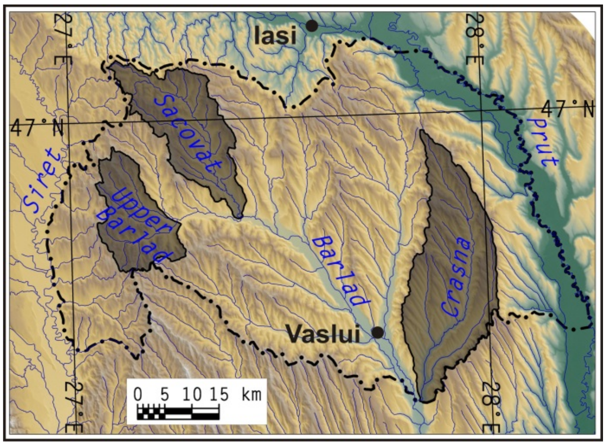

Figure 5. Location of selected catchments in the Central Moldavian Plateau of Romania

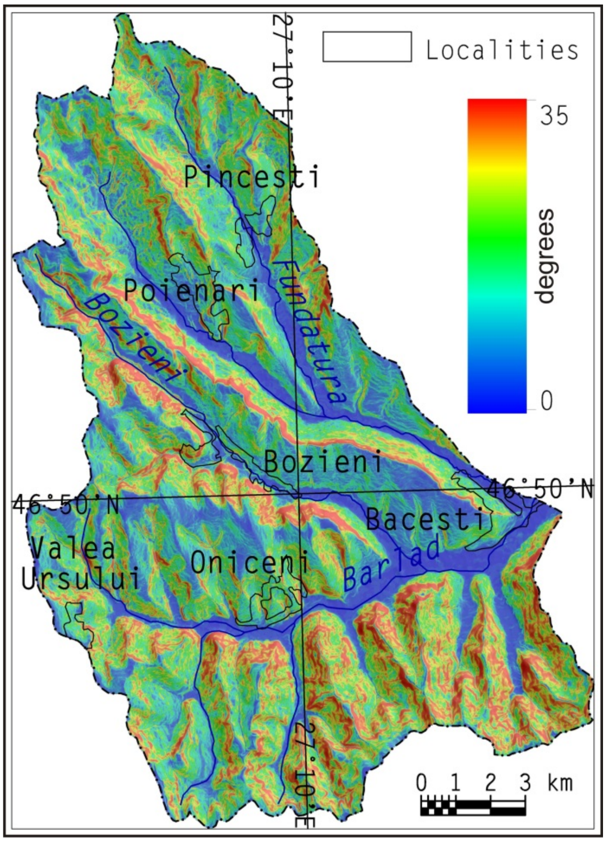

Figure 6. Slope (degrees) map of Upper Bârlad Catchment upstream of Băceşti

These drainages created classical asymmetrical valleys, where the right side is a north-facing cuesta front and the left side is a south-facing cuesta back-slope (Fig. 7).

The left side of the Upper Bârlad Catchment is sculptured almost exclusively in Bessarabian (Middle Sarmatian) formations. The right side is underlain by both Bessarabian and Kersonian (Late Sarmatian) formations. These are deep incised by small obsequent valleys (e.g. Purcica, Poiana Lunga, Pietrosu, Fundu Ocea, Pustieta, Băbuşa and Păltiniş). Most soil cover consists of Luvosols and Phaeozems.


Figure 7. The Upper Bârlad Valley between Ciornei and Băceşti (06 July 2011)

● The Şacovăţ Catchment, located in the north-western part of the Central Moldavian Plateau, covers 31,380 ha. Its elevation varies between 124 m, at the junction with the Bârlad River and 466 m in Tansa Hill, while the average altitude is 240 m. Two-thirds of the catchment (69%) is covered by slopes that vary between 3-15^0, and 6% of the total area exceeds 15^0 slope. The entire Catchment has been shaped in Bessarabian layers, mostly clayey-sandy. Two lithogical plateaux (platforms), Tansa-Suhuleţ and Zarea Domniţei-Ipatele, developed on the limestone-sandstone cap resistant rock as erosion remnants, are noticeable.

The upper Şacovăţ Valley is subsequent, west-east oriented, and the downstream section turns into a consequent one, heading southward. This feature is essentially due to the beheading of its former consequent upper catchment by the Sineşti River, a right tributary of the Bahlui River. At the catchment level, it still emphasizes the second order structural asymmetry, since the right side (initially an east facing cuesta back slope) occupies two-thirds of the total area (Ioniţă, 2000). This area was severely incised by typical subsequent valleys (Veja and Upper Şacovăţ) or moderately incised by oblique subsequent valleys, such as Călina and Durăceasa (Fig. 8). The small left tributaries (Ţibana, Poiana Mănăstirii, Gârla Pănoasă) of the Şacovăţ developed mostly re-consequent valleys and some subsequent reaches at the outlet are included.

● The Crasna Catchment, encompassing a total area of 53,885 ha, extends over the eastern part of the Central Moldavian Plateau. The minimum altitude of 87 m is on the Bârlad floodplain, the maximum of 425 m is the summit of Velniţa-

Chirceşti Hill, and the average elevation is 224 m. About 73% of the Catchment is covered by slopes between 3-15^0, and 8% of the total area exceeds 15^0. This catchment does not intercept the Bessarabian limestone-sandstone plaque. It is shaped in the Kersonian sandy-clayey layers, which exhibit clear and well developed vertical stratigraphic sequences.

Figure 8. Veja Valley at Vadu Vejei (04 April 2014)

Figure 9. Meotian cineritic sandstones in Bobu Hill (290 m), Hruşca Valley, SE of Buneşti, Vaslui County (23 September 2009)

These are covered by Meotian erosion remnants on higher hilltops (Fig. 9).

Figure 10. Second order structural asymmetry in the middle Burghina Catchment. East facing cuesta back-slope in the foreground and west facing cuesta front in the background (01 October 2011)

Slightly arched, but generally north-south oriented, the Crasna Valley emphasizes the second order asymmetry, even on the reconsequent tributaries (e.g. Burghina, Bălțați), accompanied by subsequent reaches (Fig. 10). If we exclude the Lohan sub-catchment, the right side of the Crasna Catchment extends over 40.423 ha (73% of the total). This appears as a broad and smooth ESE facing cuesta back-slope. In turn, there is an equal distribution in the Lohan sub-catchment, which resulted from the faster homoclinal shifting of the Crasna Valley to the ESE.

Two categories of movement history have been identified in the study area. The first is active landslides, which have shown movement during the study period (5 years). The second group of landslides which can be identified are inactive (stable) landslides, no matter whether they are dormant, relict or stabilized (protected by land improvements).

Maps were constructed of the three selected catchments. These included the geomorphological map and the map of landslide area (LA) at 1:5,000 scale (Figs. 11, 12 and 13). The main finding of this study refers to the LA, which covers 50,527 ha (Tab.1).

Table 1. Landslide area in the Central Moldavian Plateau

Catchment	*Area (ha)*	*Total landslide area*	
		ha	*% of the catchment area*
Upper Bârlad upstream of Băcești	21,559	10,818	50.2
Șacovăț	31,380	16,591	52.9
Crasna	53,885	23,118	42.9
Total	106,824	50,527	47.3

That means half of the Central Moldavian Plateau is under landslides in some shape or form, and this finding contradicts the one "*landslides have a reduced weight in comparison to other types of movement*" reported by Grecu & Comănescu (2010).

Secondly, most landslides are stable (inactive) and the active ones have a very slight occurrence, averaging today only 2.4% of the total landslide area (TLA). For example, active landslides now extend over 444 ha (4.1% of TLA) in the Upper Bârlad Catchment.

Ionita (1975) reported that after the much wetter precipitation period 1986-1973, active landslides covered 2317 ha, representing 21.4% of the TLA (Figs. 14 and 15).

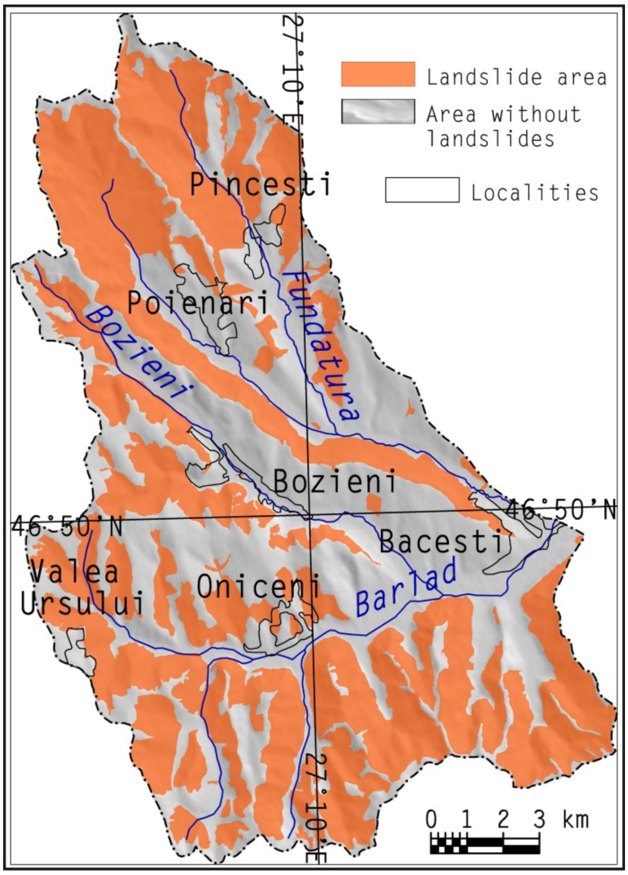

Figure 11. Landslide distribution in the Upper Bârlad Catchment upstream of Băcești

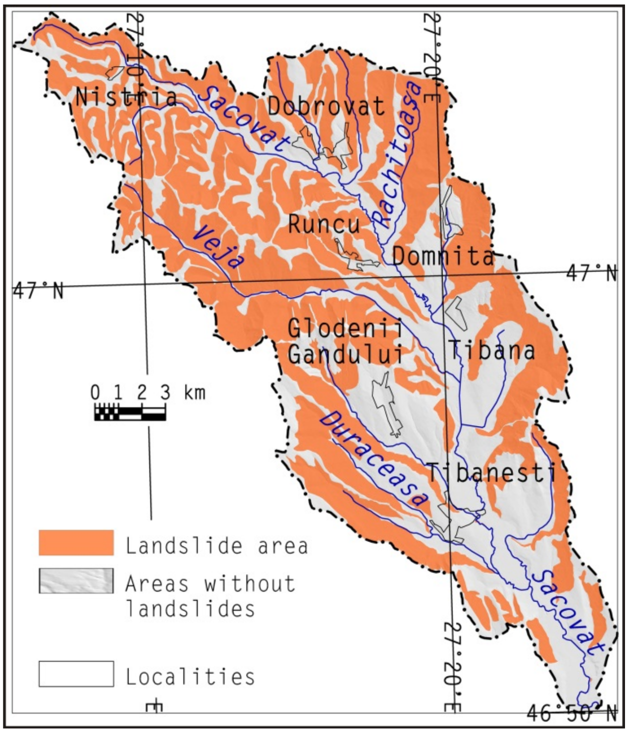

Figure 12. Landslide distribution within Șacovăț Catchment

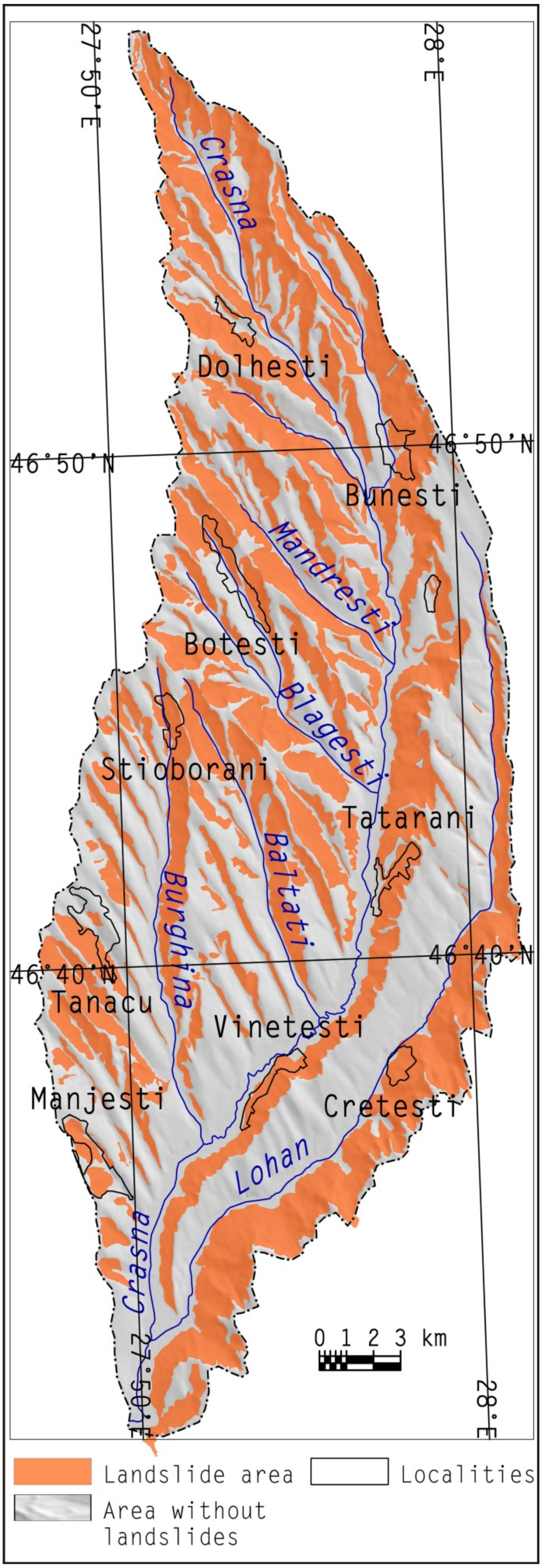

Figure 13. Landslide distribution within Crasna Catchment

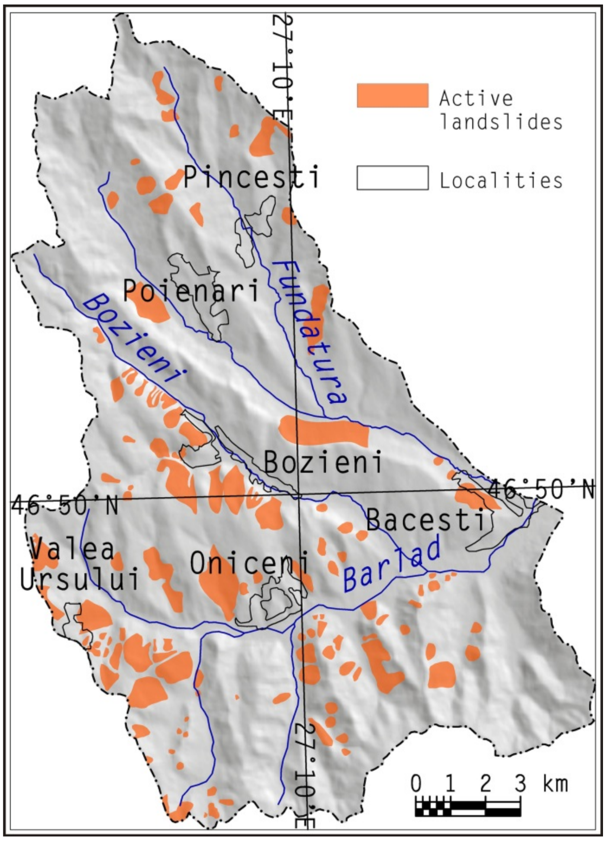

Figure 14. Map of the active landslides in 1973 within the Upper Bârlad Catchment


Figure 15. Active landslide on the right side of the Fundu Ocea Valley (September 1973)

The decline in mass movements has resulted from changes in rainfall distribution, including increased aridization since 1982, and the impact of the land improvements deployed during the 1970s and 1980s (Fig. 16).

Most of the active landslides occur by local reactivation of the areas that have previously experienced landslide activity. These reactivations are usually related to slope undermining, either by homoclinal shifting of modern drainage or gulling (Hârjoabă, 1968). Figure 17 illustrates undermining of the Bozieni cuesta front, especially by southward shifting of the river channel, while Figure 18 shows the very recent reactivation of an old landslide by gully incision in the same area.


Figure 16. Stabilized landslide by reforestation on the right side of the Fundu Ocea Valley (04 July 2011)


Figure 17. Landslides in the Upper Barlad Catchment, along the north-east facing Bozieni cuesta front, at Săcăleni (20 October 2012)


Figure 18. Gullying and landslide reactivation on the Velnița cuesta, Bozieni sub-catchment, at Iucșa (24 June 2011)

By crossing the landslide map with the hypsometric map from each catchment, it is obvious that most landslides occur on the 200-350 m contour interval within the Upper Bârlad (78%) and Șacovăț (81%) catchments, and between 150-300 m in Crasna Catchment (78%).

The Landslide-Hypsometry Index (LHI), the ratio of the landslide area (LA) to the total catchment area (CA) on hypsometric classes, shows a normal distribution in Crasna Catchment and a similar, but slightly asymmetrical one, in the other two catchments (Fig. 19).

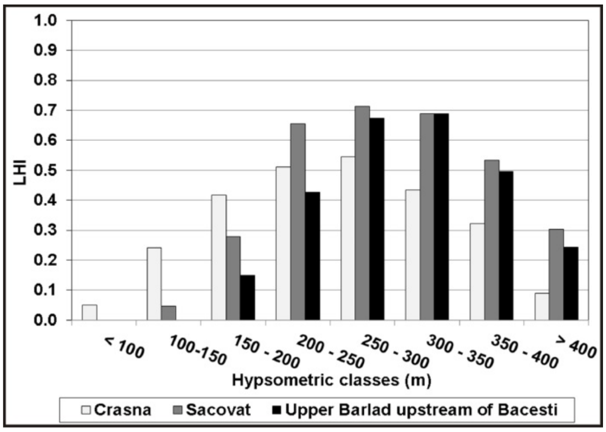

Figure 19. Landslide-Hypsometry Index (LHI) versus hypsometric classes in the Central Moldavian Plateau

The peak values of 0.54 in Crasna and 0.71 in Șacovăț are typical of the 250-300 m contour interval, while the 0.69 maximum in the Upper Bârlad upstream of Băcești is related to the 300-350 m hypsometric class. The higher LHI values from the Upper Bârlad and Șacovăț catchments (especially >250 m) could be explained by the more severe landscape dissection, mainly south of the Bârlad Valley and in the northern half of Șacovăț Catchment. They also demonstrate that local erosional remnants, developed on the Bessarabian limestone-sandstone cap rock, usually have no relevance for landslide distribution. The higher LHI values in the area <200-250 m within Crasna Catchment are associated with the marked development of the cuesta fronts, even in small sub-catchments. The lower LHI values, where elevation exceeds 250 m, results from the broader extension of hilltops, some of them being underlain by Meotian cineritic sandstones.

By crossing the landslide map with the slope map, it is evident that three-quarters of the LA occur on slopes between 5-15^0, more precisely: 80% within the Upper Bârlad, 76% in the Crasna and 73% in the Șacovăț catchments. This finding is also very well illustrated by the Landslide-Slope Index (LSI), the ratio of the landslide area (LA) to the total catchment area (CA) on slope classes (Fig. 20). On gentler slopes ($\leq 10^0$), a gap is evident between the selected sites. It underlines the broader extension of the typical, smooth cuesta back-slopes in Crasna Catchment. The other two catchments have a high proportion of un-typical cuesta back-slopes, which are severely degraded by landslides.

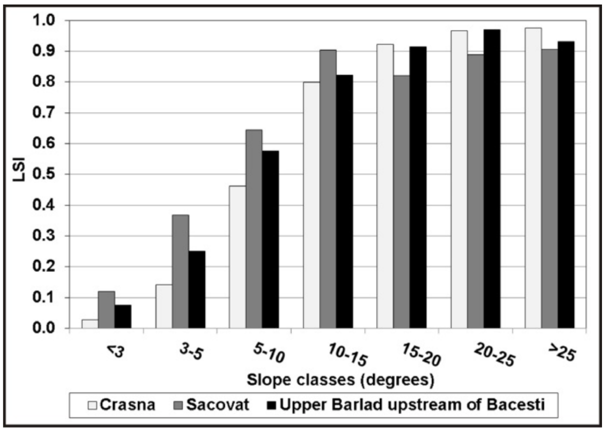

Figure 20. Landslide-Slope Index (LSI) versus hypsometric classes in the Central Moldavian Plateau


Figure 21. Deep seated landslides, locally reactivated and reforested, on the left side of Burghina Valley, (01 October 2011)


Figure 22. Reactivation triggered by gullying of a deep seated landslide below the Bessarabian cap rock at Poiana Mănăstirii, left side of Șacovăț Catchment (18 March 2014)

Most landslides develop on cuesta fronts. For example, in Crasna Catchment, 80% of TLA is related to the cuesta fronts with the remainder occurring on degraded cuesta back-slopes, especially in the upper sub-catchments. Deep seated landslides are more frequently initiated in the Kersonian layers, rather than Bessarabian layers. This is largely because of relatively higher sand content in the

Kersonian layers, associated with interbedding of sand and clay. Landslides in Bessarabian strata are related to the occurrence of the Bârnova sands in the clayey matrix (Figs. 21 & 22).

Landslide amphitheatres are characteristic of cuesta fronts. They have been locally called "*hârtoape*" and occur in small catchments, usually covering tens to hundreds of ha (Martiniuc & Băcăuanu, 1961). The landslide amphitheatres are bounded by a semicircular main scarp and the entire deluvium (landslide body) converges towards the axis of the small catchment. Two types of landslide amphitheatre can be identified, simple and complex, depending on the rate of landscape dissection (Figs. 23, 24 & 25).

Figure 23. Simple hârtop (landslide amphitheatre) on the left side of Crasna Valley (North-facing cuesta front reach), SSW of Vineţeşti (03 October 2011)

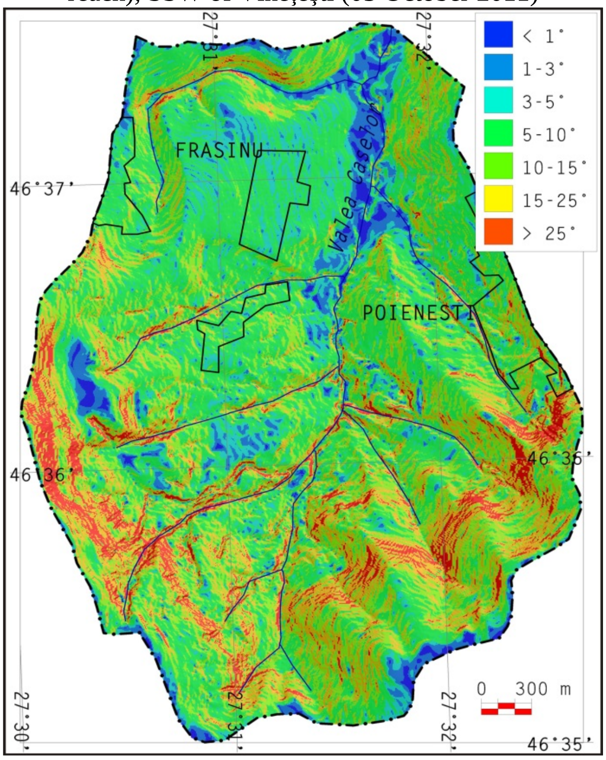

Figure 24. The slope map of the Valea Caselor complex hârtop extending over 1,117 ha of the Racova cuesta front

Figure 25. Ploposa Mare hârtop on the Bârlad cuesta front, N-NW of Rafaila, Vaslui County (23 October 2013)

4. CONCLUSIONS

The three selected catchments, extending over 106,824 ha (a quarter of the area of the Central Moldavian Plateau area), displays structural asymmetries. These are especially emphasized by the north and west facing cuesta fronts.

The maps of landslide distribution, drawn at 1:5,000 scale for each catchment, illustrate that half of the area is covered by landslides, in some shape or age. Most landslides are stable (inactive) and the active ones have a very slight occurrence, averaging today only 2.4% of the total landslide area. The active ones are triggered by local reactivation of the areas that have previously experienced landslide activity. These reactivations are usually related to slope undermining, either by homoclinal shifting of modern drainage or gulling.

The Landslide-Hypsometry Index (LHI) (the ratio of the landslide area to the total catchment area on hypsometric classes) shows normal distribution in Crasna Catchment and a similar, but slightly asymmetrical one, in the Upper Bârlad upstream of Băceşti and Şacovăţ catchments. The higher LHI values from the Upper Bârlad and Şacovăţ catchments (especially >250 m) could be explained by the more severe landscape dissection. They also demonstrate that local erosional remnants, developed on the Bessarabian limestone-sandstone cap rock, usually have no significant impact on landslide distribution.

By crossing the landslide and slope maps, it is obvious that three-quarters of the landslide area occur on slopes between 5-15^0. This finding is also well illustrated by the Landslide-Slope Index (LSI), the ratio of the landslide area to the total catchment area on slope classes.

Most landslides develop on the cuesta fronts (e.g. 80% within Crasna Catchment). Deep seated landslides are most frequently initiated in the

Kersonian layers, due to specific interbedding of sand and clay layers.

One of the most characteristic landslide types formed on the cuesta fronts are represented by the landslide amphitheatres (locally called "*hârtoape*"). They usually occur in small catchments and cover several tens to hundreds of hectares.

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