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The loess micro-depressions within the Romanian Plain. Morphometric and morphodynamic analysis

Florina GRECU[1], Alina EFTENE (GHERGHINA)[2], Cristina GHIŢĂ[1], Chaouki BENABBAS[3]

Abstract. Micro-depressions are major elements of the loess plains. They were studied in France, central Belgium, Russia, Serbia, Polonia, and Romania, but were described also in Argentina and Turkestan. Our study aims to analyse the morphometric parameters of the loess micro-depressions and their spatial distribution in four representative areas of the Romanian Plain (Bărăgan and Mostiştea basin within the eastern part, Burnaz Plain and Călmățui basin within the central part of the plain), related to local conditions, and especially to lithology.

Quantitative analyses were performed using the measured basic morphometric features of the depressions, *i.e.* circumference perimeter, area, maximum length, maximum width, and, also, several computed shape coefficients: length/width ratio, circularity coefficient, elongation ratio, shape factor, and sinuosity index. The investigation reveals large differences between the studied areas, with better correlation of measured parameters for the micro-depressions developed on typical loess, than for the ones developed on loess-like deposits. The diachronic analysis (more than 30 years) highlights morphometric and morphographic differences, due mostly to groundwater level oscillations and to intensive arable practice.

Keywords: micro-depressions, loess, morphometry, Romanian Plain.

1. Introduction

The Romanian Plain (or Danube Plain) is situated in the central – south-eastern part of Europe and is connected to the Black Sea through Lower Danube and represents a quaternary fluvial-lacustrine accumulation formed as the Pleistocene Lake that overlapped the depression inside the Carpathian-Balkan arch got silted up (Posea *et al.*, 2005). Sequent emergence, the entire plain was covered with loess or loess-like deposits. The loess thickness is large in the vicinity of the Danube River (15-30 m) and greatly diminishes in the direction of the Carpathians (0-5 m).

Loess covers areas of central and west Europe (including Pannonian and Dacian Basins), the southern of Russia and Ukraine, Loess Plateau of China, the North America (Mississippi basin, Columbia Plateau), and South America (La Plata basin). "*Typically 80-90% of the particles are between 0.005 and 0.5 mm across. On a global basis it has been estimated that some 10 per cent of the Earth's total land is covered by loess from 1 to 100 m thick*" (Summerfield, 1991, p. 256). In Romania, loess and loess-like deposits cover all the major landforms (interfluves, terraces, dejection cones), excepting the flooded or marshy areas (Gherghina *et al.*, 2006).

Micro-depressions are major elements of the loess plains. Still, in spite of the worldwide distribution of loess sediments, the international geomorphologic literature related to loess landforms is relatively rare (*e.g.* Fuller, 1922; Gillijns, *et al.*, 2005; Halliday, 2007; Kertesz & Schweitzer, 1991; Leger, 1990; Móga & Németh, 2005; Rogers, *et al.*, 1994; Rozycki, 1991; Tang, *et al.*, 2008; Zhu, *et al.,* 2002) or difficult to access because of language barriers (*e.g.* Russian, Romanian, Serbian, Polish, Hungarian literature) (Florea, 1970; Kukin & Miljković, 1988; Pécsi, 1993; Morariu, 1946; Protopopescu-Pache, 1923; Vâlsan, 1916).

In world literature they are called "closed depressions" (Gillijns *et al.*, 2005) or "depressions" (loess depressions) (Zeeden *et. al.*, 2007). Emm de Martonne (1935, p. 644) identify closed depressions (*dépressions fermées*) in Argentina, southern Russia, and Turkestan, and described them as swampy or periodically filled with more or less salty water. "*Depressions formed by compaction and* *subsidence (soutirage) on permeable land mobile .... loess, attest the crypto-karst*" (Coque, 2000, p. 78). Thus, closed depressions are similar with limestone sinkholes, sometimes been called loess sinkholes.

Data about these landforms were presented mainly in the frame of general or regional geomorphological studies (Coteț, 1976; Florea, 1970; Grecu & Demeter, 1997; Grecu & Palmentola, 2003; Ielenicz, 2004; Josan *et al.*, 1996; Marković-Marjanović, 1949; Marković *et al.*, 2005; Posea *et al.*, 2005; Summerfield, 1991; Tufescu, 1966).

Loess depressions were also studied in France (Pissart, 1958), central Belgium (Gillijns *et al.*, 2005, Serbia (Zeeden, *et al.,* 2007) Russia and Poland.

Loess depressions are defined as small, isolated, periodically filled by rain water landforms, where the hillslopes encircle a common sediment depository and the sediment eroded from the hillslopes by water and tillage erosion is trapped in the system wetlands where the sediment infill is encircled by hillslopes (Norton, 1986).

In Romanian literature these landforms are known as "crov", "găvană" or "padină", and are defined as micro-depressions in loess or loess-like deposits having circular or ellipsoidal shape, with diameters between few meters and 2-3 km, and a depth of 5-6 m (Coteț, 1976; Florea, 1970; Grecu & Palmentola, 2003; Posea *et al.*, 2005).

The origin of these micro-depressions is still debated. The most commonly accepted hypothesis is that they were formed in the post-glacial period through suffosive processes (dissolution of salt or gypsum lenses) that occur in initial depressions in the loess cover (Florea, 1970; Vâlsan, 1916).

Alternatively, loess micro-depressions could be attributed to other natural phenomena like periglacial processes, pingos (Pissart, 1956, 1958); pipe erosion (Bollinne *et al.*, 1980); morainic kettle holes (Frielinghaus & Vahrson, 1998; Norton, 1986); fluvial activity or irregularities in loess deposits (Meeuwis, 1948; Morariu, 1946), wet subsidence caused by the pressure generated by the specific weight or by an external loading (Ciornei & Răileanu, 2000) etc.

Also, many micro-depressions in Europe have an anthropogenic origin: activities around archaeological settlements, water ponds or small quarries for clay, ancient mines collapse, iron nodule or lime (Gillijns *et al.,* 2005), former quarries (mines) of calcareous loess (Surdeanu, 2003), clayey loess (Manil & Pecrot, 1950) or sandstone (Meeuwis, 1948).

The complex genesis of loess micro-depressions is highlighted in Titel Plateau (Serbia). "*The formation of the depressions may be explained with a combination of dissolution by seeping waters and an initial aeolian relief predisposition*" (Zeeden *et al*, 2007, p. 4).

Our study aims to analyse the morphometric parameters of the loess micro-depressions and their spatial distribution in four representative areas of the Romanian Plain (Bărăgan and Mostiştea within the eastern part, Burnaz Plain and Călmățui basin within the central part of the plain), related to local conditions, and especially to lithology (Fig. 1).

The first studies concerning such landforms in the Romanian literature belong to Murgoci (Murgoci *et al.*, 1908), Vâlsan (1916), Protopopescu-Pache (1923) and Morariu (1946), who stated that these small depressions represent the old morphology of sand landscapes and fluvial activity. G. Vâlsan described the morphology of the loess "sinkholes" in the Romanian Plain with diameters from several meters to 2-3 km and depths of 5-6 m, the orientation and shape of which are modified by the direction of prevailing winds. T. Morariu (1946) pointed out that loess micro-depressions formed by sagging and wind erosion, supported by the pre-existing topography and the anthropogenic activities. P. Coteț (1976) and G. Andrei (1971) highlight the role of loess and loess deposits characteristics over the dimensions of the micro-depressions. "*The density of micro-depressions is higher within the loess with dust-aleurite facies and is smaller in the regions with more clayey facies*" (Coteț, 1976, p.157).

More recent studies conducted in the Romanian Plain address especially the age of the quaternary deposits (Bălescu *et al.*, 2010; (Florea, 2010; Rădan, 2012; Vasiliniuc *et al.*, 2011) or the relief (including microforms) characterization, studied in the context of extreme phenomena in relation with hydrography, climatic variations, land use and human activity (Grecu *et al.*, 2006; Grecu *et al.* 2012; Vijulie 2010), and less the micro-depressions morphometry (Gherghina *et al.*, 2008). Some genetic explanations of the different landforms, including loess micro-depressions, are found in recent PhD theses (Albu, 2012; Cîrciumaru, 2011; Gherghina, 2009; Ghiță, 2009; Văcaru, 2010 etc).

2. Study areas

The researches have been conducted in the Romanian Plain, a fluvial-lacustrine Quaternary plain, situated in the depression between the Carpathians and the Balkans on the one side and the Dobrudja Plateau on the other, with opening and connection to the Black Sea through the Danube.

The genesis of the plain has been influenced by the Carpathians, the Balkans and the Danube, as well as by the active tectonics from the Carpathians Curvature.

2.1. The Eastern Sector, eastward from the Argeş River

The Central Bărăgan Plain (Fig. 1 - A) belongs to the Bărăgan Plain, which is considered the most typical lacustrine or lacustrine-fluvial flat plain in the region. The Central Bărăgan Plain, with a total area of 3370 sq. km (Gherghina *et. al*., 2008) is situated in the south-eastern part of Romania, on the east of the Eastern Romanian Plain, overlapping the Ialomiţa-Călmăţui interfluves (Fig. 1). The floodplains of the two rivers border the plain to the south and north respectively. *The Mostiştea basin* catchment (1780 sq. km) (Fig. 1 - B), lying in the southern part of Romania and in the eastern half of the Romanian Plain is in-between the Bărăgan on the east and the Vlăsia Plain on the northeast, to which is directly connected by a strip of land. North and northeast of the catchment as far as the Ialomiţa floodplain, and along the North Bărcăneşti-Horia-North Raşi alignment, on 146 sq. km (Ghiţă, 2009), Upper Holocene aeolian deposits and sand dunes prevail. These are disposed in continuous strip, still wider to the east. Because the deposits are stabilized, wind erosion has a secondary character.

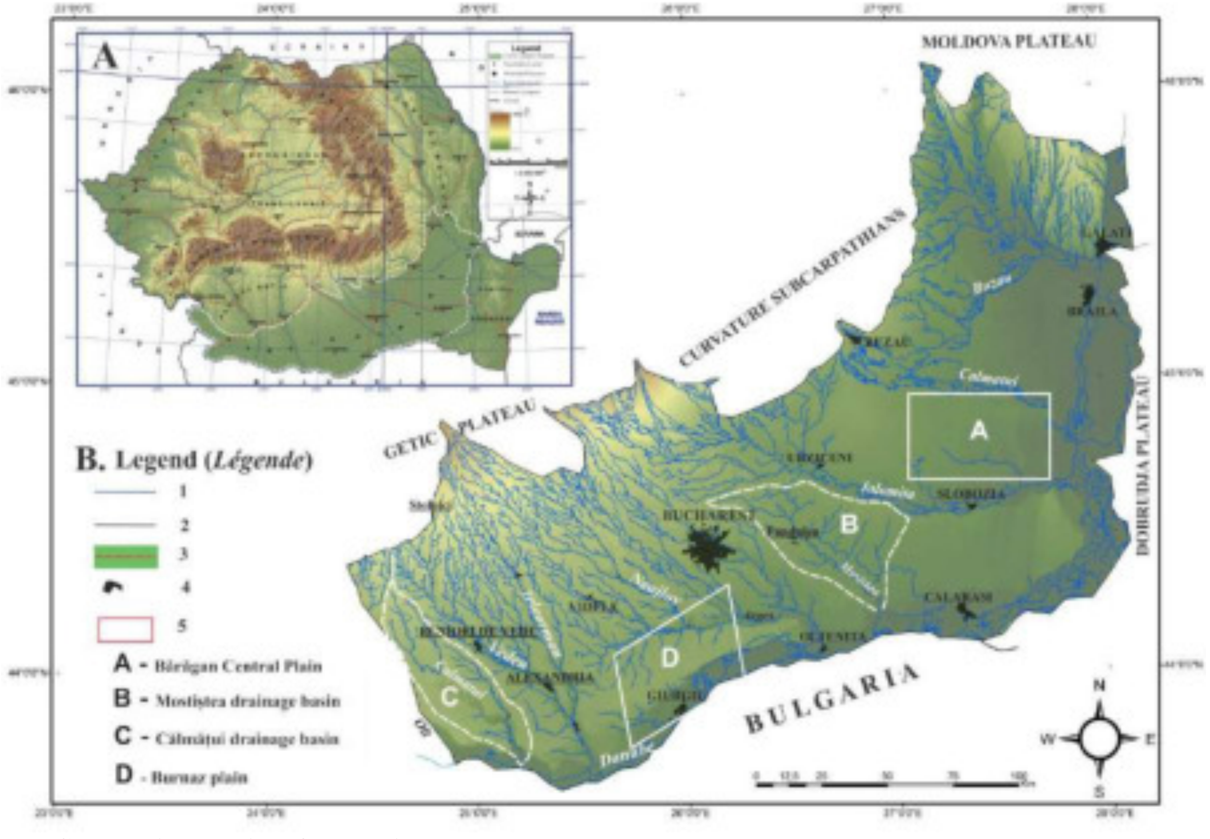


Fig. 1. **Geographical location of the studied areas:** 1 – Hydrographical network; 2 – Plain limit; 3 – Watershed; 4 – Localities; 5 – Studied areas; **A** and **B** – transversal profiles

2.2. The Central Sector of the Romanian Plain

Teleorman Plain is situated between the rivers Olt (in the west), Argeş (to the east), Danube (to the south) and the Getic Piedmont (to the north). The main inland rivers originate from the piedmont Pliocene deposits, with the water table at depths that allow the formation of springs and a higher density of the hydrographical network than in the Bărăgan Plain. The thickness of loess deposits varies between 3 and 20 m.

The Călmăţui basin/catchment (1375 sq. km) (Fig. 1 - C) is situated in the Boianu fluvial-lacustrine plain (a characteristic for the entire Romanian Plain). As sub-units, stand the following: Iminogului Plain (North Boianu Plain), a Getic piedmont plain, prolongation of the Getic Piedmont, and the Urlui Plain (South Boianu Plain, piedmont pre-Balkan plain, with Frăteşti strata) (Posea, 1987; Grecu, 2010). The micro-depressions have bigger extension in the western part of the plain that overlaps Călmăţui – Olt interfluve. *The Burnaz Plain* is a terminal-piedmont pre-Balkan plain, situated between the Danube and Câlniştea river (Fig. 1 - D). The pre-Balkan Frăteşti strata, encountered immediately under the loess deposits, constitute an important aquifer formation, situated at relatively small depths (20-25 m) with a free hydrostatic level and a debit varying from 10 l/s in the regions proximal to the Danube (where the most extended compaction depressions are found), and 3 l/s towards the interior of the plain (Liteanu, 1969).

3. Methods and data

For the purposes of this study, we created a database containing morphometric characteristics and data on the spatial distribution of micro-depressions within the central and eastern parts of the Romanian Plain, as a tool for detailed morphological investigations.

Topographic maps 1:50000 and 1:25000 scale, 1970-1971 edition, as well as 1:5000 scale ortophotoplans, 2005 edition were used as cartographic materials. These were georeferenced in the Stereographic Projection 1970, datum S42 ROMANIA by using Global Mapper program. Further on, the contours of the following contents were digitized, using Arcview 3.2 and Arc Gis/Arc Map 10.1 programs: elevation and morphology (contour lines with vertical interval of 2.5 m and 5.0 m, respectively, in the range between 15 and 110 m), hydrology, branches and drainage canals, lakes and swamps.

Field observations were carried out between 2003 and 2012 for detailed geomorphologic mapping. The database was supplemented with land use (CORINNE Land Cover, 2006) and lithological and pedological data provided by the 1:200.000 scale geological and soil maps, existing studies, and field observations.

The main applications of the database in this study are: identification and spatial distribution of the micro-depressions and precise measurements of horizontal dimensions.

Quantitative analyses of the basic morphometric features of the depressions, *i.e.* circumference perimeter (***P***), area (***A***), maximum length (***L***), maximum width (***W***), were performed using the Arcview 3.2 and Arc Gis/Arc Map 10.1 programs. Also, several shape coefficients were computed: the length/width ratio (***L/W***), the circularity coefficient (***Rc***), the elongation ratio (***Ra***), and the shape factor (***Rf)*** formulas were taken from *The morphometric analysis of the catchment*, while the sinuosity index (***Ks***) was computed as ratio between the perimeter of a circle having the same area as the depression divided by the depression's perimeter (Table 1) (Fig. 2).

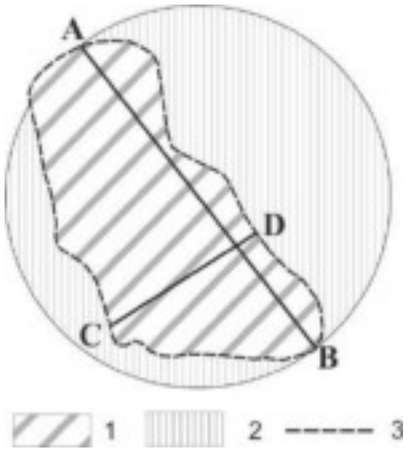


Fig. 2. **The parameters computed for micro-depressions** (AB – major axis (*L*), CD – minor axis (*W*), 1 – micro-depression area (*Ad*), 2 – area of the circle having the same diameter as the depression's major axis (*Ac*), 3 – perimeter of the micro-depression (*Pd*).

Table 1. **Computed coefficients**

Coefficient	**Formula**
Ratio *L/W*	*R = L/W* The ratio between the major axis and the minor axis of the micro-depression;
Circularity coefficient	*Rc = Ad/Ac,* The ratio of the depression's area to the area of the circle having the same diameter as the micro-depression's major axis;
Elongation ratio	*Ra = Dc/Ld,* The ratio between the diameter of the circle having the same area as the watershed and the length of the micro-depression's major axis;
Shape factor	$Rf = Ad/L^2$, The ratio between the depression's area and the squared length of the major axis; defined with reference to a square for which the reference value is 1;
Sinuosity index	*Ks = Pc/Pd,* The ratio between the perimeter of the circle having the same area as the micro-depression and the micro-depression's perimeter; defined with reference to a circle for which the reference value is 1.

4. Analysis and results

4.1. Loess, loess-like deposits and their meaning on micro-depressions morphometry

Loess and loess-like deposits overlap all the major landforms (interfluves, terraces, dejection cones) with the exception of the flooded or marshy areas (Gherghina *et. al.*, 2006). In section, generally two darker coloured, brick-red, predominantly clayey layers, considered to be buried soils interpose the loess layers (Liteanu & Ghenea, 1966). This succession has been used as a criterion in determining the age of the terraces (Brătescu, 1937). It reflects the alternance of the humid climates with the dry ones during the Quaternary (Spirescu, 1970; Panaiotu *et al.*, 2001; Vasiliniuc *et al.*; 2011). The characteristics of loess and loess-like deposits, important in the genesis and evolution of the micro-relief from the Romanian Plain are: the thickness, the content in soluble salts, grain size, the porosity/loosening degree of the rock in the presence of water (this allows certain collapsibility).

Table 2. **The grain-size composition of loess and loess-like deposits**
(analyses performed by Vasilescu P., in Andrei, 1971 with modifications)

Depth (cm)	**Fractions/ Aggregate**	**Grain diameter** mm	**Limit values** %	**Mean values** % **Clayey and clayey-sandy deposits**	**Limit values** %	**Mean values** % **Loamy-clayey deposits**
0-35	Coarse sand	2-0.2	0.2 – 0.4	0.3	0.1 - 1	0.6
	Fine sand	0.2-0.02	55 – 62	58.5	29 - 40	31.4
	Dust and clay	<0.02	36 – 40	38.0	66 – 72	65.8
	Physical clay	<0.01	28 – 32	30.0	43 – 57	52.3
	Clay	<0.002	20–24	22.0	36–41	35.2
	Fine clay	<0.001	18–22	20.0	32–37	0.5
150-220	Coarse sand	2-0.2	0.4–0.6	0.3	0.4–0.6	0.5
	Fine sand	0.2-0.02	60–70	65.0	60–70	32.8
	Dust and clay	<0.02	28–35	31.5	28–35	64.3
	Physical clay	<0.01	20–25	22.5	20–25	49.7
	Clay	<0.002	12–16	14.0	12–16	36.1
	Fine clay	<0.001	12–15	13.5	12–15	31.7

The thickness of loess and loess-like deposits varies from one area to another, being proportional with the intensity of compacting (Fig. 3). Thus, in Burnaz Plain, their thickness reaches over 25-30 m in the south and 10 m in the north; in Mostiştea Plain, because of the greater thickness of loess (up to 35 m), the compaction due to dipping presents high values (15-40 cm). In the Boianu Plain, where loess thickness does not surpass 8-10 m, the wet compaction has very low rates and a discontinuous character, which determine the reduced dimensions of the loess micro-depressions.

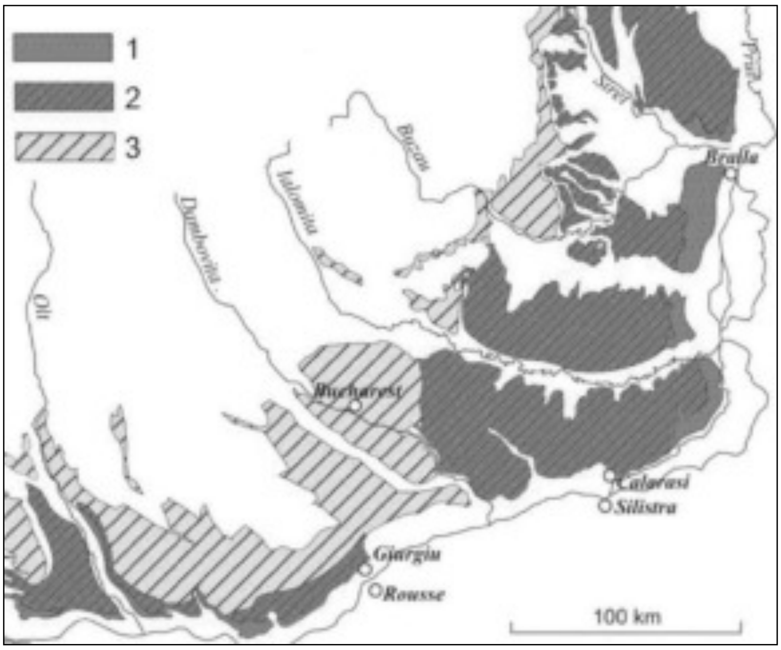


Fig. 3. **Texture of loess and loess-like deposits in Romanian Plain** (redrawn from Conea *et al.*, 1963) 1 – loess with loam and sandy loam texture, 2 – loess with silty loam texture; 3 – loess-like deposits, with silty clay loam texture

Grain-size of the deposits imposes differentiations in the intensity of the compaction and suffosion processes. Thus, on the high terraces of the Danube and along the field on the left of the Olt river loess prevails (with clayey and clayey-sandy texture) as well as the high frequency of the micro-depressions, while on the high plain the texture of the loess deposits modifies from south to north, turning more rich in clay and with a lower intensity of the compaction process. The grain size analysis conducted in several profiles from the south of the central sector of the plain, shows an increase in the clay content of loess-like deposits within the interfluves plain from south (on the superior Danube terraces) towards north (from 29-31% to 32-35% clay at 2 m depth) (Andrei, 1971). The content in coarse sand decreases on the same direction, reaching values below 1 in the north (Table 2).

The clayey character of the deposits imposes a decrease of the micro-depressions frequency from south to north, from the median and superior Danube terraces towards the high plain, also correspondent to the calcium carbonate ($CaCO_3$) content that decreases from south (15-22% $CaCO_3$) to north (12-15% $CaCO_3$) (Andrei, 1971). The significant content in limestone and the reddish color of the deposits within the micro-depressions in Burnaz certify the diluvia transport from the Pre-Balkanic Plateau (Parichi *et al.*, 2009). The accumulation of the colloids at a certain level leads to the gradual formation of an impermeable alluvia horizon, to the ceasing of the compaction process and of the micro-depressions formation (Florea, 1970). The clay enrichment of the parental material is attributed to a lacustrine excavation resulted from the oscillation of the Danube channel before the settlement of the present course (Parichi *et al.* 2009). According to the data in the literature (Conea *et al.*, 1963), the Central Bărăgan Plain (3370 sq. km) (Fig. 1 - A) displays, from north to south, the following sequence of superficial deposits: loamy sands with intercalations of fine and mobile sands, in the north; loamy-sandy deposits with different fractional percentages of coarse sands, in the northern half of the interfluve and on the east, on the terrace top; loamy deposits with different percentages of coarse sands, in the southern half of the interfluve.

Collapsibility is the compaction process of the loess and loess-like deposits, which, at the contact with water suffers sudden and irreversible modifications (collapse) of the internal structure as well as decreases of the values of the geotechnical parameters of mechanical behaviour (*The norms regarding constructions foundation*, 2008) (Fig. 4). This sensitivity of loess and loess-like deposits (Bally *et al.*, 1968; Protopopescu-Pache *et al.*, 1966) is called vulnerability to compaction. Loess-like deposits and loess present *high porosity*, between 45% and 50%, vertical cleavage that induces considerable heights of the walls, good permeability, a high erosion degree and increased vulnerability to compaction.

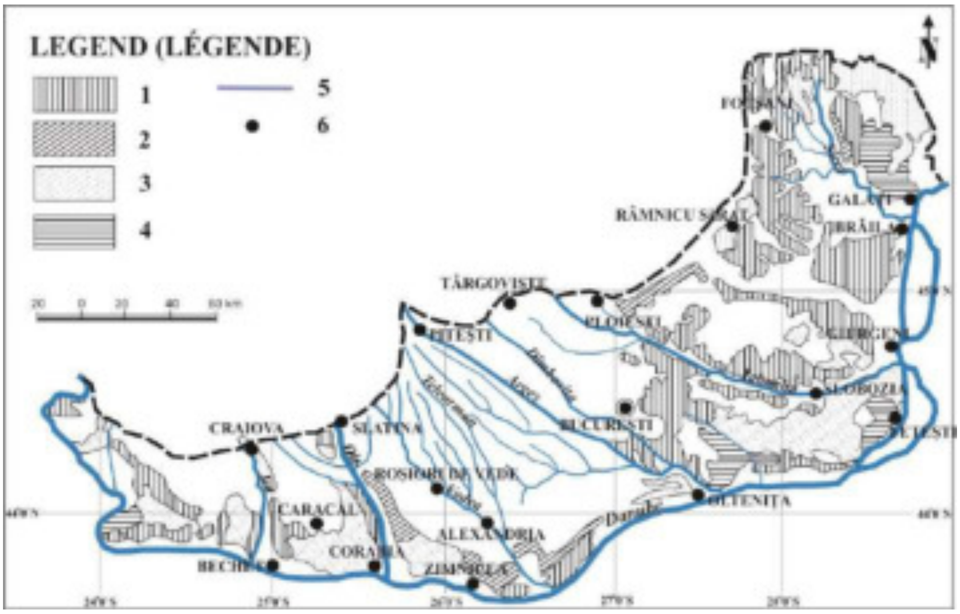


Fig. 4 – **Groups of loess and loess-like deposits sensibility in Romanian Plain** (according to the Norms regarding constructions founding, 2008); 1 – collapse loess – A1 (with continuous spread); 2 – collapse loess – A2 (with discontinuous spread) (group A – loess and loess-like deposits that experience a supplementary sagging I_{mg} < 5 cm); 3 – collapse loess – B1 (I_{mg} =5-40 cm); 4 – collapse loess (I_{mg} > 40 cm); 5 – rivers; 6 – localities; * I_{mg} = supplementary sagging index under the weight of the strata; Group A=loess and loess-like deposits that experience a supplementary sagging $I_{mg}<5$ cm; Group B=loess and loess-like deposits that experience a supplementary sagging $I_{mg}\geq5$ cm

The Călmățui drainage basin (Boianu Plain) (Fig. 1 - C) displays typical loess in the west side, loamy-sandy deposits and clays in the north. The presence of loess, with mean texture (loamy and loamy-dusty), quite sensitive to suffusion, has determined the occurrence of some larger micro-depressions (Fig. 4, 5). The prevailing element of the loess-like deposits is represented by the aeolian dust, its reshuffle by washout processes on slightly leaning surfaces leading, through the addition of clay and sand, to a more reduced sensibility to suffusion (Liteanu & Ghenea, 1966) and to the appearance of a more reduced number of micro-depressions, also small as surface and dimension (Table 3).

Table 3. **Parameters of the micro-depressions developed on typical loess and loess-like deposits in Călmățui basin** (after Albu, 2012)

Indicator	***A*** (sq. km)		***P*** (km)		***L*** (m)		***W*** (m)	
Deposits	**Typical loess**	**Loess-like deposits**	**Typical loess**	**Loess-like deposits**	**Typical loess**	**Loess-like deposits**	**Typical loess**	**Loess-like deposits**
Min	0.01	0.01	0.23	0.14	87.3	51.5	46.1	32.3
Max	0.74	0.20	8.90	1.92	1783.1	655.5	1530.7	511.9
Average	0.12	0.01	1.20	0.36	456.7	131.6	235.0	83.8

4.2. The morphometric and spatial analysis

The micro-depressions cover an area of about 170 sq. km, (5% of the total area) within the Central Bărăgan Plain (Fig. 1 - A). On this territory, 387 micro-depressions were inventoried, with 0.34 sq. km mean area and a medium density of 0.12 depressions per sq. km (Gherghina *et al.*, 2008; Ghiță *et al.*, 2012; Grecu *et al.* 2012) (Table 4, Fig. 5a). The maximum area is 2.80 sq. km, but small depressions occur more often than larger ones (73% have less than 0.5 sq. km). Most of the micro-depressions are distributed in the north and the central part of the plain, connected with Holocene sands deposits and have a smaller frequency in southern and western part.

Table 4. **Synthetic table of the micro-depressions in the investigated areas**

Study area (sq. km)	**No. of micro-depressions**	**Total area** (sq. km)	**Mean area** (sq. km)
Central Bărăgan Plain (3370 sq. km)	387	170	0.34
Mostiştea drainage basin (1780 sq. km)	191	22.33	0.15
Călmățui drainage basin (1375 sq. km)	300	23	0.13

In the Mostiştea drainage basin (Fig. 1 - B), the micro-depressions cover about 22.33 sq. km, which represents 1.23% of the catchment's area (1780 sq. km). Here, we mapped 191 micro-depressions, with 0.153 sq. km mean area, and a density of 0.11 depressions per sq. km (Ghiță, 2009) (Table 4 and 5, Fig. 5b). In the north side of the drainage basin, the density of loess micro-depressions is lower, which is explained by the hydrogeological conditions (shallow groundwater and slight loess deposits).

Table 5. **Mean, maximum and minimum values of the investigated parameters**

Indicators		**A** (sq. km)	**P** (km)	**L** (m)	**W** (m)	**Rc**	**Ra**	**Rf**	**Ks**	**L/W**
Mean	Bărăgan	0.34	2.45	935.98	384.32	0.60	0.61	0.31	0.76	2.87
	Mostiştea	0.153	1.32	456.85	226.45	0.71	0.73	0.44	0.83	1.99
	Călmățui	0.07	0.78	294.15	160	0.59	0.76	0.46	0.9	1.79
Max	Bărăgan	2.82	12.47	3652.31	1762.03	0.96	0.95	0.71	0.98	12.95
	Mostiştea	2.78	12.1	3339.88	940.6	0.96	2.37	4.41	0.98	5.56
	Călmățui	0.74	8.90	1783.1	1530.7	0.99	0.97	0.78	0.99	4.99
Min	Bărăgan	0.01	0.38	148.91	67.10	0.01	0.25	0.05	0.1	0.96
	Mostiştea	0.0012	0.13	44.29	42.45	0.18	0.39	0.12	0.43	0.99
	Călmățui	0.01	0.14	51.5	32.3	0.17	0.10	0.14	0.48	1.07

In the Călmățui drainage basin, 300 micro-depressions have been analysed, summing 23 sq. km. The highest density and dimensions occur in the western and southern part of the basin, on loess deposits (188 depressions). In the central sector, on loess-like deposits, the micro-depressions are less numerous (92), have a circular form and more reduced dimensions (Albu, 2012) (Table 4 and 5).

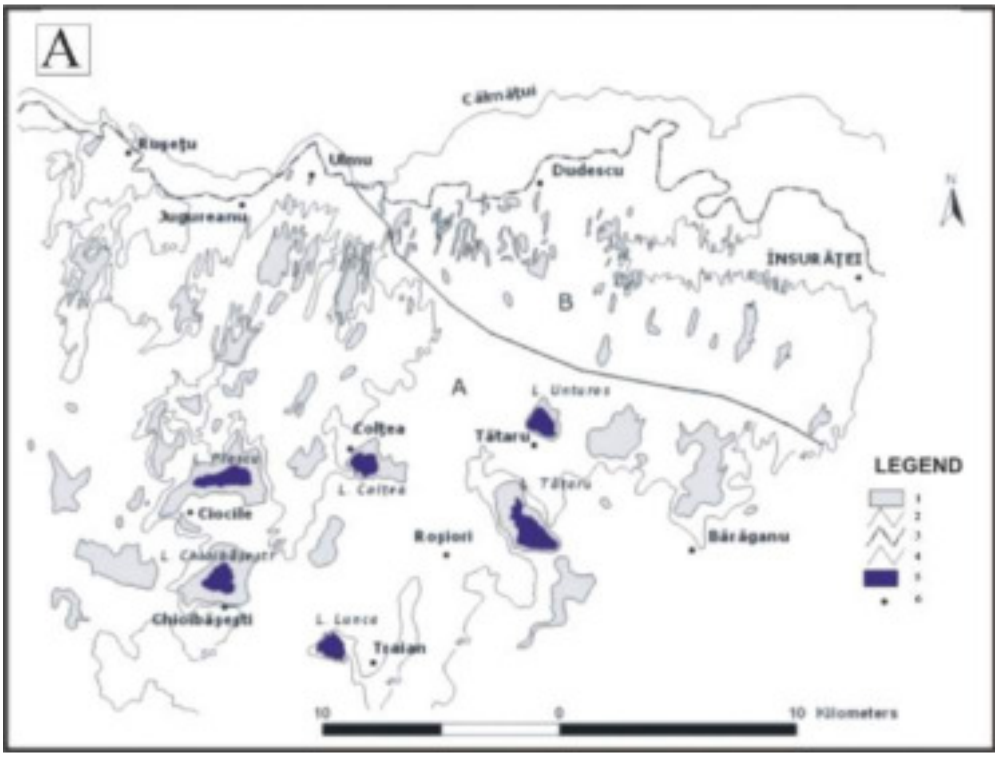


Fig. 5 a. **Central Bărăgan Plain – loess micro-depressions**
(1 – depressions; 2 – elevation; 3 – limit of the plain; 4 – rivers; 5 – lakes; 6 – localities)

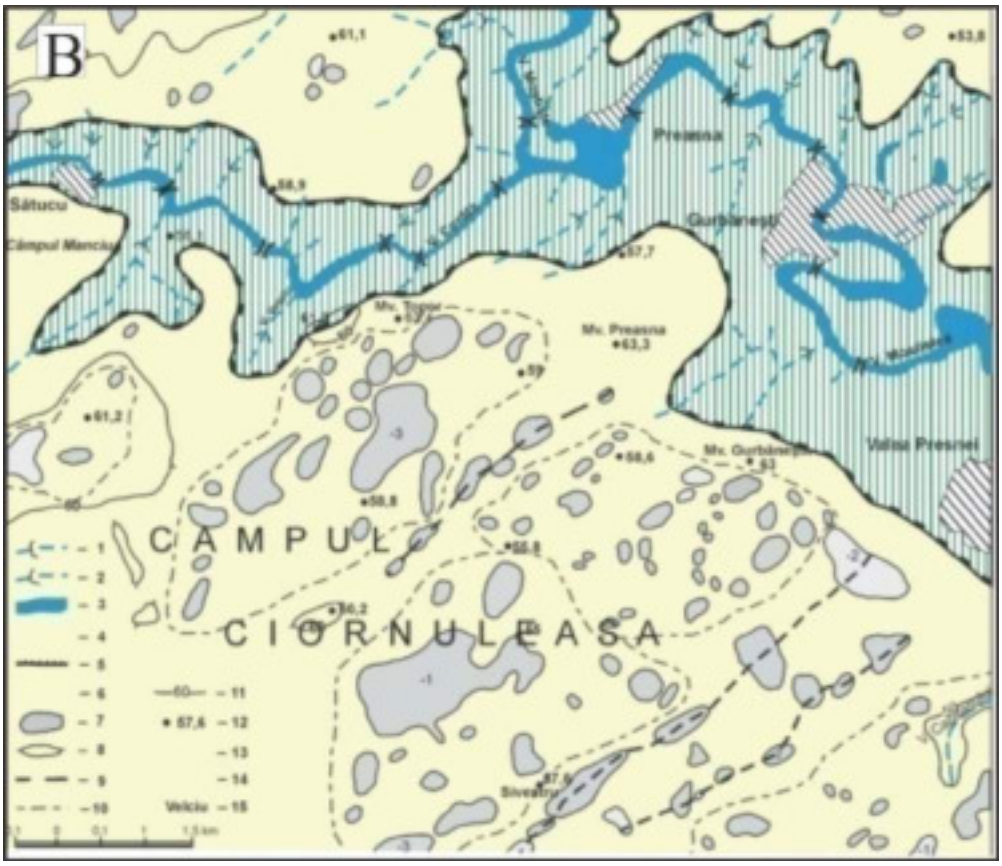


Fig. 5 b. **Ciornuleasa area (the Mostiştea basin)** (1 – overdeveloped small valleys with flat floor; 2 – small valleys, U-shaped in cross-section; 3 – artificial lakes; 4 – Mostiştei and Corâta valleys; 5 – the morphologic contact between the valley and the field relief; 6 – the morphological surface of the field; 7 – micro-depressions; 8 – earth mounds; 9 – micro-depressions alignements; 10 – limit of the areas with micro-depressions of different sizes; 11 – countour line; 12 – elevation; 13 – locality; 14 – toponym).

Table 6. **Diachronic analysis (1972-2009) for some loess micro-depressions in Burnaz Plain** (Văcaru, 2010)

Micro-depression	**Period**	**Length** (km)	**Width** (km)	**Area** (sq. km)	**(L/W)**	**Rc**	**Rf**	**Land use**
Şerpătească	1972	3.25	2.15	4.5	1.51	0.54	0.42	swamp
	2009	3.8	2.3	5	1.65	0.44	0.34	arable
Stoeneşti	1972	2.4	**1.25**	**2.2**	1.92	0.48	0.38	swamp
	2009	2.92	**2.15**	**5**	1.35	0.74	0.58	arable
La Padină	1972	0.75	0.35	0.6	2.14	1.36	1.07	swamp
	2009	0.9	0.4	0.7	2.25	1.11	0.86	arable

In the Burnaz Plain (Fig. 1 - D), the depressions are larger. The *diachronic analysis* (more than 30 years) highlights morphometric (maximum 2.8 sq. km enlargement, and 0.07 sq. km per year) and morphographic differences (slight elongation), due mostly to groundwater level oscillations and to intensive arable practice (Table 6, Fig. 6 a and b).

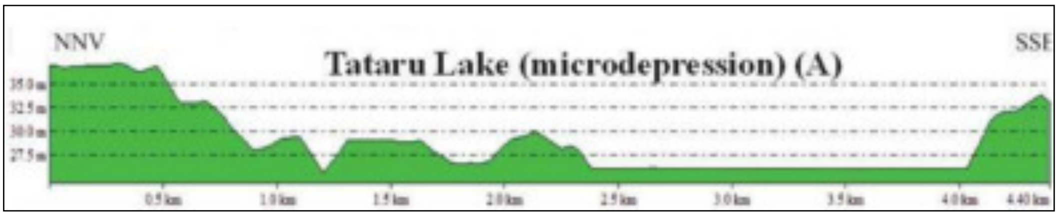


Fig. 6 a. **Transversal profiles in Central Baragan Plain**
(Tătaru Lake) in Burnaz Plain (Stoeneşti and Şerpăteasca micro-depressions)

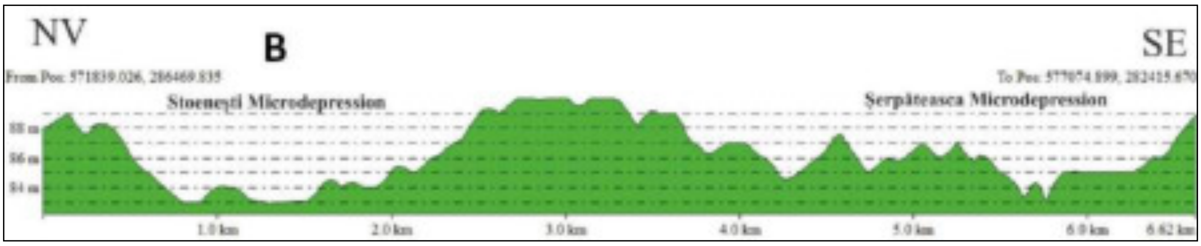


Fig. 6 b. **Transversal profiles in Burnaz Plain** (Stoeneşti and Şerpăteasca micro-depressions)

4.3. The shape of the micro-depressions

*The circularity coefficient (**R_c**)* which is reported to a circle, points out large differences between the micro-depressions within the investigated areas. In the Central Bărăgan, its values range from 0.01 to 0.96, 69% of the micro-depressions having values above 0.5. The highest values of the circularity coefficient, and consequently the circular shapes, are specific for the small-area depressions. Elongated micro-depressions can be found in the northern part of the plain, related to aeolian sand deposits and to dune landscape. In the Mostiştea drainage basin, circular loess micro-depressions are found especially on the Ciornuleasa area and on the Danube's terraces (85.86%). In Călmăţui drainage basin the micro-depressions developed on loess have a lower circularity ratio $R_c = 0.52$ comparing to those developed on loess-like deposits, much more rounded ($R_c = 0.65$).

The elongation ratio (***Ra***) shows that 55.4% of the loess micro-depressions in the Bărăgan Plain are elongated, while 65.9% of those in the Mostiştea catchment have more rounded shape. In Călmăţui drainage basin the mean value of Ra is 0.76, the micro-depressions developed on loess-like deposits being slightly elongated.

*The shape factor (**Rf**)*, which is defined with reference to a square, ranges from 0.31 in the Bărăgan Plain, 0.44 in the Mostiştea catchment and 0.46 in Călmăţui drainage basin. This coefficient clearly shows that the shape of the micro-depressions in Bărăgan is much more elongated (93.5% of the micro-depressions with values below 0.5), than the ones developed in Mostiştea and Călmăţui catchments. In the northern part of the Bărăgan Plain, this is explained by the influence of prevailing winds (north-northeast to south-southwest) on the sandy and loamy-sandy deposits (Fig. 5a).

*The sinuosity coefficient (**Ks**)*, which is reported to a circle, varies from 0.1 to 0.98. Our analysis indicates that most of the micro-depressions from the studied areas have values higher than 0.5, which means a less sinuous shape of the micro-depressions.

In the Bărăgan Plain, *the length to width ratio* (***L/W***) range between 0.96 and 12.95, while the average value is 2.87, and is exceeded by 65% of the micro-depressions (Table 4). The highest values of this parameter generally correspond to the inter-dune depressions lying on the Holocene sands in the northern part of the plain, which are extremely elongated (Gherghina *et al.*, 2008). In the case of the Mostiştea catchment, the values of this ratio range from 0.99 to 5.56, while the average is 1.99. For Călmățui catchment the L/W ratio vary between 1.07 and 4.99, but the mean value is even smaller than in the other two regions (1.78), with small differences considering the deposit (2.00 on loess and 1.57 on loess-like deposits) (Albu, 2012).

5. Discussions and conclusions

Both the size and the shape of the micro-depressions are elements that make the difference between the loess micro-depressions in the study areas, which are influenced to a large extent by the bedrock features.

In the Central Bărăgan Plain, the depressions are larger and more elongated (in the north), whereas in the Mostiştea catchment they are mainly small and rounded. One can note certain differences between both the investigated areas and at the level of the entire plain. In the Central Bărăgan Plain, on the Holocene sands in the northern section, loess depressions are smaller, less elongated and less sinuous, while in the central part of the plain they are larger, deeper, more sinuous and rounded. At present, several authors consider that the genesis of loess micro-depressions is controlled by water accumulation and stagnation, the dissolution of the salts within the loess and the relocation of the particles, which lead to the reduction of sediment volume and to the appearance of an obvious pit. As the pit grows, more water percolates the deposits, dissolving and removing the carbonates. Consequently, compaction becomes very active and the loess micro-depressions grow in area and depth. It can be ascertain the poly-and multi-genetic feature of the padding, the final causal process being represented by the compaction in deposits with high porosity. Groundwater near the surface contributes to the increasing of the intensity of compaction processes (by decreasing the porosity of loess-like deposits), and also to the emergence of numerous springs that influence the high density of river network (the Romanian Plain between the Olt and the Argeş).

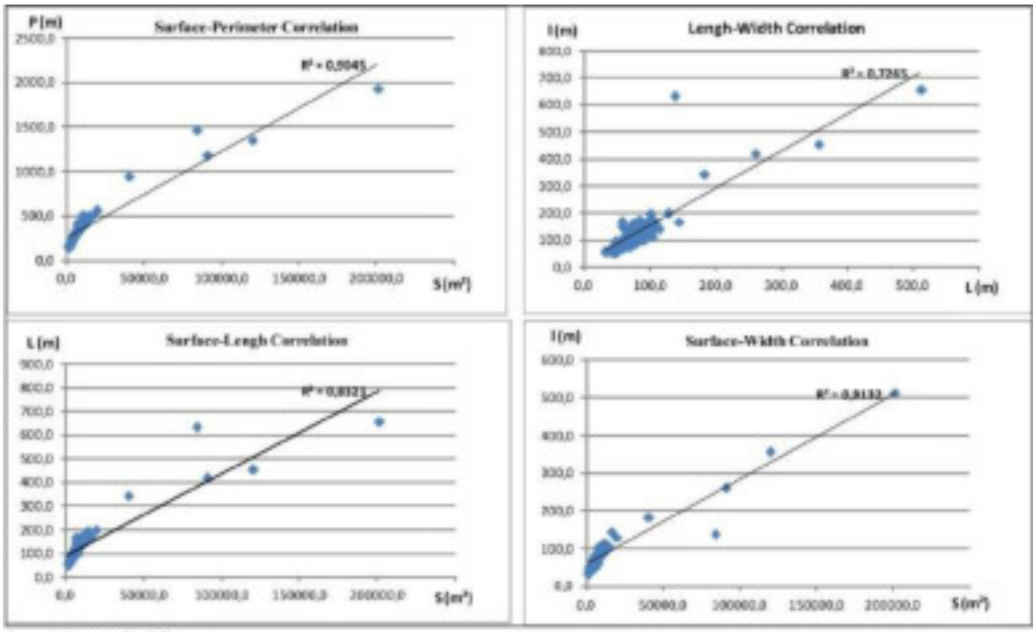
Field observations and morphometric and diachronic analyses (1972 and 2009) show the growth tendency of the dimensions of the large depressions (Table 6).

The analysis of the measured parameters reveals differences imposed by the collapsibility and permeability of the deposits, as follows:

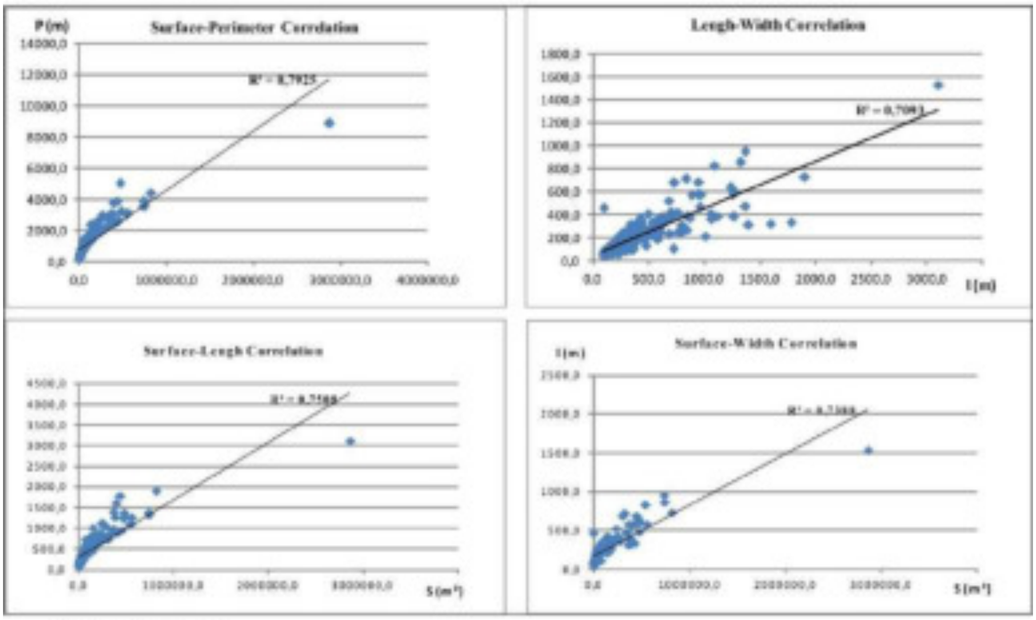
- the highest values correspond to the micro-depressions from Bărăgan, whereas the lowest belong to the ones in Călmățui basin;
- medium values, compared to the ones in the above-mentioned areas, have the micro-depressions from the Mostiştea basin;
- a special situation occurs into Burnaz Plain, where the generally large dimensions of the micro-depressions are due to the presence of the permeable Frăteşti gravels strata substratum.

The values of the measured parameters (surface-perimeter, length-width, surface-length, and surface-width) show a better correlation for the micro-depressions developed on loess, than the ones developed on loess-like deposits (Fig. 7). It can be ascertained the poly- and multi-genetic feature of micro-depressions, the compaction in deposits with high porosity constituting the final causal process. In the areas with the deep groundwater, chemical content compaction prevails due to calcium carbonate dissolution (*e.g.* the central part of Ialomița Bărăgan, Mostiştea Bărăgan) (Grecu *et al.*, 2010).

It is possible that the previous topography have influenced the loess sedimentation, but only the large depressions for which we do not have our own research; we do not debate the loess micro-depression genesis which still causes discussions**.** As the loess surface has initial relief, rain and surface flow and run-off will follow this initial relief with water remaining in shallow micro-depressions. This water will drain this part of the loess landscape. Water accumulation and stagnation, the dissolution of the salts within the loess and the relocation of the particles are the main factors which lead to the reduction of sediment volume and to the appearance of an obvious depression. As the depression grows, infiltrating water dissolves and removes the carbonates. The dissolution and the sensitivity of deposit to compaction becomes very active (*The norms regarding constructions foundation*, 2008) and the loess micro-depressions grows in area and depth. The rain drops and aeolian erosion have influenced the morphometry and morphography of the loess micro-depressions. Spatial distribution of depressions and their size are related to the characteristics of loess and loess-like deposits. The characteristics of loess and loess-like deposits, important in the genesis and evolution of the micro-relief from the Romanian Plain are: the thickness, the content in soluble salts, grain size, the porosity/loosening degree of the rock in the presence of water (this allows certain collapsibility).



A - typical loess



B - loessid deposit

Fig. 7 . **Correlation of parameters of the micro-depressions developed on loess (A) and on loess-like deposits (B) in Călmățui basin.**

Where groundwater is near the surface, the slope changes by leakage (surface and groundwater) and by compaction due to hydrodynamic piping dominates (*e.g.* Ialomița Bărăgan, the northern part). The large and sudden variations in the level of rivers intensify the underground drainage, which in its turn determines the piping of the above deposits. This is the case of the micro-depressions aligned along some valleys (*e.g.* Mostiştea Bărăgan). The large rivers assert the drainage direction and the groundwater level decreasing with the distance to the hydrographic arteries; it results that the density in relief's fragmentation is directly proportional with the increasing of the groundwater level (ex.

semi-endoreic areas of Central Bărăgan, Mostiştea, Burnaz).

Local peculiarities are due to synergetic relationships between groundwater, the hydrographic network, and the interfluves dynamics. On a relatively small area, there is a great diversity of these relationships that are connected by the general palaeogeographic evolution of the region (Grecu *et al.*, 2009, 2010).

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REFERENCES

ALBU (DINU), M., (2012), *Bazinul morfohidrografic Călmățuiul teleormănean – geneza, evoluția şi dinamica reliefului,* Teză de doctorat, Universitatea din Bucureşti, Bucureşti.

ANDREI, G., (1971), *"*Câteva considerații asupra formării şi evoluției crovurilor din sudul Câmpiei Române*"*, *Studii Tehnice şi Economice*, C, 19.

BĂLESCU, S., LAMOTHE, M., PANAIOTU, C.E., PANAIOTU, C.G., (2010), "La chronologie IRSL des séquences loessiques de l'est de la Roumanie", *Quaternaire*, Paris, 21, 2, 115-126.

BALLY, R. J., ANTONESCU, I., PERLEA, V., (1968), "Unele aspecte ale defomării masivelor de loess sensibile la umezire", *An. I.C.I.F.P., seria Hidrotehnica,* vol. II, Bucureşti.

BOLLINNE, A., PISSART, A., BASTIN, B., JUVIGNE, E., (1980), "Étude d'une dépression fermée près de Gembloux; vitesse de l'érosion des tèrres cultivées de Hesbaye", *Ann. Soc. Geol. Belg.* 103, 143-152.

BRĂTESCU, C. (1937), *"*Criterii pentru determinarea vârstei teraselor quaternar*e"*, in vol. *„Omagiu lui C. Kirițescu*", Bucureşti.

CIORNEI, AL., RĂILEANU, P., (2000), *Cum dominăm pământurile macroporice sensibile la umezire. Posibilități de fundare a construcțiilor în P. S. U.*, Ed. Junimea, Iaşi, 285 p.

CÎRCIUMARU, E., (2011), *Geneza, evoluția şi dinamica actuală a bazinului morfohidrografic Vedea*, Teză de doctorat, Universitatea din Bucureşti, Bucureşti.

CONEA, A., GHIȚULESCU, N., VASILESCU, P., (1963), "Considerații asupra depozitelor de suprafață din Câmpia Română de Est", *Studii Tehnice şi Economice, C,* 11, Bucureşti.

COQUE, R., (2000), *Géomorphologie*, Sixième èdition, Armand Colin, Paris, 504 p.

COTEȚ, P., (1976), *Câmpia Română. Studiu de geomorfologie integrată*, Ed. Ceres, Bucureşti, 256 p.

FLOREA, N., (1970), "Câmpia cu crovuri, un stadiu de evoluție al câmpiilor loessice", *STE*, C, 16, Bucureşti.

FLOREA, N., (2010), "Loess was formed, but not sedimented", *Revue Roumaine de Géographie/ Romanian Journal of Geography*, 54, (2), Bucureşti, 159-169.

FRIELINGHAUS, M., VAHRSON, W.G., (1998), "Soil translocation by water erosion from agricultural cropland into wet depressions–morainic kettle holes", *Soil Tillage Res.* 46, 23-30.

FULLER, M.L., (1922), "Some unusual erosion features in the loess of China", *Geographical Review* 12, 570-584.

GHERGHINA, A., (2009), *Bărăganul Central - Sinergism microrelief-depozite-sol,* Teză de doctorat, Universitatea din Bucureşti, Bucureşti.

GHERGHINA, A., GRECU. F., COTEȚ, V., (2006), "The loess from Romania in the romanian specialists vision", *Lucrările Simpozionului "Factori şi procese în zona temperată*", Ed. Universității "Al. I. Cuza" Iaşi, 5, 103-116.

GHERGHINA, A., GRECU, F., MOLIN, P., (2008), "Morphometrical Analysis of Microdepresions in the Central Baragan Plain (Romania)", *Revista de Geomorfologie,* 10, Ed. Universității din Bucureşti, 31-38.

GHIȚĂ, C., (2009), *Geneza, evoluția şi dinamica actuală a bazinelor morfohidrografice din Câmpia Română de Est. Aplicații la bazinul Mostiştea,* Teză de doctorat, Universitatea din Bucureşti, Bucureşti.

GHIȚĂ, C., GHERGHINA, C.-A., MOLIN, P., GRECU, F., (2012), „Analiza morfometrică a crovurilor din Câmpia Română de Est", *Lucrări şi rapoarte de cercetare, Volumul III, 19-29,* Editura Universității din Bucureşti.

GILLIJNS, K., POESEN, J., DECKERS, J., (2005), "On the characteristics and origin of closed depressions in loess-derived soils in Europe - a case study from central Belgium", *Catena*, Volume 60, Issue 1, 43-58.

GRECU, F., (2010), *Geografia câmpiilor României,* Ed. Universității din Bucureşti, 256 p.

GRECU, F., (COORD.), ZAHARIA, L., GHIȚĂ, C., COMĂNESCU, L., CÎRCIUMARU, E., ALBU, (DINU) M., (2012), *Sisteme hidrogeomorfologice din Câmpia Română. Hazard - vulnerabilitate - risc,* Edit. Universității din Bucureşti, Bucureşti, 330 p.

GRECU, F., CÂRCIUMARU, E., GHERGHINA, A., GHIȚĂ, C., (2006), *"*Semnificația reliefogenă a depozitelor cuaternare în Câmpia Română*", Comunicări de Geografie*, X, 21-36.

GRECU, F., SĂCRIERU, R., GHIȚĂ, C., VĂCARU, L., (2009), "Geomorphological landmarks of the eastern Romanian Plain. Holocene evolution", *Z.Geomorph*. N.F., 53, Suppl.1, 99-110.

GRECU, F., DEMETER, T., (1997), *Geografia formațiunilor superficiale*, Ed. Universității din Bucureşti, 150 p.

GRECU, F., PALMENTOLA, G., (2003), *Geomorfologie dinamică*, Ed. Tehnică, Bucureşti, 392 p.

GRECU, F., GHERGHINA, A., GHIŢĂ, C., COMĂNESCU, L., (2010), “Environmental synergy in the Romanian Plain (to the east of olt river)”*in Scientific Annals, School of Geology,* Aristotle University of Thessaloniki, Proceedings of the XIX CBGA Congress, Thessaloniki, Greece, Special volume, Ed. Charis Ltd, Thesaloniki, 100, 71-80.

HALLIDAY, W.R., (2007), “Pseudokarst in the 21st century”. *Journal of Cave and Karst Studies*, 69, 103-113.

IELENICZ, M., (2004), *Geomorfologie*, Editura Universitară, Bucureşti, 344 p.

INSTITUTUL GEOLOGIC, Harta Geologică, scara 1:200 000 (1965-1968), Comitetul de Stat al Geologiei, Bucureşti.

JOSAN, N., PETREA, R., PETREA, D., (1996), *Geomorfologie generală*, Editura Universităţii din Oradea, Oradea, 408 p.

KERTESZ, A., SCHWEITZER, F., (1991), “Geomorphological mapping of landslides in Hungary a case study of mapping Danubian bluffs”, *Catena* 18, 529-536.

KUKIN, A., MILJKOVIĆ, N.S. (1988), “Hemijska eroizija (sufozija) na lesnim zaravnima Vojvodine kao analogna pojava vrtačama u karstu”, *Zbornik 8. kongresa Jugoslovenskog društva za proučavanje zemljišta*, 73-79.

LEGER, M., (1990), “Loess landforms”, *Quaternary International* 7-8, 53-61.

LITEANU, E., (COORD) (1969), *Harta hidrogeologică*, scara 1: 1 000 000, Institutul Geologic, Comitetul de Stat al Geologiei, Bucureşti.

LITEANU, E., GHENEA, C. (1966), “Cuaternarul din Romania, Studii Tehnice şi Economice”*, seria H. Geologia Cuaternarului*, 1, 119 p.

MANIL, G., PECROT, A., (1950), “La cartographie pédologique de la région de Gembloux. In: IWONL (Ed.)”, *Comptes rendus de recherches-travaux du Comité pour l’établissement de la carte des sols et de la végétation de la Belgique*. IWONL, Brussel, 73-85.

MARKOVIĆ, S.B., MCCOY, W.D., OCHES, E.A., SAVIĆ, S., GAUDENYI, T., JOVANOVIĆ, M., STEVENS, T., WALTHER, R., IVANIŠEVIĆ, P., GALIĆ, Z. (2005), “Paleoclimate record in the Late Pleistocene loess-paleosol sequence at Petrovaradin Brickyard (Vojvodina, Serbia)”, *Geologica Carpathica* 56, 483-491.

MARKOVIĆ-MARJANOVIĆ, J. (1949), “Tamiš loess plateau”, *Geologic Annals of the Balkan Peninsula* 17, 46-59.

MARTONNE, EMM. DE (1935), “Traité *de Géographie Physique*”, tome second, *Le relief du sol*, Librairie Armand Colin, Paris, 1058 p.

MEEUWIS, A., (1948), “La représentation cartographique des depressions sans écoulement”, *Bull.-Soc. R. Belge Geogr.* 72, 201-215.

MORARIU, T., (1946), “Câteva consideraţiuni geomorfologice asupra crovurilor din Banat”, *Revista Geografică*, anul II, fasc. I-IV, 1945, Bucureşti, 37-50.

MURGOCI, GH., PROTOPOPESCU-PACHE, EM., ENCULESCU, P., (1908), “Raport asupra lucrărilor făcute de secţia agrogeologică în anul 1906-1907”, *Anuarul Institutului Geologic*, I, Bucureşti.

MỎGA, J., NEMETH, R. (2005), “The morphological research of the basalt and loess covered plateaus in the Bakony mts. (Transdanubian Middle Mts. – Hungary)”, *Acta carsologica* 34, 397-414.

NORTON, L.D., (1986), “Erosion–sedimentation in a closed drainage basin in Northwest Indiana”, *Soil Sci. Soc. Am. J.* 50, 209-213.

PANAIOTU, C.G., PANAIOTU, C.E., GRAMA, A., NECULA, C., (2001), “Paleoclimatic record from a loess-paleosol profile in southeastern Romania”, *Physics and Chemistry of the Earth, Part A: Solid Earth and Geodesy*, 26, 893-898.

PARICHI, M., STĂNILă, A.-L., (2009), “Contribuţii la cunoaşterea solului din padinile situate în Câmpia Burnasului”, *Analele Universităţii Spiru Haret, Seria Geografie*, 12, 115.

PÉCSI, M., (1993), *Quaternary and loess research*, Loess in FORM, 2, Geographical Research, Institute Hungarian Academy of Sciences, Budapest, 375 p.

PISSART, A., (1956), “L’origine périglaciaire des viviers des Hautes Fagnes”, *Ann. Soc. Geol. Belg*. 79, B119–B131.

PISSART, A., (1958), “Les dépressions fermées de la région Parisienne-le problème de leur origine”, *Rev. Geomorphol. Dyn*. 9, 73– 83.

POSEA, GR. (1987), “Tipuri ale reliefului major în Câmpia Română”, *Terra,* XVIII(XXXIX), 3, Bucureşti.

POSEA, GR., BOGDAN, O., ZĂVOIANU, I., COORD. (2005), *Geografia României*, vol. V, *Câmpia Română, Dunărea, Podişul Dobrogei, Litoralul românesc al Mării Negre şi Platforma Continentală*, Edit.Academiei Române, Bucureşti, 968 p.

PROTOPOPESCU-PACHE E., (1923*),* “Cercetări agrogeologice în Câmpia Română dintre valea Mostiştei şi râul Olt”, *Dd SIG I,* Bucureşti, 58-118.

PROTOPOPESCU-PACHE, E., CRĂCIUN, F., POPESCU, D., (1966), “Loessuri şi pământuri loessoide ca roci macroporice în R.S.R”, *Hidrotehnica, Gospodărirea apelor Apelor, Meteorologia*, 11, nr. 6, Bucureşti.

RĂDAN S. C. (2012) - Towards a synopsis of dating the loess from The Romanian Plain and Dobrogea: authors and methods through time, *Geo-Eco-Marina*, 18, Bucharest.

ROGERS, C.D.F., DIJKSTRA, T.A., SMALLEY, I.J. (1994), “Hydroconsolidation and subsidence of loess: Studies from China, Russia, North America and Europe”, *Engineering Geology* 37, 83-113.

ROZYCKI, S.F., (1991), *Loess and loess-like deposits*, Ossolineum. Publishing house of Polish Academy of Sciences, Wroclaw, 187 p.

SPIRESCU, M., (1970), “Loessuri şi soluri fosile în România”, *Studii Tehnice şi Economice*, Seria C, 16, Com. Geol., Bucureşti.

SUMMERFIELD, M.A., (1991), *Global Geomorphology*, Pearson Education Limited, Edinbourg, 538 p.

SURDEANU, V., (2003), “Contribuţii ale profesorului Tiberiu Morariu la studiul procesului de sufoziune”, in *Tiberiu Morariu. Magistrul Şcolii geografice clujene*, Editura Presa Universitară Clujeană, Cluj-Napoca, 78- 82.

TANG, G.A., LI, F.Y., LIU, X.J., LONG, Y., YANG, X., (2008), “Research on the slope spectrum of the Loess plateau”, *Science in China Series E, Technological Sciences* 51, 175-185.

TUFESCU, V., (1966), *Modelarea naturală a reliefului şi eroziunea accelerată*, Editura Academiei, Bucureşti, 618 p.

VĂCARU, L., (2010), *Bazinul hidrografic Neajlov. Studiu de geomorfologie dinamică*, Teză de doctorat, Universitatea din Bucureşti, Bucureşti.

VÂLSAN, G., (1916), “*Câmpia Română*”, *Buletinul Societăţii Române Regale de Geografie/Opere alese*, 1976, Ed. Ştiinţifică, 314-568.

VASILINIUC, S., TIMAR GABOR, A., VANDENBERGHE, D.A.G., PANAIOTU, C.G., BEGY, R. CS., COSMA, C., (2011), “A high resolution optical dating study of the Mostiştea loess-palaeosol sequence (SE Romania) using sand-sized quartz”, *Geochronometria*, 38 (1), 34-41, DOI: 10.2478/s13386-011-007-8.

VIJULIE, I., (2010), *Dinamica peisajului rural în Câmpia Boianului*, Edit. Universităţii din Bucureşti, 326 p.

ZEEDEN, C., HARK, M., HAMBACH, U., MARKOVIĆ, S.B., ZÖLLER, L., (2007), "Depressions on the Titel loess Plateau: Form – Pattern – Genesis", *Geographica Pannonica* 11, 4-8.

ZHU, T.X., LUK, S.H., CAI, Q.G., (2002), "Tunnel erosion and sediment production in the hilly loess region, North China", *Journal of Hydrology* 257, 78-90.

*** (1970-1971) – *Hărți topografice*, 1: 25 000, 1: 50 000, 1: 200 000.

*** (2005) – *Ortofotoplanuri*, scara 1: 5 000.

*** (2008) – *Normativ privind fundarea construcțiilor pe pământuri sensibile la umezire colapsibile (The norms regarding constructions foundation)*, contract 347/2008-10-28, Universitatea Tehnică de Construcții, București.

[1]**University of Bucharest, Faculty of Geography,**
Department of Geomorphology, Pedology & Geomatics,
1 Nicolae Bălcescu Blvd, 010074, sect. 1, Bucharest, Romania
florinagrecu@yahoo.com
[2]**National RD Institut for Soil Science,**
Agro-chemistry and Environment -ICPA, Bucharest, Romania
61 Mărăşti Blvd, 011464, sect. 1, Bucharest, Romania
alina.eftene@icpa.ro
[3]**University of Constantine 3, Algeria**
benabbas.chaouki@gmail.com

The metamorphosis of a braided river channel during the last 100 years: Moldova River as a case study

Francisca CHIRILOAEI[1], Maria RĂDOANE[1]

Abstract. In this paper we discuss the response of a braided river to climate and human changes in the last 100 years. Between Gura Humorului and the confluence with Siret River, on a length of about 110 kilometres Moldova River has the features of a braided river channel, supplied with water and coarse sediments by the tributaries which originate from the area of crystalline and flysch mountains. Between years 1910 and 2005, the river channel of Moldova River continuously narrowed on a descendent linear trend until about 76%. At the same time, the marginal vegetation extended its surfaces within the alluvial plain from 38% in 1960, to 71% in 2005. The result is the metamorphosis of river channel from braided to wandering and from wandering to sinuous. The phenomenon has first installed downstream of the extra-Carpathian reach and migrates towards upstream.

Key words: planform channel changes, braided channel, narrowing, Moldova River

1. Introduction

River channels represent a natural environment with great potential for change, in time. This is the reason why the interest of the scientific community is focused on them, for better understand the manner of response to different driving factors. Perhaps the most interesting, according to many researchers opinion (Hooke, 2000; Brierley & Fryirs, 2005; Rădoane *et al.*, 2013b), is the answer to the following question: how sensitive are the natural environment components to climate changes in the last century? The necessity of responses with high degree of accuracy made that the interest for rivers and landforms to increase of good reasons: on one hand, because the adjacent areas of rivers are the most used in human terms, and on other hand, these hydro-geomorphological landforms may be considered true research laboratories of temporal changes.

Choosing a period of 100 years to assess the phenomenon of river channel change at reach scale is motivated by the source of evidences used to asses these changes (in this case, instrumental registrations from year 1959 and cartographic documents, from year 1910). For Romania, the oldest cartographic sources for a detailed analysis of planform channel chan ges are dated in 1764 (Transylvania) and 1894-1910 (for the rest of the territory) (Rădoane *et al.*, 2013a). Considering the European context, the evaluation period of river channel planform changes on basis of cartographic documents can reach 200-250 years (Surian *et al.*, 2009).

In this context, overall, we wanted to know the type of response of a braided river to climatic and anthropic changes for the previous 100 years. Moldova River, between Gura Humorului and the confluence with Siret River presents the characteristics of a braided channel, supplied by water and coarse sediment by the tributaries which originate from crystalline and flysch mountains. The planform changes of Moldova River for a period of about 100 years can offer responses to the above questions, at least partially. This river channel can be considered a typical case of metamorphosis (complete transformation), in sensu Schumm (1969), through which a river modifies its dimensions, shape, gradient and channel typology as response to the alteration of water discharge and sediment load balance.

2. Study area and working methods

Study area is represented by the extra-Carpathian reach of Moldova River (downstream of Păltinoasa village (Table 1, Fig. 1) with a length of about 110 km. In this paper, our attention is focused on the alluvial plain, respectively on the river channel, active width and floodplain width and the modifications recorded in the last century. The general slope gradient of the river within this sector is 0.0021 m/m, which commonly indicates a river characterized by strong alluvial transport activity.

Table 1. **Characteristics of Moldova River and its drainage basin at 5 hydrometric stations (the grey band refers to the study area from this paper)**

Hydrometric station	River basin area A (km^2)	Elevation H (m)	River length (km)	Mean annual discharge (m^3/s)	**Suspended sediment load** (kg/s)
Fundu Moldovei	294	739	45	3.57	
Prisaca Dornei	567	657	94	7.30	2.44
Gura Humorului	1887	480	120	17.04	
Tupilați	4016	236	157	32.84	35.30
Roman	4299	180	213	35.27	16.10

The Moldova River crosses the first two units diagonally between Lucina Peak (1588 m) and Gura Humorului (480 m), and downstream from Gura Humorului to Roman (180 m), the river flows into the extra-Carpathian region, where the last two units are present. Consequently, metamorphic rocks, which are the most resistant to erosion, are located in the upper area of the drainage basin; sedimentary rocks, such as sandstones, limestone, and marls, are found in the median area of the basin; the most friable materials are present in the inferior part of the basin.

The petrographic diversity of the perimeter of the drainage basin and the high sediments reworking rates in this area are the main causes for the large extent of the extra-Carpathian floodplain of the Moldova River, which is an important area for exploitable mineral aggregates.

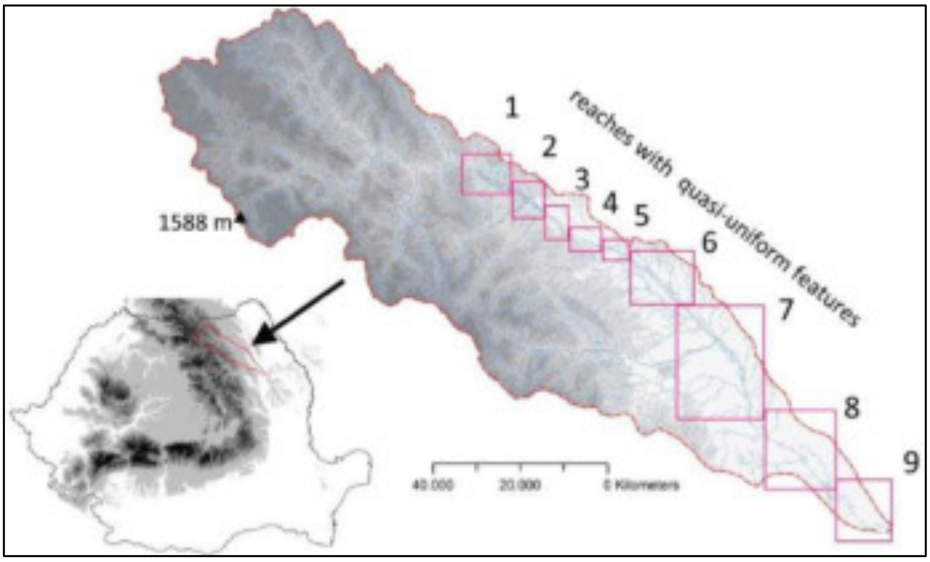

Fig. 1. **Location of the extra-Carpathian alluvial plain of Moldova River and the position of 9 reaches with quasi-uniform features. Discussions in text**

In order to elaborate the specific measurements regarding planform channel changes of Moldova River in the extra-Carpathian reach, we detain a consistent database, edifying for the last century: the Austrian maps from 1910, topographic maps edition 1960, topographic maps from 1980 and orthophotos, edition 2004-2006 (Table 2).

Table 2. **Synthesis of cartographic materials utilized in this study**

Name of the map	Date of survey	Scale	Projection	Institution	Spatial resolution
Third Austro-Hungarian military surveying	1890-1910	1:25.000	Stereographic Projection Tg. Mureş on Bessel ellipsoid 1841	Institute of Military Geography, Vienna	
Topographic maps	1957	1:25.000	Cylindrical Projection Gauss – Kruger Pulkovo 1942	Romanian Military Survey Service	
Topographic maps	1980 -1985	1:25.000	Cylindrical Projection Gauss – Kruger Pulkovo 1942	Department of Military Survey	
Orthophotos	2004-2006	1:5000	Stereographic Projection Stereo 70 Krasovschi Ellipsoid	ANCPI	0.5m/pixel

The methodology used to elaborate the measurements was described in detail by Rădoane *et al.*, (2013a) and we will not return to this aspect. It is very important to highlight the importance of segmentation in sub-reaches, as much as possible homogeneous of planform river channel, in order to avoid the alteration of obtained results. The delimitation of sub-reaches represents an activity based on expert type judgements regarding the abrupt changes in channel width, of braiding index, sinuosity index, lateral migration, human disturbances etc. (according to Rinaldi *et al.*, 2011). In the same manner was determined the degree of artificiality or human intervention on river channel which varies between 0 (completely natural) and 100 (completely artificial). For Moldova River, on the studied reach Rădoane *et al.*, 2013b calculated that almost 30% from river length is included in the category of low artificiality, 47% presents a moderate degree of artificiality and only 23% from river length presents a high morphological quality index (MQI). These values indicate that Moldova River evolved in quasi-natural conditions, and the factor that conducted to the increasing of the degree of artificiality is mainly represented by the presence of gravel pits and the damming of some sub-reaches.

3. Results

On a length of 110 km from the Carpathian exit of the river until the confluence with Siret, Moldova River presents the dominant features of a braided river with gravel bed, river banks with a height which does not exceed 2 m, composed by gravels and a layer of fine materials, sandy at surface. A more detailed analysis of planform configuration showed that there are 9 reaches where the type of channel may be different (Fig.1). A brief description of them is given below.

Sub-reach 1 (Păltinoasa-Berchişeşti). Presents a length of 11 km, semi-confined (degree of confinement of 62% and index of confinement of about 1.2, according to the methodology proposed by Rădoane *et al.* (2013a); it represents the exit of the river from the mountain area, with an average general slope of 0.0054m/m, average of floodplain width of about 1000 m, channel width, 234.2 m (in the last century the channel narrowed with 75.2%). It is ***braided*** type, with an average of the braiding index of 1.66. The degree of artificiality is 0.88, which means that the human disturbances in this reach are at small scale.

Sub-reach 2 (Berchişeşti-Cornu-Luncii), ***braided*** (braiding index, BI=2.29), 10.2 km length, non-confined. Average slope of this reach is 0.0051m/km, floodplain width, 1300 m and channel width, 573 m. The artificiality increases to 1.22, and this is given by the presence of 3 gravel pits, but also the presence of water works for supply public utilities, which contributes to the reduction of river channel water discharge.

Sub-reach 3 (Cornu-Luncii-Bogata (Baia). A non-confined reach (with no degree or index of confinement), 5.6 km length which fits to ***braided*** typology (BI=2.19). Mean slope along reach is 0.0033m/m, floodplain width, 2500 m and channel width, 650 m. The presence of 4 gravel mining points determines an increasing of the artificiality degree.

Sub-reach 4 (Bogata-Fântâna Mare) is a ***braided*** reach (BI=2.37), with a length 0f 9.7 km. At present, the channel is 293 m width and floodplain is 2100 m. Mean channel in this reach slope is about 0.0032m/m. Regarding the degree of artificiality or the human intervention, this reach is characterized by the presence of 3 gravel pits and, consequently, by a low degree of artificiality.

Sub-reach 5 (Fântâna Mare-Roşiori) with a length of about 8.4 km and characterized by a general slope of 0.003m/m, channel width, 754 m and floodplain width, 2500 m. This reach is braided (BI=2.72). An explication of channel width increasing in this reach may be the contribution (water and sediments) brought by right tributary, Râşca River, but also the high erodability of river banks in the area Fântâna Mare-Roşiori, which determines sediment supply downstream and automatically is a favourable factor for channel widening. In this reach, human intervention is represented by 4 gravel pits, such as the degree of artificiality is 0.65.

Sub-reach 6 (Roşiori-Cristeşti), braided (BI=2.79) with a length of about 13.3 km and a general slope of 0.0027m/m. The reach is non-confined, with no degree or index of confinement, consequently characterized by no lateral constraint and a braiding index in a continuous decrease, from 3.71 (1960) to 2.79 (2005). Channel width average is 389 m and floodplain width about 3000 m. In this reach we identified 5 gravel pits, with a degree of artificiality of about 0.68.

Sub-reach 7 (Cristeşti-Tupilaţi), a braided reach, non-confined, with a length of about 25.1 km. Channel width is 329 m, floodplain width 2100 m and the general slope is 0.0021m/m. The very well sorted gravels reserve determined an intensification of exploitation along time, in present being active more than 10 gravel pits.

Sub-reach 8 (Tupilați-Cordun) represents a semi-confined reach, with a degree of confinement of 38%. Channel width average is 214 m, floodplain width, 1100 m, general slope, 0.0017m/m. At the moment, the reach has a transitional channel, from braided to wandering (even sinuous) (BI=1.61); this value is very close by the 1.5 threshold and BI is diffuse. The degree of artificiality is 0.35, characterized by the presence of 2 gravel pits.

Sub-reach 9 (Cordun-confluence with Siret River-Cotu Vameş) is a sinuous reach, with a sinuosity index of 1.18 and a length of approximately 6.6 km. Channel width is 99 m, floodplain width, 900 m and channel slope, 0.0013m/m. Regarding the human intervention in this reach, it is characterized by the damming of the river channel (in order to protect Roman city) and gravel pits less as number, 1 respectively.

A succession of cartographical imagery depicting reach no. 3 shows significant decadal changes in terms of the decrease in the number of branches and channel narrowing (Fig. 2A). Channel adjustment mechanisms, at least post-1950, occurred in relation to an increase in streamflow discharge and decreasing suspended sediment load (Fig. 2C). Intensive extraction of coarse sediment in the 101 gravel plants distributed along Moldova River contributed to a large extent to channel narrowing and incision. The volumes of mineral aggregates extracted in interval 2009-2011 varied between 1.071 and 0.868 x 10^6 m^3. These quantities represented 54% from the alluvial materials supplied by the source area basin, 458 $m^3/km^{-2}year^{-1}$, respectively (Rădoane *et al.*, 2013b). Thus, in the 1950-2010 period, the mean monthly streamflow discharge increased with 20% (according to the general trend of increase of the precipitations in the NNE side of Siret drainage basin). Regarding the suspended sediment load discharge, this also increased with 55%, in the same interval.

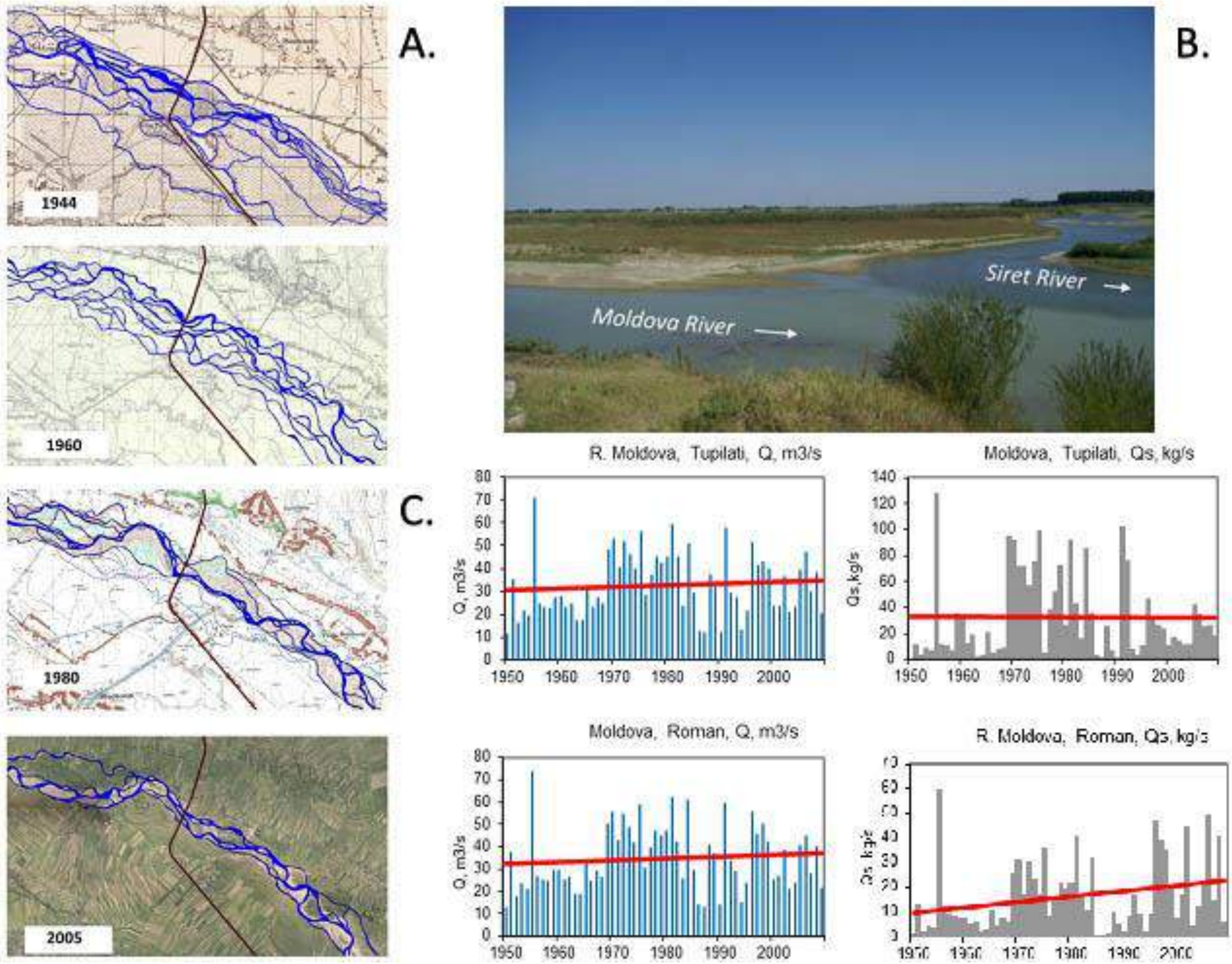

Fig. 2. **A. Succession of cartographic imagery of reaches no. 2 and 3 of Moldova channel between 1944 and 2005, showing the decrease of the number of branches and the invasion with vegetation of old isles. B. Junction between Moldova and Siret rivers. The sediment load of the river originates from the gravel plants. C. The multiannual variation of streamflow discharge and suspended sediment load in the extra-Carpathian sector of Moldova (the tendency of increase in suspended sediment load in the closing section of the river is a result of sediment remobilization by intensive gravel mining, particularly post-1995).**

Moreover, anthropogenic intervention within the channel led to an increment in suspended sediment load towards the junction with Siret River, thereby explaining the increasing suspended sediment load values in Roman, particularly after 1995 (Fig. 2C). In the image showing the junction of the two rivers the high suspended sediment load of river Moldova is apparent; considering the absence of flood events within its drainage basin, this image is conclusive for the anthropogenic effect in sediment remobilization.

In conclusion, at least for the previous decades, the extra-Carpathian reach of Moldova River presents a controlled morphological quality, natural and anthropogenic, as follows: a natural increase of streamflow discharge according to the general trend of the increase of precipitations; a decrease of the volume of coarse material and an increase of the sediment suspended load, both phenomenon due to the presence of 101 gravel pits distributed along the river. These aspects, as discussed in the next sections of the paper, present direct and quiet dramatic effects on the morphological elements of the river channel.

3.1. Channel planform changes

From the given example (Fig. 2), we can deduce that the parameter with the most significant modifications in planform configuration is channel width. This index has the most sensitive adjustment to flow regime changes and determines the modification of all other variables of river channel geometry. Gravel bedrivers corroborated with erodible banks (such as Moldova River) are the best examples in this sense. Channel width of Moldova River continuously narrowed on a linear descendent trend, in the last century, from 1219 m (1910) to 691 m (1960), 487.6 m (1980) and 293.6 in 2005. If channel width from 1910 is considered 100%, than the mean narrowing for the extra-Carpathian reach, was about 43% in 1960, 59% in 1980 and 76% in 2005 (Table 3). We can remark 2 phases of narrowing: a first one, more pronounced, until 1960 (a narrowing of about 10.5m/year) and a second one, after 1960, with a narrowing of approximately 8.8 m/year.

The total narrowing (in %) for the 110 km length (extra-Carpathian reach) is not uniform; it varies along the reach from 47% in the median course to 85.6% near the confluence with Siret River. We consider that this variability is given by the succession of sedimentation areas, separated by sectors with relative narrowing called nodes, is well preserved and evidenced by the variation of the braiding index along the river (Fig. 3B). It is related to the pulsating mechanism of water and sediment transport (Church & Jones, 1982; Bertoldi *et al.*, 2008), resulting in an alternation of transport zones (whereby the channel is “almost unitary”, acting as nodes) and sedimentation zones (whereby accumulation occurs in the sense of isles and lateral erosion increases). In the case of Moldova River, the graphs of the braiding indices in three successive time frames during the past 45 years show the sequence of nodes and sedimentation zones, as well as the continuing loss in amplitude of the latter. Instead, the position of nodes remained largely unchanged throughout this entire period. Sedimentation zones also develop vertically, *i.e.* the thickness of Holocene sediments along Moldova consists of a succession of “alluvial fans”, as labelled by Ichim (1979), with maximum thickness in the proximal area (Fig. 3A).

Channel narrowing is correlated also, with the modification of braiding index. This parameter was estimated using Ashmore (1991) method (defined also by Egozi & Ashmore, 2008) in order to eliminate as much as possible the imperfection of subjective measurements. Overall, the braiding index indicates a decrease in the last 50-60 years, from 3.2 (1960), to 2.6 (1980) and 2.0 in 2005. We did not take into account the year 1910, because of the lack of precision in mapping the channel braids. In time, the flow concentrated, the number of braids reduced (from maximum 10 in 1960 to 8 in 1980 and approximately 5 in 2005). The decrease of braiding index took place at the same time with the reduction of bar surfaces and after that, their transformation in islands and floodplain annexation (marginal vegetation). This mechanism was surprised within a year (Fig. 4).

Tabel 3. **Mean values of channel width (meters) and total narrowing (%) for the 9 reaches**

Year	Reach1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9
1910	938.46	1053.32	1290.78	1201.47	1380.36	1239.89	1573.13	1048.74	687.55
1960	493.46	573.01	699.89	582.02	731.33	758.72	757.32	768.47	630.69
1980	416.64	479.94	519.47	469.05	756.77	644.46	535.76	409.59	235.75
2005	234.16	363.36	657.04	293.59	754.70	389.15	320.43	214.58	99.57
Total narrowing (%)	75.2	65.3	49.1	75.1	47.0	68.6	79.7	79.6	85.6

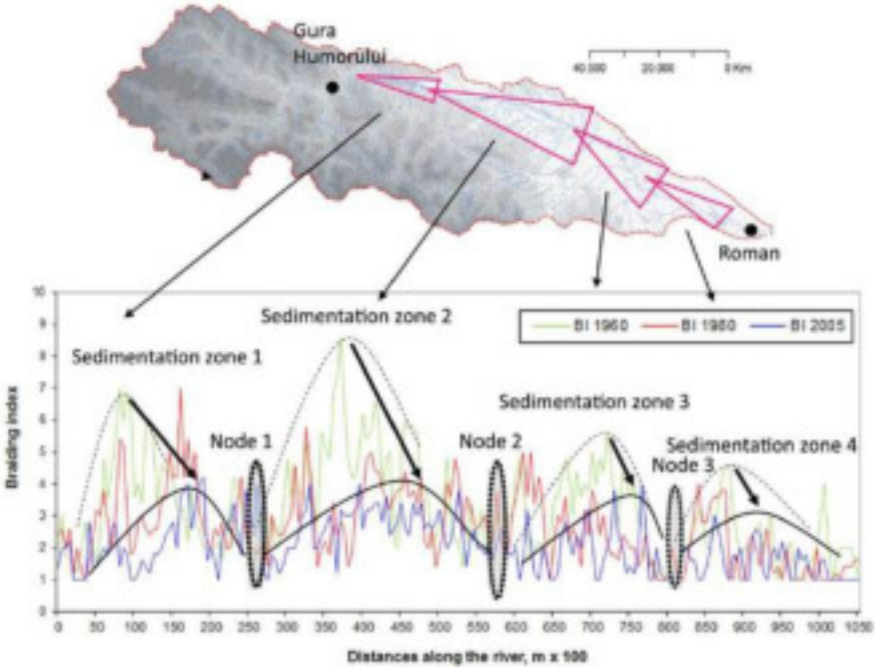

Fig. 3. **A. Location of the large alluvial fans identified also in vertical plan along the extra-Carpathian reach of Moldova. B. Spatial-temporal variation of the braiding index on river Moldova – extra-Carpathian sector, 1960-2005. The decreasing amplitude of sedimentation zones, as the channel underwent narrowing and the number of branched diminished, is highlighted in the chart.**

Fig. 4. **Bar evolution through annexation to an island and transfer from within channel vegetation to marginal vegetation (Păltinoasa area)**

Table 4. **Synthesis of braiding index values for the 9 reaches of Moldova River**

Year	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9
1960	3.4	3.33	2.71	3.02	5.64	3.71	3.12	2.22	1.96
1980	2.57	3.37	2.67	2.82	2.9	3.36	2.56	1.93	1.22
2005	1.66	2.29	2.19	2.37	2.72	2.79	1.94	1.61	1.09
%	48.8	68.8	80.8	78.5	48.2	75.2	62.2	72.5	55.6

Braiding index evolution for each of the 9 reaches analysed is presented in Table 2. The most affected were the areas overlapped on sedimentation zones 1, 2 and 3 from Fig. 3A, and the least affected the reaches superimposed on the nodes areas. In reach 9, the last one before the confluence with Siret River, the braiding was already reduced in 1960 and almost totally disappeared in 2005, river channel becoming wandering-sinuous.

Additionally to braiding index, the sinuosity index was also determined in different considered moments in time. If in the year 1960 none of the 9 reaches was characterized by pronounced sinuosity (all sinuosity values registered were situated under 1.03), in 2005 the lowest reaches (7, 8 and especially 9) started to be more and more sinuous (SI exceeds 1.1) (Table 5).

Table 5. **Synthesis of sinuosity index values for the 9 reaches of Moldova River**

Reach 9	Year	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8
1.09	1960	1.03	1.02	1.05	1.01	1.01	1.01	1.02	1.04
1.10	1980	1.01	1.01	1.02	1.01	1.01	1.01	1.02	1.05
1.18	2005	1.03	1.01	1.03	1.02	1.03	1.01	1.10	1.12

In conclusion, the 3 morphometric variables analysed (channel width, braiding index and sinuosity index) indicate with high fidelity the river channel metamorphosis of Moldova River during the last monitored 100 years. All these variables are registering a threshold between reaches 6 and 7; here is the point where a change of channel typology occurs. In the synthesis diagram which summarises this observation (Fig. 5) we can deduce that typology changing tendency migrates from the confluence with Siret River towards upstream, and the sinuous and wandering types are replacing the braided typology.

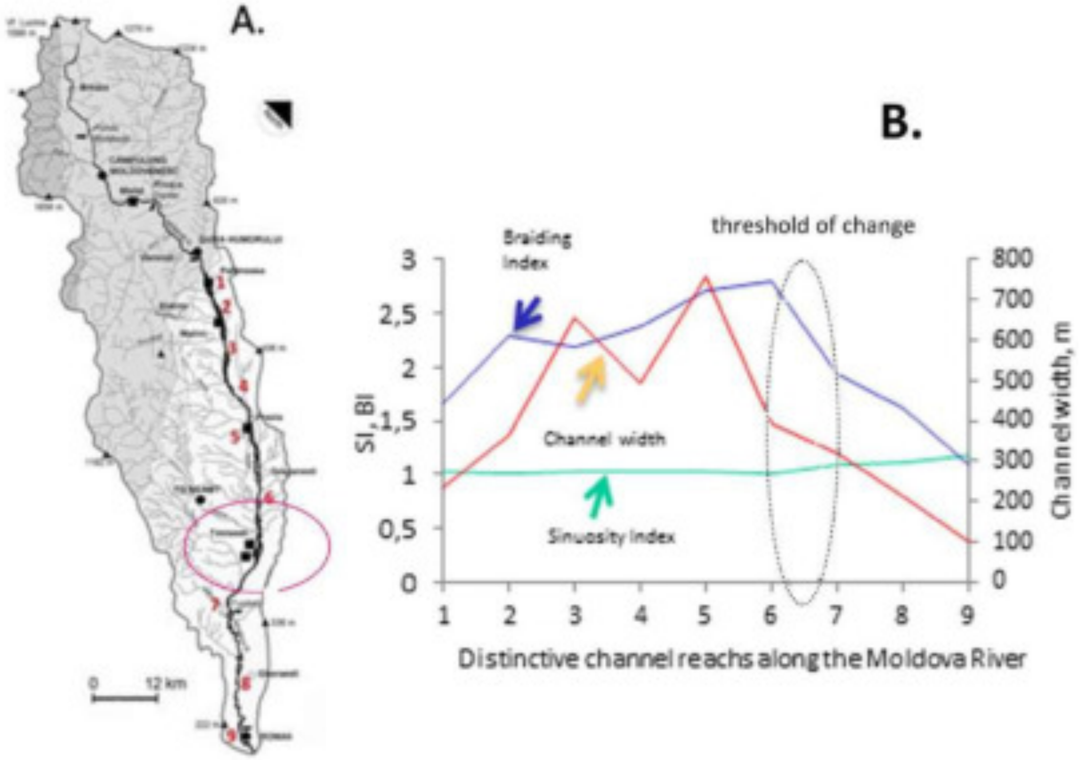

Fig. 5. **Threshold of channel typology change from braided to wandering-sinuous between reaches 6 and 7 and its upstream migration tendency.**

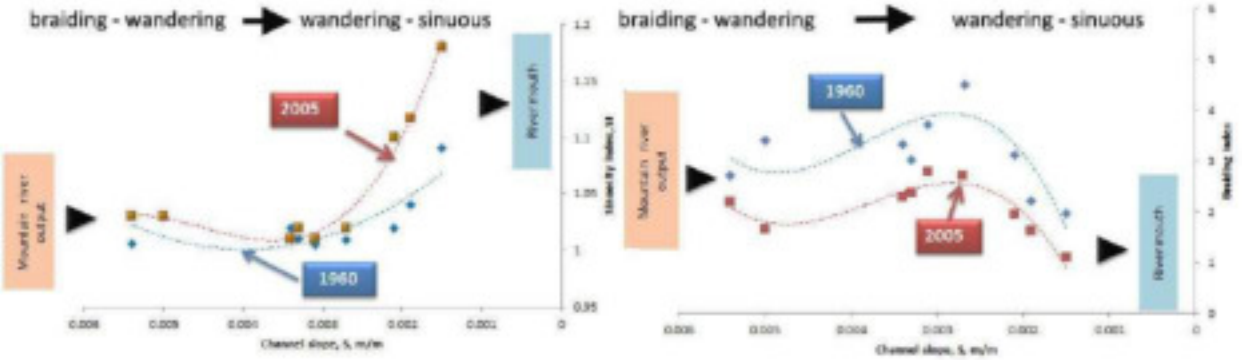

Fig. 6. **Relationship between channel slope (S) and sinuosity (SI) and braiding (BI) indices on the extra-Carpathian sector of river Moldova. Each correlation point stands for an average value for each of the 9 representative reaches in 1960 and 2005**

This mechanism is better understood if we analyse how the two morphometric indices (sinuosity, SI, and braiding, BI) and channel slope, S, are related (Fig. 6). Between 1960 and 2005, on its 110 km-long course between the exit from the Carpathian area and the junction with River Siret, the sinuosity index begins to change at slope values of about 0.003 m/m. In 2005 the flexure of the sinuosity curve around 1.2 is much sharper compared to 1960, when SI was barely above 1.05. At present, the process of channel change from braided-wandering to wandering-sinuous is in progress. Moreover, a decrease in the braiding index (BI) also occurs at slope values around 0.003 m/m, with values dropping from above 4 to under 2.

3.2. Vegetation cover dynamics

The alluvial plain of Moldova River is covered with vegetation represented especially by mesophilic and meso-xerophile meadows. To this can be added species of hygrophile vegetation in the areas with humidity exceed and floodplain meadows, along the main course, secondary braids and even tributaries. In the area Bogata-Baia, Bogdănești and Râșca there are big surfaces covered with hygrophile vegetation. Specific to Moldova River floodplain are genera: *Phragmites, Potamogetus, Ranunculus, Polygonum, Mentha* etc.

In the past, within the alluvial plain of Moldova River the groves and meadows were much more extended. With time, deforestation was conducted and this phenomenon continues at the present. The forests that we can observe along Moldova River nowadays are those from Baia-Cornu Luncii area. At the same time with deforestation, the agricultural area increased, and other surfaces from Moldova River floodplain, after hydro-amelioration works, were covered with cereals and technique plants (Râşca-Baia zone) (Amăriucăi, 2000).

The measurements realized in the first 4 reaches along the extra-Carpathian reach of Moldova River (with a length of about 36.5 km) showed that marginal vegetation developed continuous in the last decades, detrimental to active channel width (unvegetated) and vegetation developed within the channel. The results represented in Fig. 7 are edifying.

Marginal vegetation extended continuously its occupied surfaces from 38% in 1960, to 71% of the alluvial plain in 2005. At the same time, the surface of islands and active width progressively decreased, concomitant with the channel incision and narrowing phenomenon. In islands case, the surface decreases from approximately 30% to 8% and the active width from 32% to 20% (from 400 ha to 200 ha).

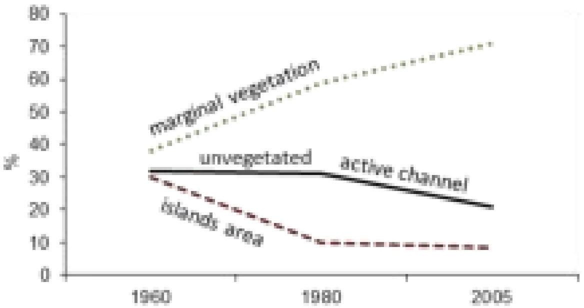

Fig. 7. **Proportion of the alluvial plain occupied by the unvegetated active channel, marginal vegetation and islands**

In conclusion, channel planform adjustment is founded in direct relation with the modifications of riparian vegetation. The decrease of channel width means actually the advancement of arboreal vegetation and shrubs in the domain within river channel (braids or older bars). This type of vegetation, especially the arboreal through the radicular system, contributes intensively to the acceleration of incision and narrowing of river channel.

4. Discussions and conclusions

The increased interest for knowing the temporal tendencies of channel changes, their magnitude and causality is determined by the necessity of choosing the best management measures of rivers. The case of the behaviour of Moldova River is representative for Romanian geographic area, being one of the few classic braided rivers (BI reached values of about 5.64, in reach 5, Table 4).

The changes registered by the morphometric indexes of channel narrowing in this paper are not singular, they subscribe to the general trend surprised for other rivers at continental level. Not few of about 32 European rivers were cited by Rădoane *et al.* (2013b) with similar behaviour like Moldova River, and in Romania rigorous researches conducted to similar results for Prut River (Rădoane *et al.*, 2008), Someșul Mic River (Perșoiu, 2010), Prahova River (Armaș *et al.*, 2012). Moreover, river metamorphosis in recent times was not confined to the European territory and was also documented in China, South America, the USA, or Canada (James, 1997; Paige & Hickin, 2000; Stover & Montgomery, 2001; Amsler *et al.*, 2005; Price & Leigh, 2006; Simon & Rinaldi, 2006; Li *et al.*, 2007).

In the synthesis realized by Rădoane *et al.*, (in press) is shown that for rivers in Romania, compared with those in Western Europe, the changes are smaller (62% from the studied cases) under the aspect of incision (with magnitudes between 0.15-1.25 m). At the same manner, regarding the degree of narrowing, smaller changes are registered at Carpathian rivers, than to the Alpine ones. The reason is found, according to the authors quoted, into a much greater rhythm of sediment mobilisation from source areas towards delivery area in the studied zone than in other areas of Europe.

Concerning the temporal tendencies of channel changes, the modifications of channels towards incision and narrowing began with the 20th century, and in the last 30-40 years, the reports were numerous for different regions of Europe. For the region of Italy we detain the most detailed analysis of temporal and spatial changes of river channel for the last 100 years (Surian *et al.*, 2009). The authors divided 4 phases: phase 1 until 1950, phase 2 between 1950 and early 1990 and phase 3 after 1990. Our own observations are synchronized with the ones made by Surian *et al.* (2009), with the mention that the decade 1980-1989 was marked by the changes with the highest magnitude, in the case of Moldova River channel.

The mechanism through which the river controls its own metamorphosis is represented by the variability of general slope. Figure 6 is edifying in this sense. The metamorphosis of river channel from braided to wandering status takes place through a sensitive slope modification, and the migration of this change is manifested from downstream towards upstream. We think that wandering type will migrate also towards upstream and replace braided style. In the lowest reaches (9 and especially, 8) the wandering and sinuous style from nowadays, will be replaced with meandered style in the future, a type much more stable and resistant to changes in time. The next steps in time when these metamorphoses are about to happen depends on the acceleration of human disturbances in strong relation with climatic global changes. At least for the next 50 years when economic pressure will increase progressively on river channels, we predict an accentuation of the tendencies highlighted in this paper. But, economic pressure must be supported/neutralized by a friendly legislation and a good sustainable management of rivers, such that their self-regulation lawfulness would be blocked as little as possible.

Acknowledgements

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REFERENCES

AMĂRIUCĂI, M. (2000), *Şesul Moldovei extracarpatice dintre Păltinoasa şi Roman. Studiu geomorfologic şi hidrologic*, Edit. Carson, Iaşi.

AMSLER M.L., RAMONELL, C.G., TONIOLO, H.A. (2005), ”Morphologic changes in the Parana River channel (Argentina) in the light of the climate variability during the 20th century”, *Geomorphology,* **70: 3-4**, 257-278.

ARMAȘ, I., GOGOAȘE NISTORAN, D.E., OSACI-COSTACHE, G., BRAȘOVEANU L. (2012), ”Morpho-dynamic evolution patterns of Subcarpathian Prahova River (Romania)”, *Catena*, **100**, 83-99.

ASHMORE, P. E., (1991),”How do gravel-bed rivers braid?”, *Canadian Journal of Earth Sciences*, **28**, 326-341.

BERTOLDI, W., ASHMORE, P., TUBINO, M., (2008),”A method for estimating the mean bed load flux in braided rivers”, *Geomorphology*, **103**, 330-340.

BRIERLEY, G.J., FRYIRS, K.A., (2005), *Geomorphology and River Management. Applications of the River Styles Framework*. Blackwell Publishing, 398 p.

CHURCH M., JONES D., (1982), ”Channel bars in gravel-bed rivers”, In: HEY R.D., BATHURST J.C. THOME C.R. (eds.), *Gravel-bed rivers*, Wiley, 291-324.

EGOZI, R., ASHMORE, P., (2008), ”Defining and measuring braiding intensity”, *Earth Surface Processes and Landforms*, **33**(14), 2121-2138.

HOOKE, J., (2000),”Spatial variation in channel morphology and sediment dynamics: Gila River, Safford Valley, Arizona”, *IAHS Publication*, 251-274.

ICHIM, I., (1979), *Munții Stânişoara. Studiu geomorfologic*, Editura Academiei, București, 123 p.

JAMES, L.A., (1997),”Channel incision on the lower American River, California, from streamflow gage records”, *Water Resources Research*, **33**, 485-490.

LI, L., LU, X., CHEN, Z., (2007), ”River channel changes during the last 50 years in the middle Yangtze River, the Jianli reach”, *Geomorphology*, **85**, 185-196.

PAIGE, A.D., HICKIN, E.J., (2000), ”Annual bed-elevation regime in the alluvial channel of Squamish River, Southwestern British Columbia, Canada”, *Earth Surface Processes and Landforms*, **25**, 991-1009.

PERȘOIU, I., (2010) *Recostruction of Holocene geomorphological evolution of Someşu Mic Valley*, Unpublished PhD thesis "A. I. Cuza" University, Iaşi, Romania.

PRICE, K., LEIGH, D., (2006), "Morphological and sedimentological responses of streams to human impact in the southern Blue Ridge Mountains, USA", *Geomorphology*, **78**, 142-160.

RĂDOANE, M., OBREJA, F., CRISTEA, I., MIHAILĂ D. (2013b),"Changes in the channel-bed level of the eastern Carpathian rivers: Climatic vs. human control over the last 50 years", *Geomorphology*, **193**, 91-111.

RĂDOANE, M., PERȘOIU, I., CHIRILOAEI, F., CRISTEA, I.. (in press),"Styles of channel adjustments in the last 150 years", In: RĂDOANE M., VESPREMEANU-STROE A. (eds.), *Landform and relief evolution in Romania*, Springer Verlag.

RĂDOANE, M., PERȘOIU, I., CRISTEA, I., CHIRILOAEI, F., (2013a), "River channel plan channel planform change based on successive cartographic data. A methodological form change based on successive cartographic data", *Revista de Geomorfologie*, **15**, 69-88.

RĂDOANE, M., RĂDOANE, N., CRISTEA, I., OPREA, D., (2008), "Evaluarea modificărilor contemporane ale albiei râului Prut pe granița românească", *Revista de Geomorfologie*, **10**, 57-71.

RINALDI, M., SURIAN, N., COMITI, F., BUSSETTINI, M., (2011), *Guidebook for the evaluation of stream morphological conditions by the morphological quality index*, Istituto Superiore per la Protezione e la Ricerca Ambientale, Rome, 84 p.

SCHUMM, S.A., (1969),"River metamorphosis", Journal of Hydraulics Division, 95, 255-273.

SIMON, A., RINALDI, M., (2006),"Disturbance, stream incision, and channel evolution: The roles of excess transport capacity and boundary materials in controlling channel response", *Geomorphology*, **79**, 361-383.

STOVER, S.C., MONTGOMERY, D.R., (2001), "Channel change and flooding Skokomish River, Washington", *Journal of Hydrology*, **243**, 272-286.

SURIAN, N., RINALDI, M., PELLEGRINI, L., AUDISION, C., MARAGA, F., TERUGGI, L., TURITTO, O., ZILIANI, L. (2009), "Channel adjustments in northern and central Italy over the last 200 years", In: JAMES L.A., RATHBURN S.L., WHITTECAR G.R. (eds.), *Management and Restoration of Fluvial Systems with Broad Historical Changes and Human Impacts*, Geological Society of America Special Paper, **451**, 83-95.

[1] **"Ștefan cel Mare" University of Suceava,**
Faculty of History and Geography, Department of Geography
13 Universității Street, 720229, Suceava, Romania.
francisca@usm.ro

Geomorphological processes within the alpine level of Parâng Mountains

Cătălina SĂNDULACHE[1], Iulian SĂNDULACHE[2], Florina GRECU[2],
Robert DOBRE[2], Anişoara IRIMESCU[3]

Abstract. The alpine level of Parâng Mountains is situated at altitudes higher than 1800 m a.s.l. over a surface of about 133 km2 (18.3%) of the whole environment covered by these mountains. The present-day relief modelling within this environment is conditioned by the variety of the climatic, bio-pedo-geographic and geomorphologic conditions superposing the lithological and structural substratum – tectonically complex, which induces a diversified morphodynamic potential. The anthropic activity adds to these conditions, representing a determining link in the geographic system of Parâng Mountains alpine level. In the identification and mapping of the present-day geomorphological processes, the genetic criterion was followed. The following types were identified in the alpine level of Parâng Mountains: periglacial processes and landforms (congelifraction, soil creep, periglacial elevation), nival processes (avalanches), wind-induced processes (eolization), gravitational processes (rock collapsing and rolling), pluvial and torrential processes (surface washing, rain-wash, torrentiality), fluvial processes (erosion and accumulation), along with biogenic and anthropic processes. There is a remarkable diversity of the present-day processes and of the resulted landforms, conditioned by altitude and by the morphoclimatic characteristics specific to the high mountains, framing within the level of the periglacial processes.

Keywords: Parâng Mountains, alpine level, potential morphodynamic processes, present-day geomorphological processes

1. Introduction and objectives

The present-day aspect of Parâng Mountains is just a stage in the long-standing evolution of these mountains which have been registering significant modifications along time. Due to the variety of the morphodynamic factors existing within this Carpathian environment, there is a wide range of ongoing geomorphological processes, of which the periodicity and intensity vary largely at regional level.

Mountain area characteristics derive from the general laws of nature and in this regard the altitudinal distribution of the geographical phenomena was imposed as a principle of the research, accessible for analysis of restricted areas or for synthesis of regional areas. The scientific and practical importance of the alpine area determined constantly investigated starting with De Martonne, since end of XIX century up to present-day. This interest for mountain research became more diversified during last 25 years, been connected with modern research techniques.

Two physical-geographical stages imposed by the altitude and morphoclimatic characteristics: the upper Carpathian level/alpine (above 1800 m) and the mean level/forest (800-1800 m), according to most studies regarding the mountains in the Southern Carpathians (Velcea, 1961; Niculescu, 1965; Iancu, 1970; Urdea, 2000; Voiculescu, 2002; Nedelea, 2006; Săndulache, 2007; Săndulache, 2010, Ielenicz and Oprea, 2011; Onaca *et al.*, 2011; Grecu *et al.*, 2011; Voiculescu & Ardelean, 2012; Popescu *et al.*, 2014; Vasile, 2015; Vasile *et al.*, 2014; Săndulache, 2014; Gheorghiu *et al.*, 2015). The recent PhD thesis can be added to the above mentioned studies. The alpine morphodynamic potential analysis is based on the lithological and structural elements, relief energy, drainage density, slope and slope exposure, vegetation, climate and human activity, which are variable in time and space with evolutions difficult to predict. The lithological and structural base, declivity, climatic and biotic factors together with the time lapse (having the role of controlling the relief and responding to the climate change reaction on it) are the key factors for alpine morphodynamic potential determination.

The main objective of the paper represents the inventory, classification and mapping of the actual geomorphological processes, based on in-situ measurements, observations and researches.

The description of the different process stages are presented based on data extracted from thematic maps and climatic data recorded. The final aim is to elaborate the geomorphological processes map that helps stakeholders from different economic sectors: agriculture (pastoral), tourism and construction (mountain resort – Rânca or Transalpina road).

2. Study area

The Parâng Mountain represents the high western part of the mountain group situated between the Olt and Jiu rivers within the Southern Carpathians in Romania. The geographic location (45030'N) determined the temperate continental climate with altitudinal variations (the maximum altitude is 2519 m on Parangul Mare Peak and the minimum altitude about 310 m at Bumbesti-Jiu at the Sadu and Jiu rivers confluence).

The major relief is dominated by the main ridge, oriented from west to east, carried on a length of 33,5 km, where the upper level of the Borascu erosion surface can be found above 2000 m high.

Parâng Mountains are located in the western half of the Southern Carpathians, being framed by Vâlcan Mountains at the west, Căpățânii and Latoriței mountains at the east, Şureanu Mountains at the north and Petroşani Depression at the north-west. The boundaries are mainly created by the hydrographic network: at the west – Jiu River, at the east- Oltețul River, Latorița, Lotrul and Jiețul at the north, only the southern border being the contact steepness between the mountain area and the Subcarpathian, Oltenia Depression.

The alpine area is approximately between the contour lines on the main and secondary ridges facing north. These morphometric characteristics together with the geographical location are reflected in the main landscape modelling factors.

The alpine level of the Parâng Mountains has an area of approximately 133 km2 (which represents 18.3% of the massif). It occupies about 48 km2 on the northern side (6.7% of the massif) and about 85 km2 on the southern side (11.7% of the massif). The glacial relief represents most part of the alpine level (glacial complexes from the Jieț and Lotrului springs), extended on corrugated interfluves present in Southern Parâng (Fig. 1a,b).

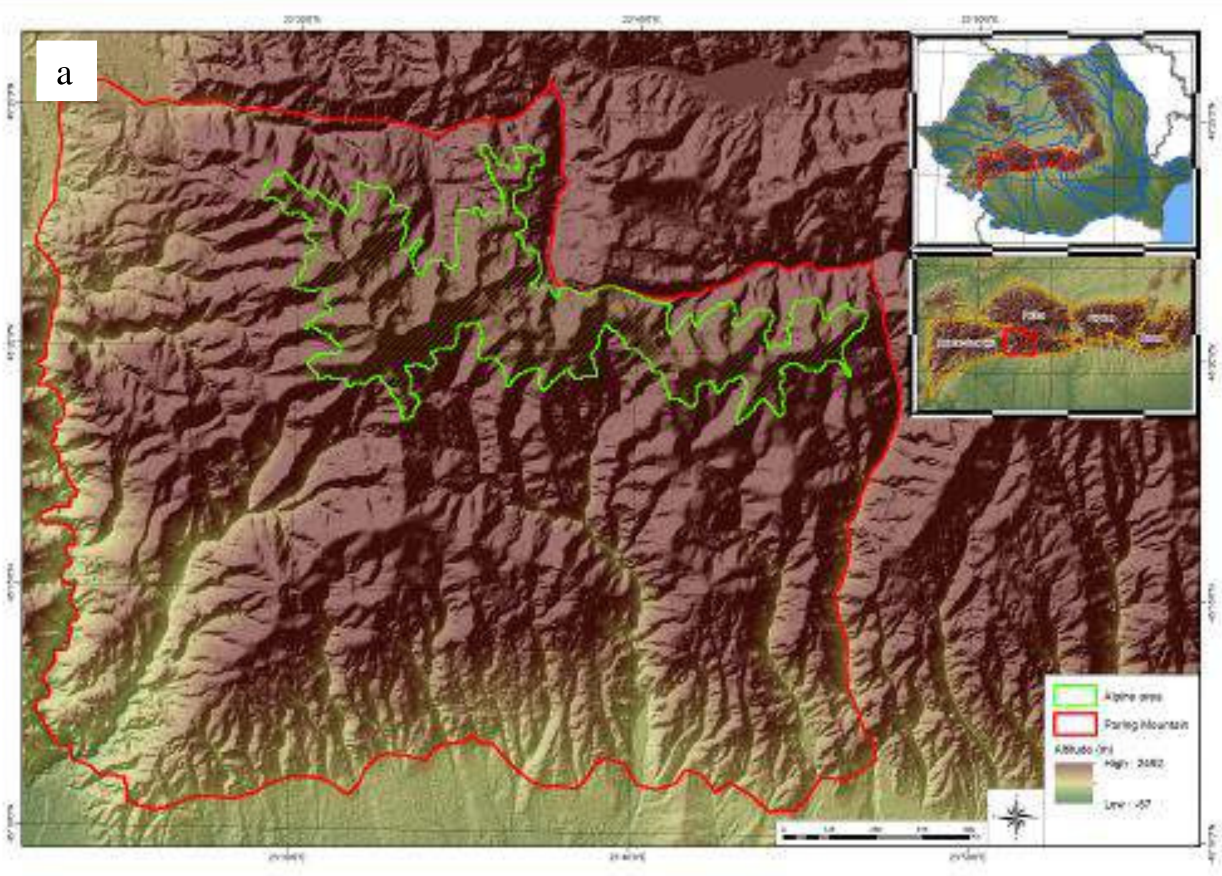


Fig. 1 a. **Geographic location of the Parâng Mountains**

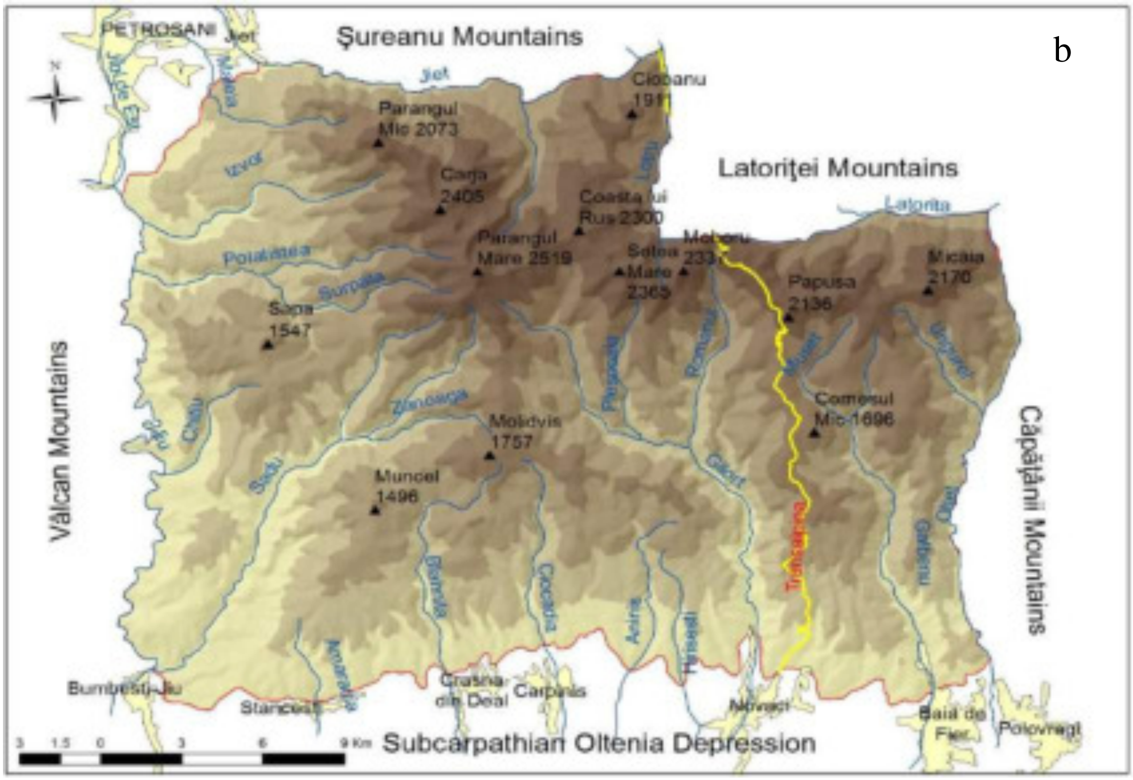


Fig. 1 b. **Geographic location of the Parâng Mountains**.

3. Data and Methodology

Various materials were used for the achievement of this study: the 1:25 000 topographic map, thematic (geological, pedological, vegetation) maps, contour lines extracted from the numerical terrain model (DEM), climatic data over a 20-year interval (1982-2002) from the weather stations in the area or the surroundings existing in the archive of the National Meteorological Administration, 1:5000 orthophotoplanes, tourist maps. The achieved stages aimed at: reading dedicated papers from the specialized literature, analysing the thematic maps, numerous field campaigns during which mapping of the alpine level was performed on the 1: 25 000 topographic map, processing charted elements in the 1:25 000 topographic map were processed using Microsoft Excel, on-field measurements and observations, taking pictures, processing weather data in ArcMap-GIS and Corel-Draw, receiving information from the Gorj and Hunedoara Mountain Rescue teams. The most difficult phase was the fieldwork mapping of the current processes, taking into account the difficult weather conditions at this stage and the physical effort required in high mountain; those have been worked on colour topographic maps at 1: 25,000 (copies, scale 1: 1 thereof) by going through the entire subalpine and alpine area of the mountain, mapping the current geomorphological processes by colour conventional signs; the resulting maps looked like ones in the Fig. 2.

4. Analysis and results

4.1. Morphodynamic potential

Geological factors. From the geological standpoint, in the alpine level of Parâng Mountains, crystalline schist rocks are remarkable (the central-western crest, west of Parângul Mare peak, the eastern summit, east of Păpuşa Peak, Sliveiul Mare glacial cirque within the Jieţ complex), granitic intrusions (the central crest, between Parângul Mare and Urdele peaks) and intrusions of crystalline limestones, pegmatite rocks and green tuffogenic rocks (Găuri cirque, within the Lotrului complex) (Fig. 3). Generally, these are hard and semi-hard rocks that may crack and disintegrate in the climatic conditions within the alpine level. The rocks resistance to the action of the external agents is revealed by the rock strength index. These rocks are generally hard and semi-hard, which may crack and disintegrate in the climatic conditions of the alpine area. The crystalline schist, granite, unspoiled and non-cracked limestone are hard rocks with a medium hardness of 5-6 (Mohs scale) and a strength coefficient of 8-15 (Protodiaconov scale), (Stamatiu, 1962). Semi-hard rocks (3-5 hardness) and soft rocks (2-3 hardness) are considered those with an advanced degree of cracking and deterioration.

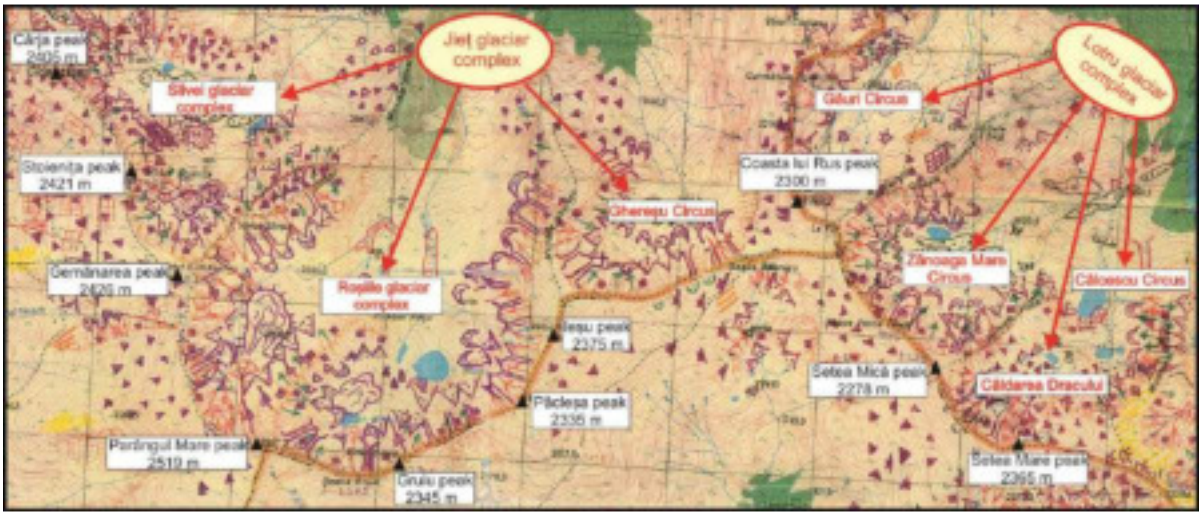


Fig. 2. **Topographic map in the fieldwork phase**

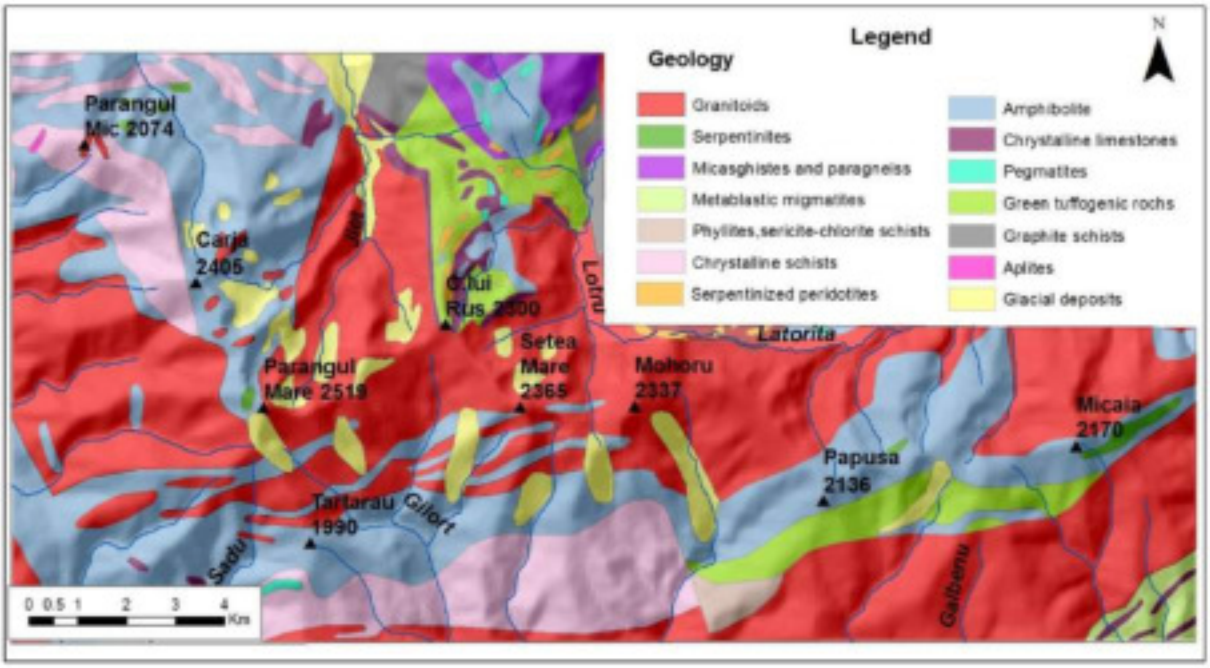


Fig. 3. **Geological map of the alpine level within Parâng Mountains (after the Geological Map, scale 1: 200 000, sheet 26 Orăştie and sheet 33 Tg. Jiu, 1968)**

Geomorphological factors. From the geomorphological standpoint high relief energies are remarkable of 300 – 400 m and over 400 m (in the central and western part) but also of 200 – 300 m (in the eastern part). The fragmentation density keeps high, more than 8 km/km2, within the glacial complexes Jieț and Lotru, displaying values of 6 – 8 km/km2 and 4 – 6 km/km2 towards the borders of the alpine area, both in the west and in the east. This is an indicator expressing the capacity to drain the water from precipitation in a shorter or longer time interval, which induces a high morphodynamic potential. Slopes are steep, reaching 20 – 30º and over 30º (on one side ad the other of the main crest and on the mountain sides of the glacial cirques), with slopes less than 15º steep (along the interfluvial summits and on the bottom of the glacial cirques) (Fig. 4). The declivity of the mountain sides influences the present-day morphodynamic potential, favouring the prevalence of certain processes or others. Thus, the steep inclines favour the activity of the cryogenic agents, while the mild inclines – the nival modelling. The slope is one of the determining factors in the acceleration of some present-day geomorphological processes, like avalanches, collapses and rock falling.

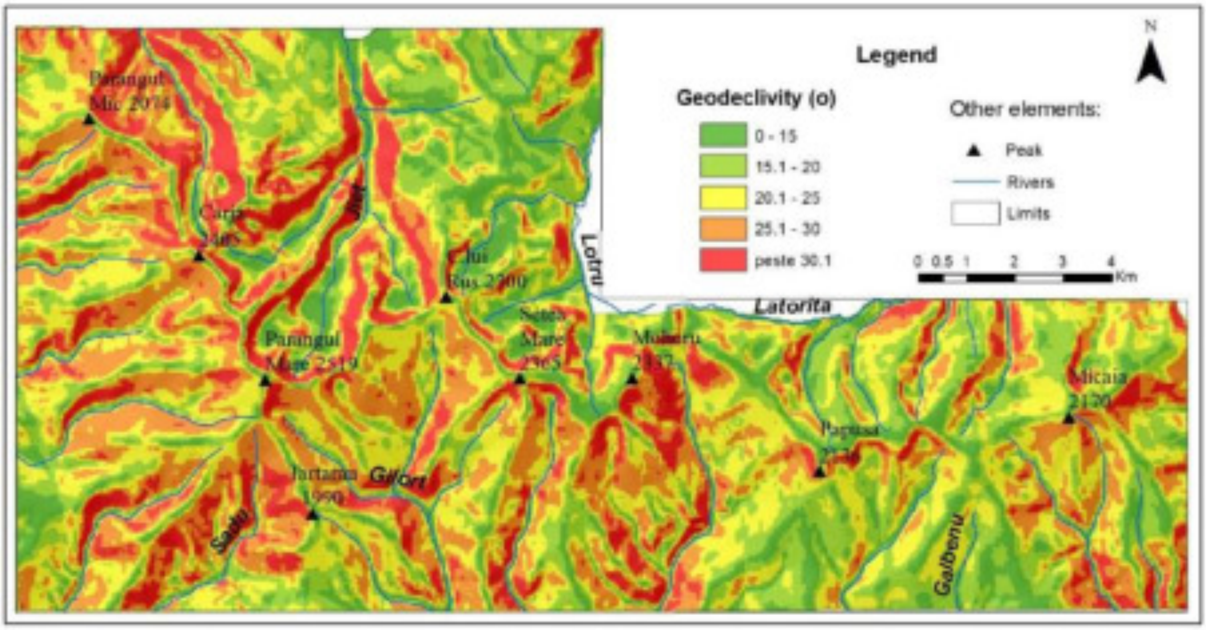


Fig.4. **Map of geodeclivity in the alpine level of Parâng Mountains**

Climatic factors. The analysed area unfolds in the circumstances of the alpine climate, within one cold and one very cool thermal stage and at the same time in one moderate-nival and one nivo-pluvial precipitation level respectively. In order to analyse the climatic parameters that condition the start, rhythm and intensity of certain present-day geomorphological processes, we used climatic data from the N.M.A. Archive and from three weather stations located in the Southern Carpathians, over a 20-year period (1982-2002) (Table 1).

Table 1. **Main climatic parameters characterizing the alpine level of Southern Mountains**

Weather station	Altitude/ exposure	Mean annual temp.	Min. abs. Temp.	No. of freezing days	Mean annual precip. mm	No. of days with rain
Omu Peak	2504 m/-	-2.3oC	-35.5oC	254	1136	55.2
Bâlea Lake	2038 m/ Northern	0.3oC	-27.4oC	208	1134	99.7
Parâng	1585 m/ South-Western	3.6oC	-23.5oC	160	938	86.6

Weather station	Altitude/ exposure	Max. precip. in 24 hrs.	No. of days with snow	No. of days with snow layer	Snow layer depth (cm) Mean/Max
Omu Peak	2504 m/-	83.5	111	220	32 / 132
Bâlea Lake	2038 m/ Northern	195.6	108	223	60.7 / 158
Parâng	1585 m/ South-Western	70.2	65	151	15.7 / 52

**data processed from the N.M.A. Archive (1982-2002)*

The role of the climatic factors is very important in the evolution of present-day dynamics, since they influence the type and intensity (rhythm, magnitude and duration) of every process, the climatic factors being considered initiating factors of many processes (congelifraction, avalanches, surface washing, streaming, ravine-formation, torrentially).

Analysis of the Peltier (1950) diagrams applied at weather stations situated at various heights in the Southern Carpathians (Voiculescu 2001; Grecu *et al.*, 2011), shows that the stations located above 2000 m (Omu Peak – 2505 m and Balea Lake – 2038 m) are within the area the most exposed to gelifraction, mass displacements and eolization and also within the area where alteration and fluvial erosion occur with a moderate/ weak intensity. Thus, it is proved that the intensity and periodicity of those geomorphological processes are direct influenced by the climatic factors. Experiments and temperature data sampled in the alpine area within the Bucegi, Făgăraş and Retezat Mountains in places with diverse slope and exposition show that the thermal values display function of slope and exposition (Vasile *et al.*, 2014, Vasile, 2015).

However, the periglacial processes vary in surface function of the rock type and vegetation cover degree, according to our in-situ observations and mapping.

Biotic and pedological factors. The vegetation of the alpine summits is not unitary, displaying differentiations with respect to the environment conditions between the upper and the lower parts of those sectors, which trigger the existence of totally different vegetation within the sub-alpine and alpine level respectively. The main components of the sub-alpine vegetation are: the alpine bushes made up of boreal-alpine and alpine shrubs, (mountain pine or juniper, dwarf juniper, mountain alder, snow rose), shrubs (blueberry bushes, cranberry), lawns made up of graminaceae.

The alpine level shelters the vegetation situated on the highest summits and peaks of this mountain massifs, displayed as islands at altitudes higher than 2200 – 2300 m a.s.l. (in fact, the lower limit of this level is the line up to which the juniper – Pinus montana – climbs in isolated samples. This level is characterized by dwarf shrubs and alpine lawns (association of small-size grass, dwarf wooden plants, sub-shrubs and associations of plants grouped in spherical shapes) (Fig. 5).

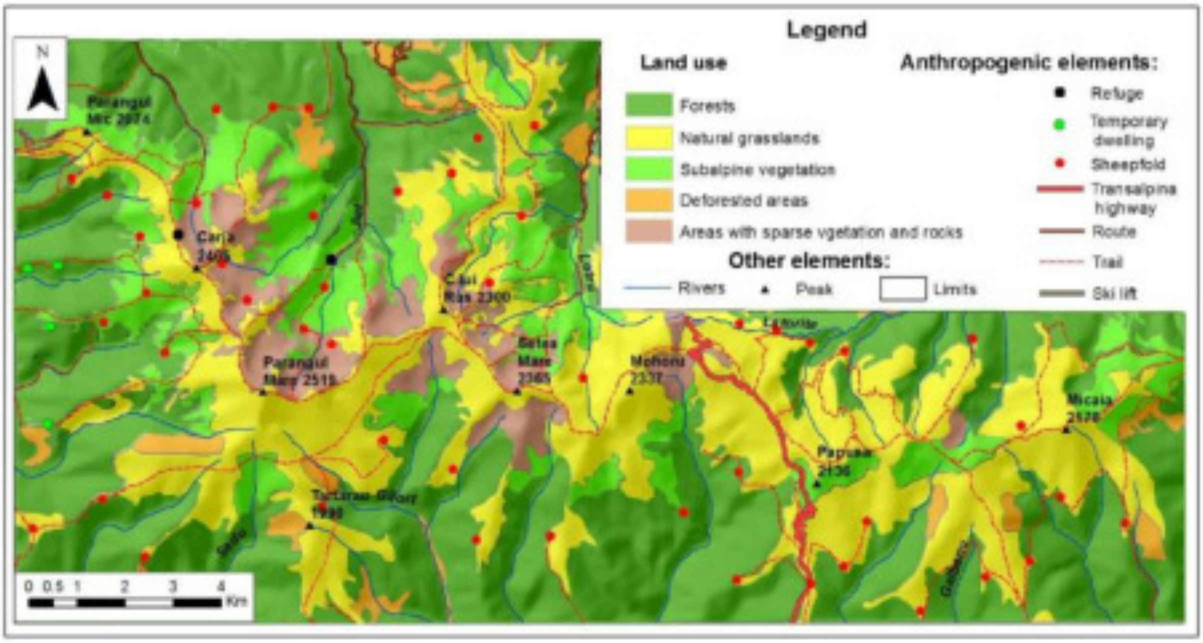


Fig. 5. **Land cover / land use map (after CLC, 2000) and the anthropic impact in the alpine level of Parâng Mountains**

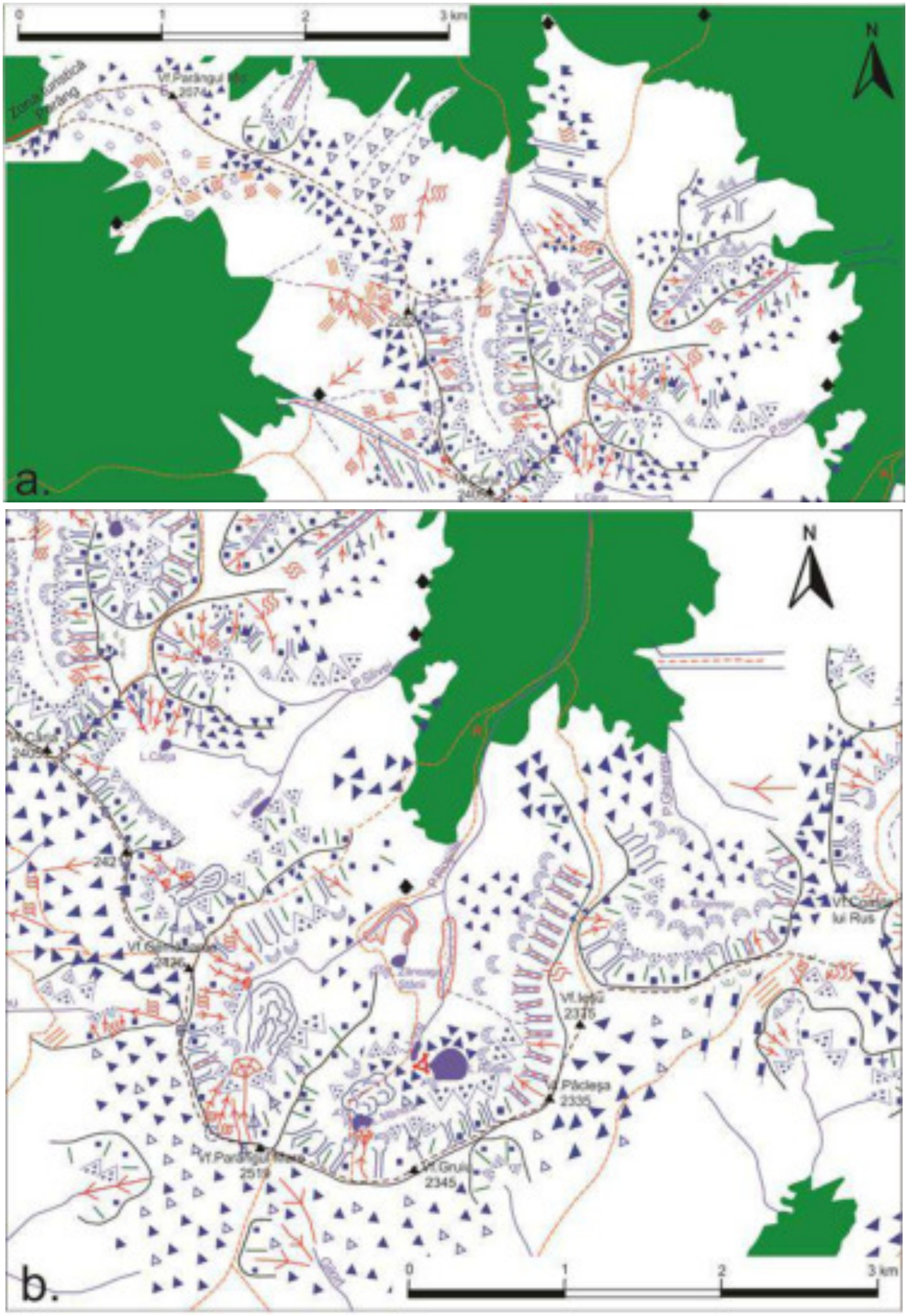
The soils within the analysed mountain environment belong to the spodosols class (represented by podzols developed under the resinous forests vegetation, at their upper limit, or under the juniper associations, from the lower alpine stage), umbrisols (represented by humico-silicatic soils, developed under the vegetation of the alpine lawns and primitive soils (represented by lithosols, thin soils undergoing the initial formation stage, on the heavily inclined mountain sides, on recent detritus, on steepness areas, in the upper part of the narrow summits and along the crests).

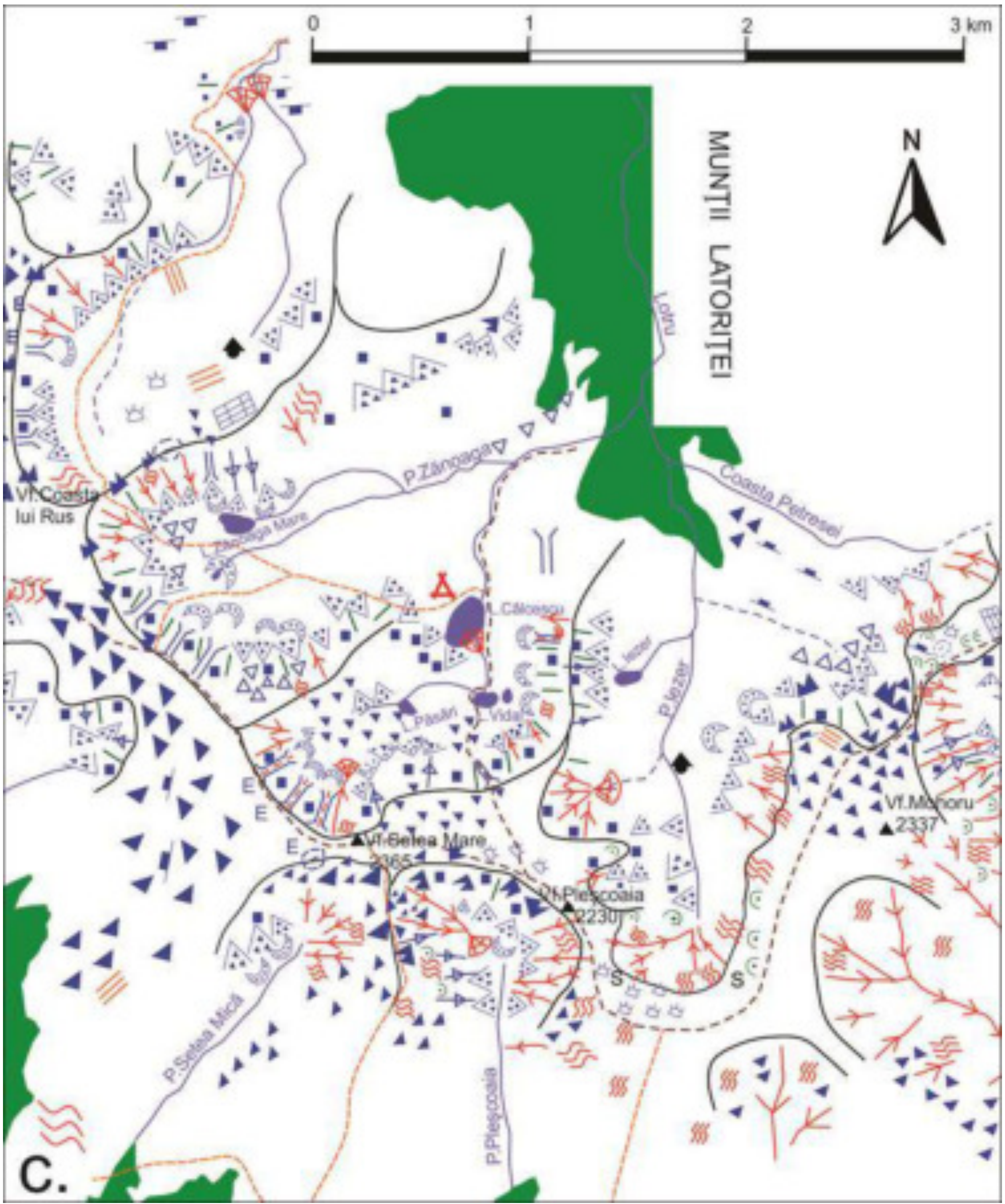
Anthropic factors. The anthropic activity is a determining link in the geographic system of the Parâng Mountains alpine level. The involvement of man in morphogenesis through its multiple and diverse activities influences the present-day morphodynamic, being also a morphogenetic agent (Urdea, 2000). In the alpine level of Parâng Mountains, the anthropic activities which cause imbalance within the environment are tourism and grazing (Fig. 5).

Excessive grazing marks its results through centres of erosion (in Dengheru, Iezer and Urdele Mountains) and through the destruction of the vegetal carpet. With respect to the other forms of aggression on nature, tourism acts through enhanced construction activity in Rânca – Corneşul Mare and Parângul Mic sections, uncontrolled rock exploitation in Păpuşa – Dengheru section which triggers imbalance in the mountain sides, acceleration of the erosion along the paths and their deepening, some of them becoming ravine-like juniper cutting for fire etc. Building communication ways and especially the Transalpina main road negatively impacts the environment. To cut such roads through, clearing necessarily takes place along with destabilizing the base of the mountain sides and activating much more active morphodynamics oriented to streaming, torrentially, collapses and landslides.

4.2. Geomorphological processes – identification and mapping

In identifying and mapping the present-day geomorphological processes and the resulting landforms, we tracked the genetic criterion (Grecu, 2007; Grecu & Palmentola, 2003). We thus have identified in the alpine level of Parâng Mountains the above types of processes and landforms: periglacial and nival, wind, gravitational, pluvial and torrential, fluvial, biogenic and anthropic (Fig. 6 a, b, c, d) (Săndulache, 2010).

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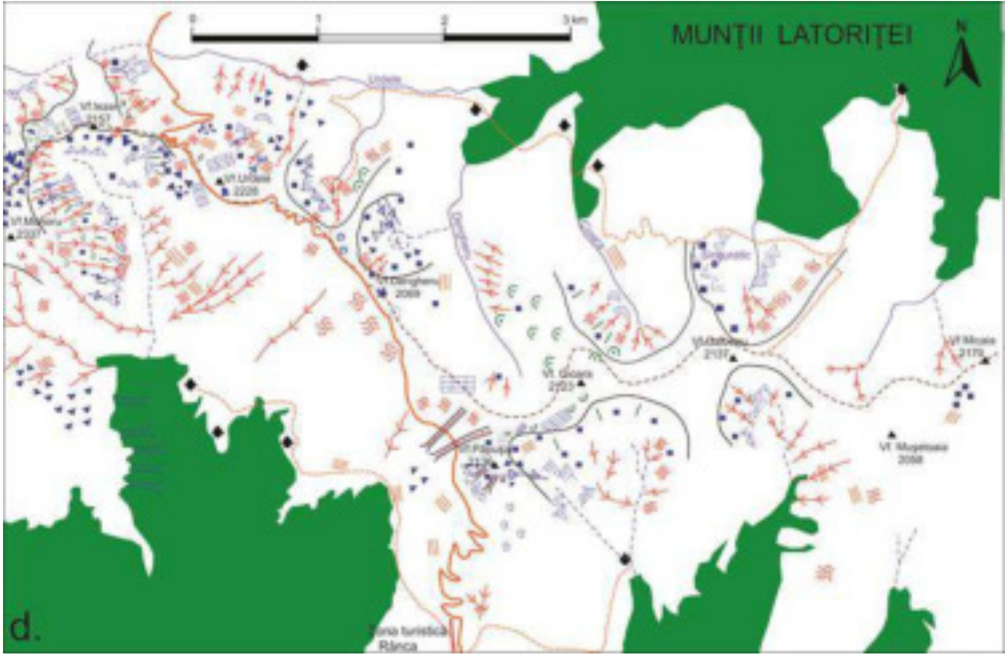
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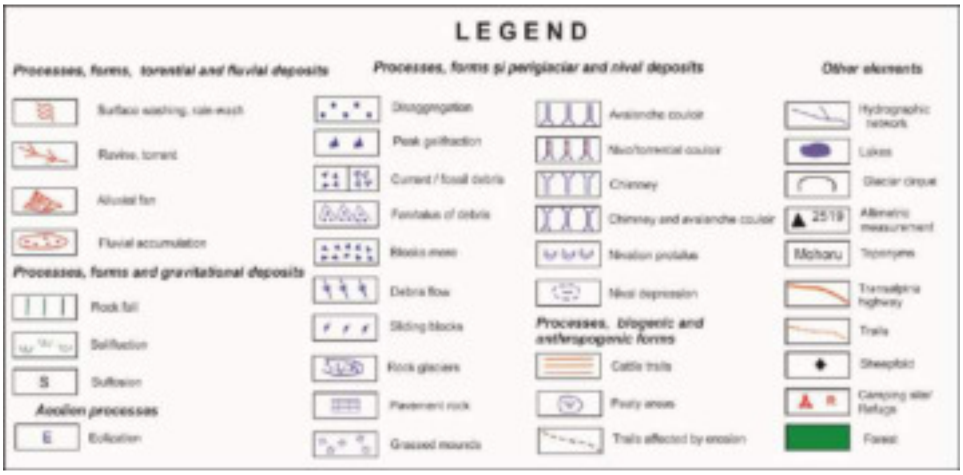

Fig. 6. **Present-day geomorphological processes in the alpine level of Parâng Mountains: a. Western section; b. Jieț glacial complex; c. Lotru glacial complex; d. Eastern section (Săndulache, 2010)**

4.2.1. Periglacial processes

These processes encompass phenomena connected to the action of freezing and thawing and act through gelifraction, periglacial elevation and soil running. The periglacial morphogenetic environment is encountered there where the influence of the freezing –thawing oscillations prevails (Tricart, 1963).

Congelification is the process caused by the freezing and thawing of the water in the cracks of the rocks and by insolation. It is conditioned by the oscillations of the temperature through 0ºC. Such oscillations act intensely in frost-cleaving rocks. As a result, gelifraction occurs, *i.e.* the mechanical process of rock fragmentation (disintegration), as more than 125 congelification cycles occur yearly in Parâng Mountains (Urdea & Vuia, 2000) (Fig. 7).

”At present, frost-cleaving processes act with a lower intensity and affect the crests and the high summits. During the Pleistocene, those processes were affecting a wider area, in the lower part of the mountain, the proof being the old detritus from the foot of the mountain, now covered by vegetation. Therefore, the disintegration forms take the aspect of ***residual relief*** (*sharp crests* – Cârjei indentation, Silveiului crest, the main crest between Cârja – Stoienița – Gemănarea – Parângul Mare – Gruiu – Ieşu – Setea Mare peaks, *pyramid-shaped peaks* – Cârja, Parângul Mare, Gruiu peaks), or ***accumulation forms*** represented by detritus resulted from the accumulation of big-sized materials. The main landforms resulted through the disintegration process are the gelifraction mountain sides (Piciorul Tecanului), *rivers of rocks, torrents of rocks, detritus trains* (Circul Mija) (Fig.8), widespread all over the high area of Parâng Mountains” (Săndulache, 2010, pag. 60).

Fig. 7. **Rock disintegration process (Culmea Stăncior) (August 2008)**

Fig. 8. **Detritus trains in Mija Circus (August 2005)**

Soil creep is a periglacial process that takes place in the area bordered by the annual isotherm of 3ºC, *i.e.* as a rule at an altitude higher than 1600 m a.s.l. (Voiculescu, 2000 b). The occurrence of characteristic landforms are *solifluxion terraces* (Parângul Mare – Mândra, Pleşcoaia – Mohoru Summit) and *solifluction lobes* (encountered in the western mountain sides in the Piatra Tăiată – Setea Mică, Urdele – Dengheru – Păpuşa, Galbenu – Pristosu sections).

The ***periglacial elevation*** consists in the upward pushing of the blocks stuck in the over-moisten soils due to the freezing-induced tensions, which direct those blocks with the long axis in the vertical (Băcăuanu *et al.*, 1974). This process is involved in the genesis and evolution of the *periglacial pavement, reptant blocks* (Fig. 9) and of the *periglacial mounds* (Fig. 10) (Urdea *et al.*, 2002). "Grassed mounds are present on the summit between Setea Mare – Pleşcoaia – Mohoru peaks, on Piciorul Păpuşii, Dengheru – Urdele section, under Dengheru saddle. North of Păpuşa peak typical periglacial pavement develops, and reptant blocks are widely spread in the upper level of Parâng Mountains" (Săndulache, 2010, pag. 61).

Fig. 9. **Sliding block in Găuri Circus (August 2008)**

Fig. 10. **Grassed mounds (Mohoru – Setea Mare saddling) (August 2008)**

4.2.2. Nival processes

"These processes are favoured by the snow persisting over long intervals (more than 200 days in a year in the high area, with a thickness exceeding 7-8 m in the sheltered zones). Snowfalls are a climatic phenomenon recorded in this mountainous environment from September (with a snow depth of 3-10 cm in the first 10-day period of October) to the spring months (between 13 and 23 cm in the first 10-day period of April), with a maximum depth in December – March, when the snow layer is deeper than 65 cm, even reaching 100 cm).

There is no date of the first snow in the alpine and sub-alpine level respectively. Its occurrence is probable even in the summer months. At altitudes higher than 1900 m a.s.l. the snow layer persists until later than the first half of May being present during 180-200 days annually. The areas with a northern exposure within the alpine domain preserve snow patches persisting from one year to the following. There, the snow accumulates non-uniformly because of the landforms and the wind. There are sections (crests) almost devoid of snow or sectors (sheltered areas, nival micro-depressions, lacustrine cuvettes), where the blizzard causes the snow to accumulate with depths that may reach even 7-8 m. The modelling action of the snow acts through ***slow nival settling and erosion processes*** which create *nival micro-depressions* (Fig. 11) (beneath Setea Mare peak, on the summit between Ieşu and Piatra Tăiată peaks) and through ***fast nival erosion processes*** materialized in avalanches. Their occurrence is favoured both by characteristics of the landforms (the existence of couloirs and slopes more than 30º steep) and by the climatic conditions (abundant snowfalls, duration and depth of the snow layer). Repeating year after year, avalanches favour the formation of *avalanche couloirs* and lead to the formation of specific accumulation micro-relief - *clout-shaped nival accumulations* (nival moraines) through the accretion of the eroded material at the foot of the mountain sides (Fig. 12). Avalanches are widespread throughout the high area of Parâng Mountains, on the mountain sides of the glacial cirques. When avalanches are massive, they exceed the upper limit of the forest, which avalanches modify, creating couloirs in the forest, through uprooting trees (Ţapu, Slivei, Roşiile summit)" (Săndulache, 2010, pag. 61).

In the alpine level of Parâng Mountains, the most frequent avalanches occur along slopes with a 20º-50° incline, existing in most of the mountain sides within the glacial cirques and valleys but also along the largely open mountain sides, where avalanches are wide and display surface features (beneath Coasta Păpuşii, on Piciorul Tecanului etc). The territorial distribution of the snow layer is non-uniform, varying function of the peculiarities of the active surface (mostly the presence or absence of non-homogeneities) and of the wind (owed to its intensity and direction). The snow layer is very deep, especially in the negative landforms, whereas on the convex surfaces it is much thinner.

Fig.11. **Nival depression west of Parângul Mare peak (June 2005)**

Fig. 12. **Avalanche couloir and nival protalus in Câlcescu circus (August 2008)**

“The above-displayed characteristics of the snow layer can be synthesized in three examples of nival profiles obtained on 15 February 2009 around 13.00 LT in the area of Parângul Mic Summit. This summit is west-east oriented, with altitudes in excess of 2000 m a.s.l., being characterized by the existence of the two mountain sides (with a northern and southern orientation respectively), prone to wide avalanche occurrence in the upper part, channelling however along certain couloirs when they exceed the upper limit of the forest”(Fig. 13).

The summit is crossed by a touristic crest path and by an alternative which crosses the median part of the southerly-exposed mountain side, along a contour line situated at altitudes of 1850 – 1900 m a.s.l.

Profiles were performed at various altitudes and exposures, after a three-day spell with precipitation: profile no. 1 (Fig.14), profile no. 2 (Fig. 15) and profile no. 3 (Fig. 16).

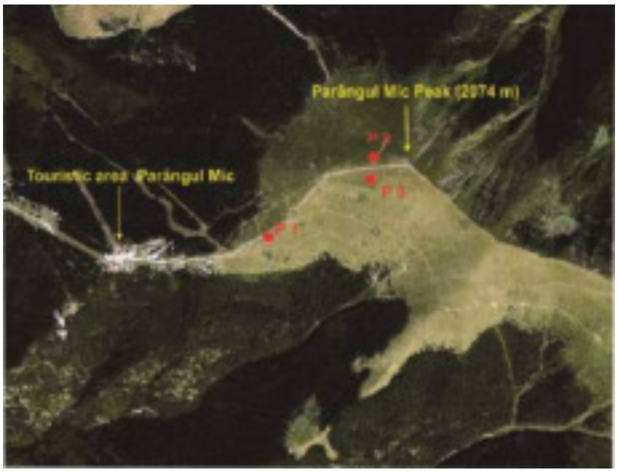

Fig.13. **Location of the nival profiles performed on Parângul Mic summit on a satellite image (www. wikimapia.org)**

Fig. 14. **Nival profile no. 1 (Săndulache, 2010)**

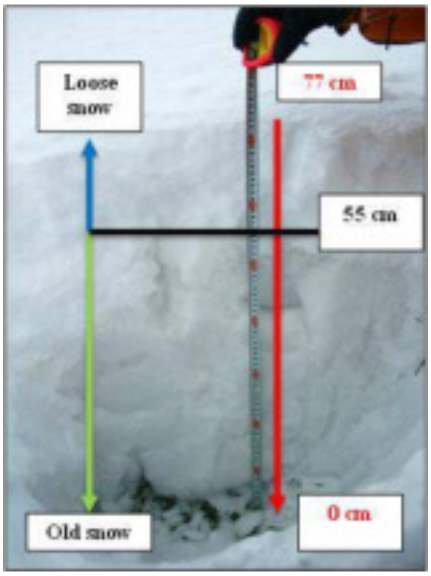

Fig. 15. **Nival profile no. 2 (Săndulache, 2010)**

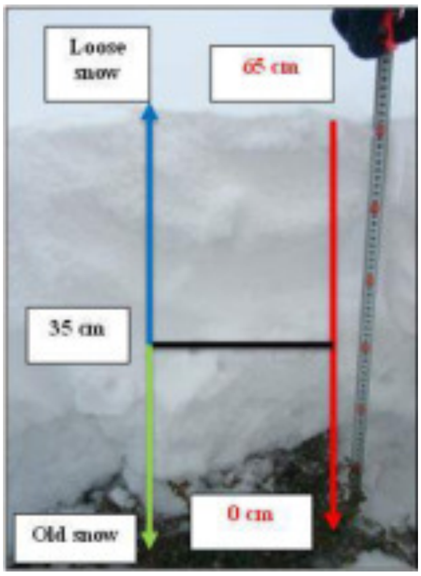

Fig. 16. **Nival profile no. 3 (Săndulache, 2010)**

Nival profile no. 1 was performed on the interfluve, at an altitude of about 1830 m a.s.l. situated lee-side, with a southern exposure. The snow layer was 110 cm deep, exclusively made up of fresh, loose snow.

Nival profile no. 2 was performed on the windward mountain side having a northern exposure, at an altitude of about 1960 m a.s.l. The total snow layer depth was 77 cm, being made up of old, hard snow between 0 and 55 cm and of fresh, loose snow between 55 and 77 cm (22 cm).

Nival profile no. 3 was performed on the southern mountain lee-side of the summit, at an altitude of about 1930 m a.s.l. The total snow layer depth was 65 cm, 35 cm of which being hard, old snow (between 0 and 35 cm) and 30 cm of fresh, loose snow (between 35 and 65 cm).

It can be noticed how the above-presented elements considered triggering factors for avalanches are found in the analysis of these profiles: the different exposure makes the depth of the frozen snow higher on the northern slope (50 cm) than on the southern one (35 cm), where the solar radiation is more intense, which causes the snow to melt. Also, on the days before performing the profiles and on the very day of the activity precipitation fell and the prevailing wind was northerly, which caused the snow to be drifted on the northern, windward mountain side, and fresh snow layer accumulated, 22 cm deep, whereas on the southern mountain side, 30 cm of fresh snow accumulated. However, under such circumstances, fresh snow avalanches could occur irrespective of the mountain side exposure, given that the snow was more than 20 cm deep and the slope in question is steeper than 30º. Yet, there was no significant risk of avalanche occurrence" (Săndulache, 2010, pag. 124-126).

4.2.3. Gravity processes

Rolling and collapses belong to the category of brisk motions developing from the inclined landforms, being accountable for the displacement of disintegration products towards / at the foot of the mountain sides. Such events are favoured by very steep mountain sides (inclination in excess of 40º) of the glacial circuses devoid of vegetation. They are frequent in Groapa Seacă a Mijei and Mija, Slivei, Stoieniţa, Gemănarea, Mândra, Roşiile, Zănoaga Mare, Găuri, Căldarea Dracului, Urdele glacial cirques and not only (Fig. 17).

4.2.4. Pluvial and torrential erosion processes

These processes are determined by large precipitation amounts and contribute to the detailed modelling of the landforms through processes of *surface washing* (pluviodenudation) and *rain-wash*. Those are the most common of the present-day processes which occur over most of the mountain environment. *Torrential processes* are based on rain-wash and its effects and represent a widespread present-day geomorphological process, whose results are easily noticeable in the landscape. They are determined by rich precipitation during the summer months and by the slow melting of the snow accumulated in the torrential reception basins which cause the formation of nivo-torrential bodies.

Fig. 17. **Roşiile glacial circus wall affected by numerous scars resulted from the detachment and collapse of disintegrated blocks (August 2008)**

"Areas with diffuse erosion (surface washing, rain-wash) are very frequent in the area of Parâng Mountains, typical sections being encountered on Muntele Scurtu – Parângul Mic, on the mountain sides of Mija I cirques, of Lacul Îngheţat, Zănoaga Gemănării, Zănoaga Mare – Gâlcescu, Setea Mică – Pleşcoaia, Iezer, Mohoru (Fig. 18 a), Cioara, Bălescu (Fig. 18 b), beneath Ghereşu saddle, beneath Coasta Păpuşii, etc.

In the surface erosion process, the analysis of certain climatic parameters is very important, especially the precipitation-related ones, which are the triggering factor for this process. In this sense, we analysed the number of days with rain, the number of days with certain precipitation amounts and the Angot index. The number of days with rain and the number of days with certain precipitation amounts are indicators of the erosion processes intensity, contributing to the fragility state of the systems. We used climatic data from Bâlea Lake weather station, located in similar conditions with respect to those from the alpine area of Parâng Mountains (Fig. 19 a, b).

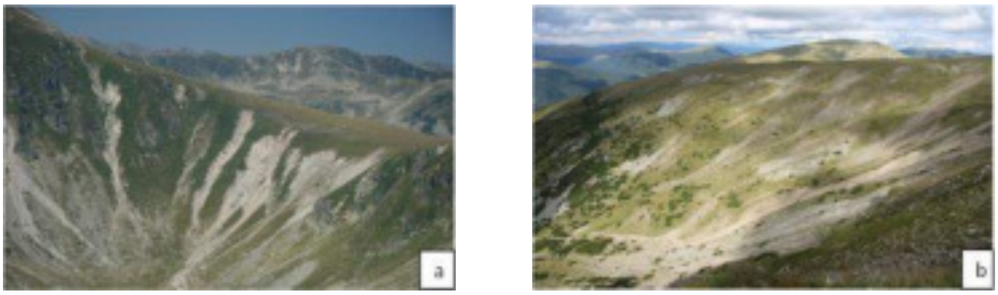

Fig.18. **Surface washing, rain-wash and ravining in***:*
(a) Gaura Mohorului and (b) Bălescu Circuses (August 2008*)*

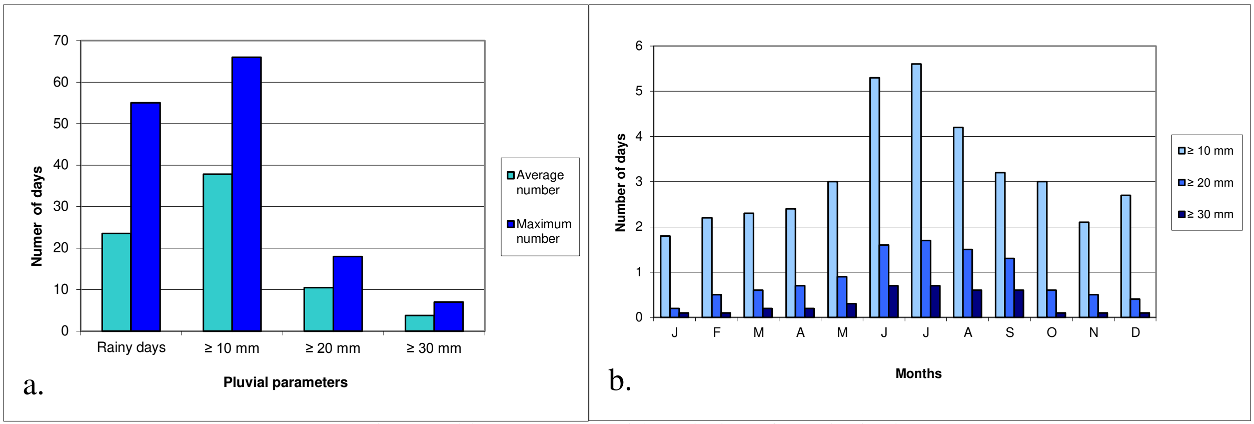

Fig. 19. **Annual (a) and monthly (b) variation of pluvial indicators**
(data processed from the N.M.A. Archive 1982-2002)

It can be noticed that the highest number of days with rain and various precipitation amounts is recorded in the summer months (June – August).

Another indicator of the precipitation regime, important to the modelling process and to the various economic activities specific to the mountain area is the value of the *Angot precipitation index* which helps us determine the rainy or droughty character of each month taken apart. Values greater than one point at rainy months, whereas the sub-unit ones point at droughty months. Months displaying values close to one may be considered normal with respect to moisture. Figure 20 a. discloses that the rainiest months are the summer ones, from the May – August interval in the high area of the massif, which causes pluvial erosion to enhance and induce disturbances in the summer seasonal activity within this mountainous environment (tourism, grazing etc.) This is also ascertained by fig. 20 b., which renders the Angot precipitation index computed over the warm interval (May – October) against the cold one (November – April).

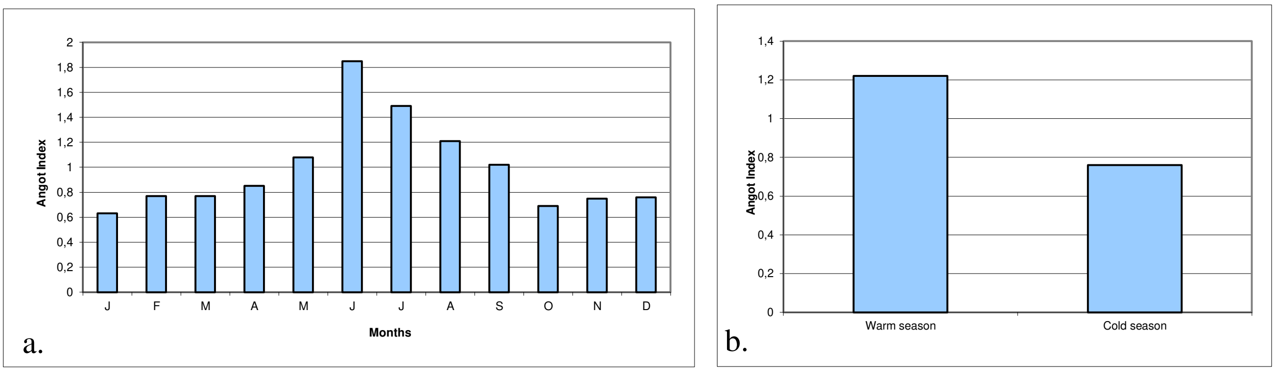

Fig.20. **a. Mean monthly values of the Angot precipitation index, and b. Mean seasonal values of the Angot precipitation index** *(data processed from the N.M.A. Archive 1982-2002)*

When rain-wash enhances evolved forms take shape (*ravines, ruts, torrents*) concentrated on the mountain sides with erosion glacis, on the mountain sides with friable rocks devoid of vegetation at the springheads of every valley. Some of those display large sizes, like the ravine located at the springheads of Iezer brook (Fig. 21): lengths of about 250 m, widths of 30 – 50 m (with a maximum of 55.3 m) and depths of about 15 m. They are located in the wall of Iezer circus, at 2150 m a.s.l. being the unique case in Parâng Massif of the hydrographic network expanding upstream the wall of a glacial circus, a phenomenon reported by Emm. de Martonne in 1907 (Iancu, 1970).

Fig. 21. **Ravines at the springheads of Iezer brook (August 2008)**

Torrential processes are active processes, acting during rainfalls of above-average intensity (torrential rain). "In the alpine environment, torrential rainfalls exceeding 30 mm in 24 hrs. frequently occur, reaching 195 mm (on 3 June 1988 at Bâlea Lake weather station). The highest intensity of torrentiality is specific to the summer season " (Săndulache, 2010, pag.148-150).

Within the torrential bodies, the erosion and transport power is high, and when other processes, especially nival, aggregate, large size debris cones are formed. Although the possibility that the torrential network develops exists everywhere, except for the surfaces covered by seas of blocks, torrents are mostly concentrated on the mountain sides of the glacial cirques and valleys. Torrents on the rocky mountain sides develop there where the declivity is in excess of 40º with lengths greater than 100 m, as are those from the central high area, devoid of vegetation or only barely covered by it. There, torrents display a leaking channel, with a V-shaped transversal profile (Răboj, 2009).

4.2.5. Other geomorphological processes

Eolisation acts having the wind as agent, occurring in any season but most efficiently in winter (especially from December to February) but also during the months with scanty precipitation (March – April, October – November and to a lesser extent September) (Mihai, 2005). It contributes to enhancing disintegration and to *rock pavements* formation.

Fluvial processes act continuously, with different season to season intensities, with a highlight on both the ***in-depth and lateral erosion*** and ***accumulation*** however not remarkable through severe effects in the morphodynamics of the alpine geomorphological landscape of Parâng Mountains. The fluvial erosion has a small overall intensity in the alpine stage. All the rivers within the upper reach, characterized by steep slopes, markedly erode moraine deposits from the bottom of the valleys then become fainter when reaching the tough substratum. Accumulation is only possible in the narrow sections of the silted glacial stairs, where small meadows are created, where the river gets meandered (Zănoaga Stânii, Slivei and Găuri brooks).

Animal paths are 10-30 cm wide stair-shaped micro-landforms. The most typical of those are encountered in the eastern part of the massif (Culmile Urdele, Dengheru, Păpuşa, Bălescu, Muşetoaia) but also in the western part (Scurtu – Parângul Mic Section).

Anthropic processes act through eroding and deepening the touristic paths and as a result of constructing the Transalpina highway in the high area of these mountains.

5. Conclusions

The way present-day geomorphological processes act, their intensity degree and frequency are determined by altitude, which yields the climatic staging, by the climatic conditions, the morphometric and morphogeographic characteristics of the relief, by lithology and geological structure. The elaborated cartographic materials and the in-situ observations show that the geomorphological agents and processes are spatially associated, with differentiated action, function of the mentioned factors combine, an important role being held by the dynamics of the climatic elements. A direct relationship is noticed of the spatial extent of the periglacial with the upper limit of the forest. Thus, the periglacial stage is situated beyond the upper limit of the forest are stretches in the altitude up to the higher mountain crests (Răboj and Codreanu, 2008). As regards the mean annual air temperature, the 3°C isotherm delimitates the periglacial stage, closing the areas with periglacial processes. This thermal value delimitates the maximum expansion of the periglacial domain, at its contact with the forest domain (Voiculescu, 2000 a, 2002). On the northern slopes, the upper limit of the forest reaches altitudes of 1800-1900 m.a.s.l., which causes the periglacial stage to expand less with respect to surface compared to the southern slopes, where the upper limit of the forest is situated at 1600-1700 m.a.s.l.

The analysis of the maps highlights the high frequency of the periglacial processes on the northern slope, spatially determined by the quaternary glacial relief, more precisely by the complexes of the glacial circuses from the springs of Jiet and Lotru rivers.

Periglacial relief forms are frequent, *e.g.* the disintegration forms represented both by sharp crests and pyramid peaks (the main crest between Cârja and Setea Mare peaks but also secondary crests like the Cârja or Slivei ones) and accumulation shapes (cones and detritus trails) present at the basis of Mija, Slivei, Mândra, Ghereşu, Găuri, Zănoaga Mare, Pleşcoaia and Gaura Mohorului glacial circuses. Soil running, grassed mounds and reptant blocks are present in the central part of the massif, on the Parângul Mare – Mohoru summit but also in the eastern part, on the Urdele, Dengheru, Păpuşa and Galbenu summits. Rock pavements are encountered in the eastern section of the massif, nearby Iezer, Urdele and Păpuşa peaks. Avalanche couloirs are very widely spread, being present in glacial circuses. Some of them are markedly expanded, reaching the forest limit (below Cârja peak, the western mountain side of Mija Mare valley, Mohoru summit).

The pluvio-torrential processes and shapes are imposed by the marked precipitation regime within the summer season, when the sum of the fallen amounts reaches 350 mm at Parâng weather station in the June – August interval. Pluvio-torrential shapes are represented by the areas with diffuse erosion (surface washing and streaming), frequent on the southern mountain side of the main summit, between Curtu peak and Cârja, along Pleşcoaia-Mohoru and Păpuşa-Urdele summits but also within the glacial circuses within the eastern section of the massif (Dengheru, Cioara and Galbenu). More evolved shapes (ravines, tracks and torrents) are frequent both in the areas of the central glacial circuses (Slivei, Zănoaga Mare, Gaura Mohorului, Iezer and Găuri) and along the milder summits from the central-eastern part of this mountain massif (Galbenu-Micaia Summit), favoured by the lack of forest vegetation and the intensity of pasture activities. From the in-situ measurements and observations, the amplitude of the torrential shapes reaches lengths of 100-200m for certain torrential corridors analysed within Căldarea Dracului and Găuri circuses and 250 m for the ravine within Iezer circus, situated at an altitude of 2150 m.a.s.l.

Gravity processes imposed by the slope are frequent within the glacial circuses and in the upper part of the glacial valleys, on the mountain sides steeply inclined and devoid of vegetation, where disintegration processes are remarkable. Rock falling and rolling from the mountain sides of Mija and Slivei are frequent, developed on amphibolites, but also in Mândra, Roşiile, Zănoaga Mare and Căldarea Dracului circuses, developed on granitoids. At the basis of the circuses, detritus foot or cone shapes are formed (very much expanded being those from Mija Mare Circus, Gemănarea, Roşiile, Găuri and Căldarea Dracului).

The dynamics of the present-day processes is the support for the occurrence of certain geomorphological hazards that act because of the conditioning between the environment elements and components.

REFERENCES

BĂCĂUANU, V., DONISĂ, I., HÂRJOABĂ, I., (1974), *Dicționar geomorfologic*, Edit.Ştiințifică, Bucureşti.

GRECU, F., (2007), *Legenda hărții proceselor geomorfologice*, in Comunicări de Geografie, vol. XI, Bucureşti.

GRECU, F., PALEMNTOLA, G., (2003), *Geomorfologie dinamică*, Editura Tehnică, Bucureşti.

GRECU, F., CRISTEA, M., TISCOVSCHI, A., TOROIMAC–IOANA, G., (2011), *Relations entre les éléments climatiques et les processus géomorphologiques dans les montagnes de făgăraş (Carpates Roumaines)*, in vol., Climat Montagnard et Risques, Actes du Colloque de Association International de Climatologie, 6-10 sept.2011 MART-Rovereto, p. 285-290, ISBN 9782907696173.

GHEORGHIU, D.M, HOSU, M., CORPADE, C., Xu., S., (2015), Deglaciation constraints in the Parâng Mountains, Southern Romania, using surface exposure dating. Quaternary International, 1-12.

IANCU, S., (1970), *Munţii Parâng. Studiu geomorfologic*, teză de doctorat, manuscris, Cluj – Napoca.

IELENICZ, M., OPREA, R., (2011), *România. CARPAŢII-caracteristici generale,* Editura Universitară, Bucureşti.

MIHAI, B., (2005), *Munţii din Bazinul Timişului. Potenţialul reliefului şi amenajarea spaţiului*, Editura Universităţii Bucureşti.

NEDELEA, A., (2006), *Valea Argeşului în sectorul montan. Studiu geomorfologic*, Editura Universitară, Bucureşti.

NICULESCU, GH., (1965), *Munţii Godeanu.Studiu geomorfologic,* Editura Academiei, Bucureşti.

ONACA, A., URDEA, P., TÖROK-OANCE, M., ARDELEAN, F., (2011), *Electrical resistivity measurements in sensitive periglacial environment from Southern Carpathians (Romania)*, Annals of DAAM for 2011 & Proceedings of the 22nd International DAAM Symposium, 21, 1, Viena, 885-886.

PELTIER, L.C., (1950), *The geographic Cycle in periglacial regions as it is related to climatic geomorphology*, Annals of the Association of American Geographers, 40(3), 2014-236.

POPESCU, R., VESPREMEANU-STROE, A., ONACA, A., CRUCERU, N., (2014), *Permafrost research in the granitic massifs of Southern Carpathians (Parâng Mountains)*. Zeitschrift für Geomorphologie 59, 1: 1-20.

RĂBOJ, C., (2009), *Consideraţii privind sistemele de modelare actuală a reliefului în Munţii Parâng,* Comunicări de geografie, nr.XII, Bucureşti.

RĂBOJ, C., CODREANU, T., (2008), *Consideraţii privind etajele morfoclimatice în Munţii Parâng – Latoriţa*, Lucrări şi rapoarte de cercetare, vol. II, Centrul de cercetare Degradarea terenurilor şi dinamică geomorfologică, Editura Universităţii, Bucureşti.

SĂNDULACHE, I., (2007), *Relieful bazinului hidrografic Bistricioara*, Editura Universitară, Bucureşti.

SĂNDULACHE, I., (2014), *Curs de Carpaţi,* Editura Cetatea Doamnei, Piatra-Neamţ.

SĂNDULACHE, C., (2010), *Hazarde şi riscuri naturale în Munţii Parâng*, Editura Universitară, Bucureşti.

STAMATIU, M., (1962), *Mecanica rocilor,* Editura Didactică şi Pedagogică, Bucureşti.

TRICART, J., (1963), *Géomorphologie des regions froides*, P.U.F., Paris.

URDEA, P., (2000), *Munţii Retezat. Studiu geomorfologic*, Editura Academiei, Bucureşti.

URDEA, P., VUIA, F., ARDELEAN, M., VOICULESC, M., TÖRÖK-OANCE, M., (2002-2003), *Consideraţii preliminare asupra elevaţiei periglaciare în etajul alpin al Carpaţilor Meridional*i, Revista de Geomorfologie, nr. 4-5.

URDEA, P., VUIA, F., (2000), *Aspects of periglaciar relief in the Parâng Montains*, Revista de Geomorfologie, vol.2, Bucureşti.

VASILE, M., (2015), *Procese şi forme de dezagregare fizică a rocilor în areale din Carpaţii Meridionali şi Munţii Măcin.* Teza de doctorat, Universitatea din Bucureşti.

VASILE, M., VESPREMEANU-STROE, A., POPESCU, R., (2014*), Air versus ground temperature data in the evaluation of frost weathering and ground freezing.Axamples from the Romanian Carpathians*, Revista de geomorfologie, 16, 61-70.

VELCEA, V., (1961), *Masivul Bucegi.Studiu geomorfologic,* Editura Academiei, Bucureşti.

VOICULESCU, M., (2000 a), *Consideraţii asupra etajelor morfoclimatice din Masivul Făgăraş*, Comunicări de geografie, vol.IV, Bucureşti.

VOICULESCU, M., (2000 b), *The morphodynamic potential of the Cryonival Level in the Fagaras Massif,* Revista de Geomorfologie, vol.2, p. 59-66.

VOICULESCU, M., (2001), *Some considerations on the dynamic and types of the morphogenetic processes in the Făgăraş Massif,* Revista de Geomorfologie, vol.3, p. 47-60.

VOICULESCU, M., (2002), *Studiul potenţialului geoecologic al Masivului Făgăraş şi protecţia mediului înconjurător*, Editura Mirton, Timişoara.

VOICULESC, M., ARDELEAN, F., (2012), *Snow avalanche – disturbance of high mountain environment. Case study – the Doamnei glacial valley the Făgăraş massif-Southern Carpathians, Romanian Carpathians*, Carpathian Journal of Earth and Environmental Sciences, Vol. 7, No. 1, p. 95-108.

[1]Railway Technical College „Mihai I „
Geography Department,
10, Butuceni Str., Sector 1, Bucharest, Romania
catalinaraboj@yahoo.com
2University of Bucharest, Faculty of Geography,
Department of Geomorphology-Pedology and Geomatics,
1, Nicolae Bălcescu Blvd, , Sector 1, 010074, Bucharest, Romania
sandulachei@yahoo.com, florinagrecu@yahoo.com,
dobre@geo.unibuc.ro
[3]Romanian National Meteorological Administration,
Remote Sensing and GIS Laboratory,
97, Sos. Bucureşti-Ploieşti, Sector 1, 013686, Bucharest,
Romania
anisoara.irimescu@meteoromania.ro

Endokarst Morphology in the Rarău Massif

Dinu OPREA-GANCEVICI[1], Georgiana BUTA[1], Adrian DONE[2]

Abstract. The Rarău Massif holds a series of morphologically diverse, genetic types of landforms, among which the petrographic landforms developed on limestone and dolomite are the most notable. As regards the typology and distribution of carbonate deposits, the Rarău Massif is not known for its endokarstic landforms. The most famous of its caves – Peştera Liliecilor, is not remarkable through karst formations, but through the colonies of bats it has sheltered over the years. Limestone klippes currently display a greater diversity of underground caverns. These caverns most often correspond to gravitational cracks present in the rock or are the result of chaotic position of scree aggregates detached by physical processes from the main rock. The only signs of karstification processes manifested in some cavities are represented by *montmilch* on the walls and also small corrosion shapes. A few potholes have been reported in the cracks present within the klippes. Corrosion is a process with weak manifestation in the caves mapped around the Pietrele Doamnei area. Our approach aims to improve the picture of the relatively poorly developed karst in our study area, with the more complex diversity specific of this genetic type of petrographic landforms. We can assert that our research is developing, our expectations being stimulated by identification of certain underground caverns.

Key – words: Rarău Massif, karst, cavities, karst morphology, cracks, endokarst

1. Introduction

Karst topography in Romania is associated with a variety of karstifiable rocks, among which limestones and dolomites are the most representative as regards covered area and form variety. Apuseni, Banat, Cerna, Southern Retezat, Căpăţânii and Vâlcanului Mountains, as well as Mehedinţi Plateau and South Dobrogea Plateau are just a few examples in this regard. Located on the crystalline axis in the northern part of the Eastern Romanian Carpathians, the Rarău Massif holds a series of morphologically diverse, genetic types of landforms, among which the petrographic landforms developed on limestone and dolomite are the most notable. Such features favor the development of karst processes in the Rarău Massif, despite that the forms identified and mapped so far cannot be compared in what concerns size and number with the landforms of other classic karst areas. Karst morphology, particularly the exokarst, contributes to the shaping of an emblematic image of Rarău, through the presence of the group of large residual rocks known as Pietrele Doamnei (the Lady's Rocks).

Research on the study area can be found since the end of the 19th century, *i.e.* the monography of K. Paul - 1876 (after Rusu, 2002). Research expanded in the twentieth century with Uhlig - the first to speak of the Rarău Mesozoic marginal basin, followed by Atanasiu, Băncila who develop the hypothesis of normal geological structures and Preda, Elias, Popescu-Voiteşti who consider that the geological structure of the area is represented by overthrust nappes. In the second half of the current century, important geological contributions of paleontological, mineralogical and tectonic - structural nature are provided by Mutihac (1965, 1968) and Turculeţ (1963, 1964, 1966, 1971).

Geomorphological characteristics of the massif are approached by Sârcu *et al.* (1971), Popescu Argeşel (1972), Iosep (1972) and Rusu (1997, 2002). Karst topography is addressed in general studies by Bleahu (1972) and in particular by Valenciuc (1964), Bojo *et al.*, (1975), Rusu in the works already mentioned, Done *et al.*, (2011). Notable is also the mapping fieldwork conducted by Cristea (1954), Bleahu, Bucovina Speleology Club (1980, 1991, 1992, 1994 Club GEISS Iaşi), and more recently by Bouaru (2005, 2012) and our team (2013-2014).

1.1 Study area

Located at the northern end of the central group of the Eastern Romanian Carpathians, the Rarău Massif has a maximum altitude of only 1651 m. The massif neighbors two major valleys towards the north and south, which are also physical and geographical boundaries, *i.e.* the Bistriţa River and the Moldova River valleys. The Rarău Massif is bordered by a series of mountain units - Giumalău

Mountains to the west, Bukovina Mountains towards the north, Stânişoarei Mountains to the east and south and Bistriţa Mountains to the south (Fig. 1). The eastern and western boundaries are less clearly delimited. Within these limits, questionable only as regards the transition towards the Stânişoarei Mountains, the Rodna Massif covers an area of 160 km².

1.2 Methods

The research of karst landforms in the Rarău Massif involves a series of classical methodological stages: bibliographic information, analysis of cartographic material resulted from previous research, geomorphological mapping of karst areas, documentation and mapping of underground caverns, construction of genetic hypotheses. Geomorphological surface mapping was based on the 1/25000 cartographic maps published by the Military Topographic Directorate between 1980 and 1986.

2. Results and discussions

2.1. Geological characteristics

The Rarău Massif shows a typical syncline structure, with layers arranged chronologically in a tectonic basin (Fig. 2). The metamorphites have a basal position, whereas the Mesozoic strata consisting of dolomites, sandstones and conglomerates, jasps, wildflisch and massive limestone appear towards the surface. At the top of the mountain, many allogenic limestone blocks of various sizes were identified, known under the name of klippes. They are of Triassic (Piatra Şoimului, Piatra Zimbrului, Popchii Rarăului) and Cretaceous (Pietrele Doamnei, Rarău and Hăghimişul Peaks) age, some of them originating from coral reefs that were "placed" in the wildflisch by complex tectonic overthrust (Mutihac *et al.*, 1968).

The limestones and dolomites of the **klippes** appear massive and the presence of corals indicates coral reefs as a likely origin (Turculeţ, 1971). Generally, there is no evident stratification of these rocks, except for the Rarau and Hăghimiş peaks. In the first case, the layers are placed in vertical position.

2.2. Geomorphological controls of the karst development in Rarău

The characteristics and position of karstifiable rocks in the Rarău Massif are somewhat atypical compared to the important karst areas in Romania, where they appear as compact and thick horizons (*e.g.* ca. 600 m thickness in the Apuseni Mountains). In terms of karst morphology, two main important units can be defined in our study area:

i) Triassic deposits (Campilian - Anisian) consisting of a thick blanket (50-150 m) of dolomites and dolomitic limestone which are positioned over the crystalline schists, with outcrops only on the syncline flanks;

ii) Triassic and Cretaceous limestone klippes of the Transylvanian Nappe, buried in the Cretaceous deposits of the *Wildflisch Unit***.**

The area covered by this type of rocks in the Rarău Massif is over 35 km², based on the Geological Map 1:200.000, Rădăuţi sheet. In relation to typology and covered area, karst development occurs differently. Fossilization of the Campilian - Anisian dolomitic limestone horizon makes the development of Exokarst morphologies almost impossible. However, the synclinal position of the strata may suggest favorable underground drainage, which may contribute to the development of endokarstic landforms. No underground holes associated with this horizon have been reported so far, but their formation is hypothetically possible.

The klippes cover relatively small areas from the total karstifiable area. Their position at the surface makes them susceptible to corrosion exerted by rain or snow melt water. Moreover, periglacial morphological conditions have left obvious traces in their current geomorphology.

Apart of the physical and chemical properties of limestone and dolomites, intense tectonization of the olistholits generated a network of cracks that may have a fossil origin, resulted either during rock consolidation or burial in the wildflisch.

Cracking may depend in some situations on the general lines of geological strata – as in the case of Rarău – Hăghimiş, or on the relation between the klippes and slope lines, *i.e.* Pietrele Doamnei Rocks. The emergence, evolution of gravitational cracks and development of underground holes, such as Peştera Liliecilor (the Bats Cave), are explained by Bleahu (1974), who cites theories developed by Gajac (1963) and Renault (1967, 1969).

Deepening of the river network and generation of slope systems, along with the malleable substrate can favor gravitational sliding of the blocks, which results in creation of new gravity crack lines or development of the existing cracks. This instability is also influenced by depth of valleys that determine different base levels for each slope. Consequently, the blocks will be subjected at the base to gravitational compensation which tends to keep the klippe in a stable equilibrium. There is also a direct relation between the slope and the decompression forces acting on the extremities of the klippes. Cracking may progress to the phase of full separation from the main block, the detached part being subjected to fragmentation through collapse or sometimes involved in delapsive movement (Fig. 3 D).

Depending on the degree of development, cracks can be open or closed. The latter retain in their top part a heavily fissured rock mass. On the background of the crack system development, fragments of various sizes collapse from the ceiling, some of which being trapped in the narrower middle or bottom part of the crack.

Meanwhile, individualization of blocks on the cracking lines favors their movement on the Wildflisch clay substrate, with a rotational/ delapsive motion. The hypothetical development we refer to is supported geomorphologically by the presence on the south – eastern side of the Pietrele Doamnei Rocks of a lineout of large blocks which preserve the result of such movements through their position.

Basically, the klippe morphology highlights karst cavities which can be classified into several categories and stages of development: cavities in the disaggregated blocks, caves related to the tectonic litho- morphological fissures and tectonic-corrosive caves (Oprea *et al.*, 2011).

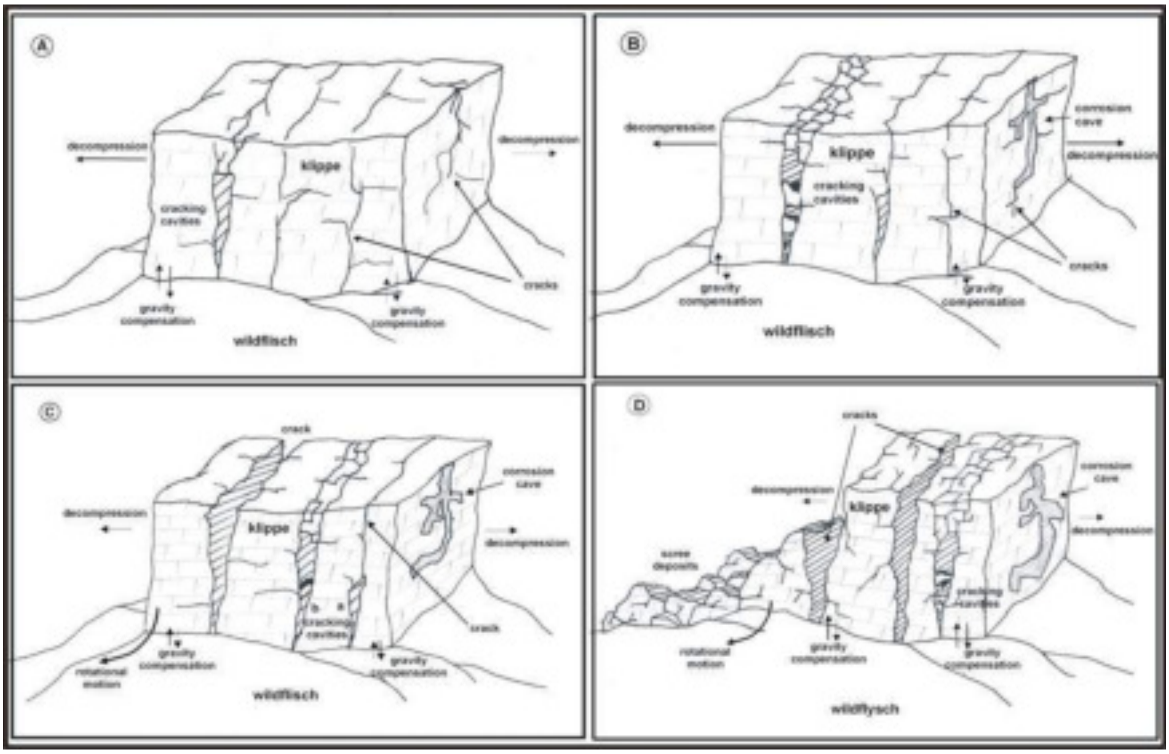

Fig. 3. **Stages of the morphological evolution of the klippes and endokarst typology in the Rarău Massif**

3. Karst morphology in the Rarău Massif

Karst morphology is the result of chemical and mineralogical properties of karstifiable rocks; the generated landforms have peculiar characteristics in land geomorphology. Development of karst topography is the direct consequence of a single dominant morphological process, namely dissolution. The others are somewhat secondary compared to the development of other genetic types of landforms, where geomorphological processes have a rather balanced importance. Weathering, erosion and sediment transport generate distinct types grouped into types of erosion and accumulation, both at the surface, *i.e.* the exokarst, and below the ground, *i.e.* the endokarst.

3.1. The exokarst

The typical exokarst – the surface karst in the Rarău Massif, covers a rather small area compared to the total area of the massif. There is no published literature exclusively focused on the study of the Rarău exokarst. Moreover, its landforms are relatively few and poorly shaped, *i.e.* polished surfaces, karrens, dolines, gorges.

Landforms resulted from the "polishing" of klippes and carbonate blocks by sheet or rill runoff are most representative for this area (Sîrcu *et al.*, 1971). The areas with the most typical such landforms are the slopes of Piatra Şoimului, Pietrele Doamnei, Piatra Zimbrului rocks and the northern slope of the Rarău Peak.

Photo 1. **Karrens**

Karrens are micro-landforms which appear as elongated, rectilinear rills, but also with sinuous directions (sometimes tubular, developed vertically in the rock mass), centimeters deep (photo 1). They appear frequently on the steep slopes of klippes, but also on smaller blocks. They develop especially on steep slopes, where they can reach lengths of 10-15 m. We identified such landforms on the side towers of Pietrele Doamnei area, but also on the north side of the Rarău Peak.

Sinkholes (dolines) are relatively small karst hollows, usually developed on flat or low declivity areas, funnel or plate shaped. In Rarău their diameters do not exceed 40-50 m. Although classical sinkholes are the result of karst processes, in our study area many of them are likely caused by suffusion processes occurred in the scree. The most evident sinkholes are located near Cabana Speo (the Speological Cottage), on the access plateau to Pestera Liliecilor (the Bats Cave), on the plateau region of the northern side of Popchii Rarăului (Bojo *et al.*, 1975). They are buried in the weathered rock layer or in the soil horizon. No active sinkholes with steep slopes have been identified. A few negative landforms are noted, with amphitheater shaped morphology, open towards the slope line, which resemble collapse sinkholes. They were identified at the edge of the plateau between Popchii Rarăului and Stâncile Popchii rocks, on the route linking the Plateau from the Moara Dracului gorge. The author above mentioned also marks more advanced landforms on the geomorphological map of the Rarău karst, such as sinkhole valleys – around Popchii Rarăului rocks, and even a 'sohodol' (*i.e.* dry valley)**,** which is located between the Pastoral and Speo cabans.

Gorges represent narrow valley sectors bounded by steep slopes, which basically could have developed antecedently (old valley that develops on the same path despite lifting tectonic movements), but also on the background of underground drainage (caves). Narrowing sectors or gorges were identified on the rivers that drain the NE areas, tributaries of Moldova, *i.e.* Izvorul Alb (the Piatra Buhei sector) and Valea Caselor (Moara Dracului gorges, currently a natural reserve). Rusu (1997) mentions a similar sector on the Pârâul lui Ion brook, a tributary of the upper Slătioara River.

Slopes constitute a distinct morphological feature, often associated to calcareous or dolomitic klippes. Representative in this regard are the northern slope of the Rarău Peak with a length of ca. 2 km and wall heights up to 200 m, as well as the slopes of Piatra Zimbrului, Pietrele Doamnei and Piatra Şoimului.

3.2. The endokarst

As regards the typology and distribution of carbonate deposits, the Rarău Massif is not known for its endokarstic landforms. The most famous of its caves – Peştera Liliecilor, is not remarkable through karst formations, but through the colonies of bats it has sheltered over the years.

Lithological and structural differences in the limestone, *i.e.* the sedimentary rocks laid over the crystalline of the Syncline and the klippes trapped in wildflisch, allow us to consider both genetic and morphological differences between the potential karsts landforms of such rocks. Unfortunately, for the Campanian - Anisian dolomites no caves have been reported so far, but their thickness and synclinal position support our assumption that caves may still be present. Our reasoning is based on the position of these dolomites at the base of the Syncline and on the fact that the shape of the Syncline favors the concentration of groundwater (karst morphogenetic factor) towards the middle.

Limestone klippes currently display a greater diversity of underground caverns. These caverns most often correspond to gravitational cracks present in the rock or are the result of chaotic position of scree aggregates detached by physical processes from the main rock. The only signs of karstification processes manifested in some cavities are represented by *montmilch* on the walls and also small corrosion shapes. A few potholes have been reported in the cracks present within the klippes.

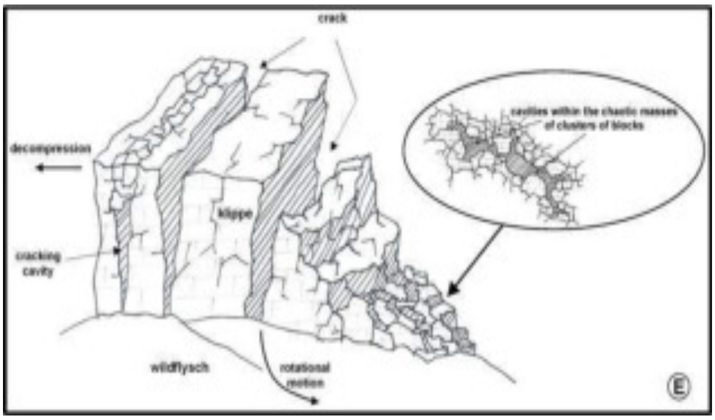

Fig 4. **The position of underground cavities in the scree mass - *talus cave***

Corrosion is a process with weak manifestation in the caves mapped around the Pietrele Doamnei area. Despite that the Rarău plateau does not offer great variety in terms of karst landforms, two new caves have been discovered on the northern steep slope of the Rarău peak: i) Pestera Fisurii, with the longest inner gallery of all known local caves; ii) Pestera cu Cot, the first endokarst landform that retains clear traces of corrosion.

Based on morphology, we can classify the underground holes in our study area in three categories:

1. cavities in the chaotic clusters of blocks - ***talus cave***, are the most numerous among the mapped underground holes near Pietrele Doamnei rocks;
2. caves associated to litho-tectonic-morphological cracks;
3. caves with mixed origin, *i.e.* tectonic-corrosive.

3.2.1. Cavities in the chaotic clusters of blocks

They are underground holes preserved in large areas covered by periglacial scree that fossilizes and buries the base of steep slopes or of limestone-dolomite klippes.

The cavities within gravitational clusters may occur in hard rock massifs, not necessarily of limestone, but compact and affected by fragmentation and gravitational collapse processes. They occur most often on the edge of steep walls from which large rock fragments can detach over time and fall towards the base of the slopes. By clustering, such large rock fragments create large or small cavities that can be connected through narrow passages, hence the relatively large spatial extent of some cavities. The team established within the Speo Club Bucovina and led by Adrian Done mapped a number of 25 such caves in the debris that fossilize the basis of Pietrele Doamnei rocks, five of which being considered potholes. Part of these cavities were mapped and recorded in the Cadastre of Caves.

From the genetic point of view, the cavities cannot be considered endokarst, because corrosion marks are absent, but holes in the scree mass (Fig. 4). Only if karst processes caused by properties of dolomites and limestone were identified, such a classification would be justified. Their higher mobility determines a permanent reconfiguration of component hollows, and under these circumstances the access through such cavities involves high risks. Pestera Liliecilor is the most representative of such cavities. It is located in the western part of Hăghimiş Mountain, on a gently sloping morphological plateau about 1 km northward of Pietrele Doamnei Rocks. Genetically, it cannot be distinguished from the cavities located around Pietrele Doamnei. The cave has a mixed development, *i.e.* on fracture lines, but also in the scree mass resulting from weathering of the klippes belonging to the allochthonous Transylvania Nappe.

The cave does not show signs of dissolution or water flow. It rather reveals a cluster of large limestone blocks following a fracture line whose flanks were distanced. It consists of a series of cavities (rooms) – *Luminată, Liliecilor, Dreptunghiulară, Conică, Ramificată, Ascunsă şi a Ceaiului*), which can be seen as hollow spaces formed during gravitational clustering of the rock fragments. These component cavities are linked through narrow passages and thresholds, developed on diaclases within an impressive mass of scree. They show a deep fracture of the olistholit which contains the cave. The fracture is not observable on the outside, with the exception of the final part. The last mapping of Pestera Liliecilor cave reveals cavities of about 340 m length (Club Speo Bucovina and Club GEIS Iaşi, 1994 Fig. 5) arranged on a slope with over 80 m elevation differences and an extension (plan length) of about 100 m. It has no concretion formations of stalactites and stalagmites type, but only montmilch flow. Screes mobility resulting either from their own mass, or from seismic and gravity movements permanently contributes to the reconfiguration of contained cavities.

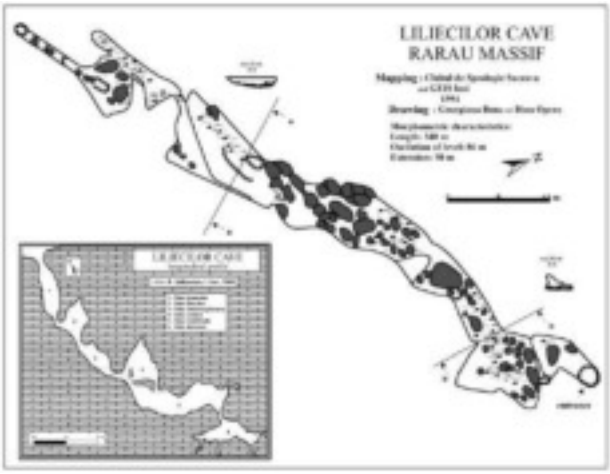

Fig. 5. **Pestera Liliecilor cave - profile and plan view**

In the Pietrele Doamnei Rocks area another cave was identified, namely Peştera Lungă cu Gheaţă (The Long Cave with Ice). With over 80 m length, the cavity has an elevation difference of about 20 m. It can be accessed through a wide pothole, after which the access gallery descends in a tilt spiral through the limestone blocks.

Moreover, it can be noted that secondary side cavities have also developed, but not very important as regards size. The basal part of the main gallery, in cavities with triangular sections resulted from the clustering of large blocks with flat walls, preserves ice throughout the year (Photo 2). Ice presence has prompted us to initiate the thermal monitoring of the gallery and ice volume of by placing thermal sensors and marks. Karst morphology is represented by weak corrosion marks observed on the walls of the blocks, resulting from rainwater or snowmelt leaching.

3.2.2 Caves associated to litho-tectonic-morphological cracks

One of the lithological characteristics of carbonate rocks is their plasticity and brittleness. Cracking occurs in different directions, which are dependent on the structural characteristics, compression or distension forces, sliding movements etc. Basically, the network of cracks appears rectangular, developed both vertically and horizontally, but can also follow insequent directions.

Photo 2. **Peştera Lungă cu Gheaţă (The Long Cave with Ice) – perennial ice**
(D. Oprea-Gancevici)

During mapping performed in the Pietrele Doamnei Rocks area a number of 8 cracks have been observed in the main block of rocks. Their general NNE - SSW orientation is defined by the 180-220 ° azimuth gap. The cracks have widths ranging between 30-40 cm and 2-3 m, as well as lengths of meters or tens of meters. Vertical development is difficult to assess, but we suspect that they cross the entire thickness of the klippe. Overall we consider cracking a result of gravitational decompression occurred in the block parallel to the slope line. Cracks can be seen both on the northwestern and on the southeastern flanks.

Similar cracks are present in the klippe limestone block where Pestera Liliecilor cave is located. In the plateau preserving the cave's entrance there is a rectangular network of cracks, the main being oriented NE-SW, similar to the cracks occurring in Pietrele Doamnei Rocks.

Their formation is related to morphological and structural relationships of the klippes with the clayey wildflisch substrate. Basically, they are produced as a result of increasing depths of valleys, a gravitational imbalance by sliding of blocks \ olistholits, which are subjected to external forces of gravitational pull which "break" the limestone-dolomite rock mass on the low resistance or lithological contact lines (usually diaclases). Cracking occurs most frequently on the mentioned directions by klippe "slicing".

Peştera Fisurii cave is representative of this category of underground cavities. It is located on the northern slope of the Rarău Massif, and was discovered relatively recently (Vasile Bouaru). Its name clearly expresses geomorphologically its appearance, given that its longitudinal profile resembles to some extent a symmetrical V (Fig. 6). Cave formation was a result of a conjoined influence of geomorphological processes and structural-petrographic characteristics of the klippe. Stratigraphically, the block layers are verticalized. Their structural position is very likely preserved from the moment of collapse and burial in the clay matrix of the wildflisch. The general orientation of the diaclase is given by the 230-240° azimuth gap, and it is coincident with the azimuth of the cracks observed in the Pietrele Doamnei Rocks area.

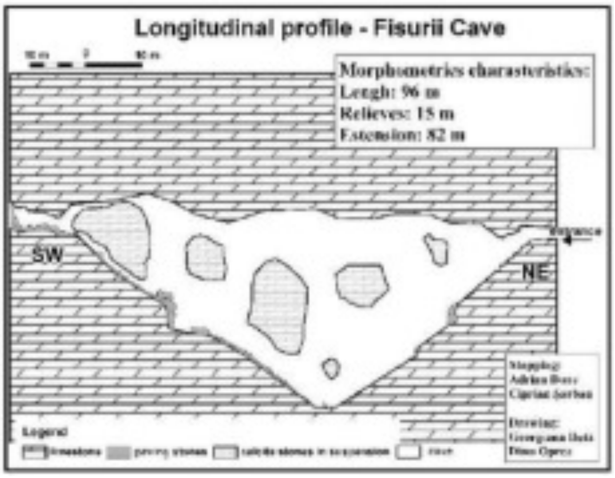

Fig. 6. **Peştera Fisurii cave (The Crack Cave) – longitudinal profile**

Provided that in the case of the latter cracking occurred on low resistance lines, Peştera Fisurii cave was formed on a lithologic contact line; it is entirely centered on a calcite diaclase with thickness between 50 and 100 cm (Photo 3). The length of the cave is about 100 m and the width about 80 m. The opening widens inward to about 1 to 1.5 m. However, the cavity displays a significant vertical development. In the middle, the gallery has a maximum height of about 15 m.

Photo 3. **Peştera Fisurii cave** (D. Oprea-Gancevici)

The next sector requires a descent on a 25 ° to 35° tilted floor, lined with numerous blocks of different sizes, jagged and very unstable, mostly composed of calcite. The blocks originate from the top part of the crack and resulted from physical fracturing. Moreover, the vertical extension of the crack contains stranded boulders of varying sizes whose width is greater than the crack size. Along the descent, there are two thresholds with heights ranging between 1.5 and 2 m, generated by large size blocks, collapsed from the top of the crack. The cave length, from the entrance to its lowest part, is about 50 m. Access on the crack line involves climbing large blocks, on an elevation difference similar to the difference calculated for the descent in the cave, which gives the cave a shape of symmetrical "V" in the longitudinal profile. The presence of blocks, stuck in the crack walls and on the floor, suggests intense fragmentation and collapse activity. The cave does not preserve important features of karst morphology. Small concretions present on the walls are caused by laminar flow of rain or snow melt water. There is a constant flow of water on the walls. The humidity varies between 94-96%, somewhat constant, and the recorded temperature from 2.3 to 2.6 °. Peştera Fisurii cave is the underground cavity with the longest and most unitary gallery identified among the other cavities mapped so far.

3.3.3 Tectonic-corrosive caves

Karst corrosion in the Rarău Massif was seldom reported, as most mapped cavities may be included in the first two categories approached in our paper. Genesis of cavities formed through karst erosion is based on cracks and diaclases which allow water flow, given that the klippes in Rarău have abundant such forms.

The corrosion morphogenetic endokarst in the Rarău Massif could be theoretically identified in the Campilian - Anisian limestone outcrops appearing on the Syncline flanks, under the clayey wildflisch and over the crystalline schists. Water can penetrate gravitationally to the limestone substrate, where it contributes to the degradation of rocks through specific processes. However, the synclinal position of the calcareous layer makes water outflow more difficult. The springs emerging from the dolomite layer flanks of the Bukovina Nappe could signal the presence of underground cavities. Presently we do not have any information in this regard. We note only the local mentioning of two such cavities which could not be located in the field, namely in the Moara Dracului (Devil's Mill) and Piatra

Şoimului (Hawk's Stone) gorges, with lengths of 7-9 m (Vasilie, 2001, http://adone.geonet.ro/speologie/comunicari /bucuresti2001/rarau/rarau.html).

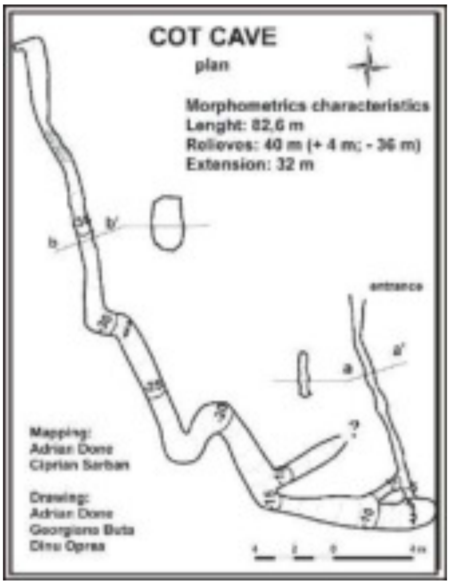

Fig. 7. **Peştera cu Cot Cave – plan view**

The only cavity of this type, mapped in the area of the klippes, is the Peştera cu Cot cave, also located on the northern slope of Rarău, and also reported by Vasile Bouaru. The cave develops on crack lines independent of the klippe stratigraphy, although the entrance and some small sectors appear to correspond to the stratigraphy. The 83 m length, 40 m elevation differences and 32 m extension, the corrosion morphology, karst microforms of coralite type distinguish this cave as the most developed endokarst landform identified so far in the Rarăului Massif.

Photo 4. **Peştera cu Cot Cave – downward gallery (C. Sarban)**

The downward gallery follows a spiral path after the first 10 m from the entrance. The floor slope frequently varies between 30 and 45 °, but there are also threshold-shaped sectors. The final part of the gallery appears horizontal, with a length of about 5-6 m. High slope is reflected in the gallery morphology, *i.e.* circular - ellipsoidal (Photo 4). At the top there is even a diffluence (bifurcation) of the gallery of over 4-5 m length. Two secondary cavities can be separated from the main gallery, with lengths of 3-4 m. Punctually, centimeter-sized circular galleries can be identified in the cave ceiling, which function as water drains. Water flow has generated evorsion processes on crack lines, and the walls preserve the result of turbionary flow under the shape of lateral marmites. The temperature recorded expeditionally (June 2014) reveals values between 5-6 ° C, whereas humidity amounts to 96%.

Peştera cu Cot cave is presently a unique case in the Rarău Massif karst morphology. It preserves clear traces of karst shaping through corrosion, *i.e.* concretion microforms known as coralites, but also small corrosion holes, spoons, evorsion marks, pillars, floor ditches etc. Research of these microforms will continue both from the geomorphological perspective and for assessing environmental conditions and mostly the topoclimate of underground caves. For the latter research direction, the caves are subjected to constant monitoring by thermal sensors that record hourly temperature. The duration of observations will include an annual cycle.

Conclusions

No typical endokarstic landforms have yet been mapped in Rarău. Most existing cavities were generated by the plasticity of rocks and tectonic impacts, by the structural arrangement of limestone - dolomite olistholits, scree masses and large size of blocks detached and gravitationally accumulated at the base of steep slopes.

The majority of underground cavities found in the Rarău Massif have a tectonic and geomorphological genesis. They were formed by deposition or sliding and decompression of limestone blocks on the wildflisch layer. Thus significant accumulation of scree and formation of longitudinal cracks generally oriented towards NE - SW occurred in the area. The rock fragments move, leaving behind cracks that permanently resize over time. Along these cracks sliding and collapse of blocks may occur on the clayey substrate, which by clustering at the base of the slope can preserve open spaces between them, thus creating caverns and tectonic caves – litho – morphologic caves.

Our approach aims to improve the picture of the relatively poorly developed karst in our study area, with the more complex diversity specific of this genetic type of petrographic landforms. We can assert that our research is developing, our expectations being stimulated by identification of certain underground caverns which show, for the first time in the Rarău Massif, clear marks of corrosion, *i.e.* Pestera cu Cot cave. Furthermore, identification of fossils ice in the Peştera Lungă cu Gheaţă cave, as well as of the bats colony in the Peştera Fisurii cave open new research directions and perspectives, Endokarst evolution of the Rarău Massif, together with other geomorphological elements, gives a distinctive note to this mountainous area. As regards information level, karst research opportunities acquire new levels through identification of new underground caverns, which will be rendered valuable through further investigations.

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REFERENCES

BLEAHU, M., (1974), *Morfologia carstică – condiţionarea geologică şi geografică a procesului de carstificare*, Ştiinţifică Publishing House, Bucharest.

BLEAHU, M., (1982), *Relieful carstic*, Albatros Publishing House, Bucharest, 1982.

BOJOI, I., PAULENCU, D., (1975), *Relieful carstic din regiunile muntoase Hăghimaş şi Rarău, elemente de atracţie turistică*, in Lucrările Colocviului Naţional de Geomorfologie Aplicată şi Cartografiere Geomorfologică, Iaşi.

DONE, A. and colab., (2011), *Peştera Liliecilor din Rarău*, Fundaţia Speologică Bucovina Publishing House, Suceava.

MUTIHAC, V., (1968), *Strcutura geologică a compartimentului nordic din sinclinalul marginal extern*, Academiei Publishing House, Bucharest.

OPREA-GANCEVIC, D., CHEIA, G., (2011), *Touristic Potential, Management and Development in the Rarău Masif*, in Journal of Tourism, no. 11, Suceava.

POPESCU-ARGEȘEL, I., (1973), *Relieful periglaciar de la Pietrele Doamnei*, in Studii şi comunicări de ocrotire a naturii, Suceava

POVARĂ, I. *et al.*, (1990), *Speologie – Ghid practic*, Sport-Turism Publishing House, Bucharest.

RUSU, C., (1997), *Masivul Rarău – Aspecte fizico-geografice*, Helios Publishing House, Iaşi.

RUSU, C., (2002), *Masivul Rarău – Studiu de geografie fizică*, Academia Română Publishing House, Bucharest.

SÂRCU, I., BARBU, N., PAULESCU, D., (1972), *Contribuţii cu privire la geomorfologia Masivului Rarău*, published in *Analele Ştiinţifice ale Universităţii "Al. I. Cuza" - Iaşi, Tomul VIII, s. II c.*

TURCULEȚ, I., (1971), *Calcarele urgoniene din regiunea Rarău*, extras din *Studii şi comunicări. Ştiinţele naturii*, Suceava.

TURCULEȚ, I., (2004), *Rezervaţiile geologice şi paleontologice din Rarău,* Iaşi.

VALENCIUC, N., ION, I., (1964), *Peştera de la Rarău. Date ecologice asupra coloniilor de lilieci din aceasta peşteră*, in Analele ştiinţifice ale Universităţii „Al. I. Cuza”, secţ. II (Ştiinţe naturale), Biologie, tom X, fasc.2, Iaşi.

http://adone.geonet.ro/speologie/comunicari/bucuresti2001/rarau/rarau.html.

[1] Universitatea Ştefan cel Mare Suceava
[2]Fundatia de speologie Club Speo Bucovina Suceava

Landslides in Olpret Valley Basin

Violeta-Elena RETEGAN[1]

Abstract. Olpret Valley basin is an integral part of higher order relief unit of Cluj and Dej Hills, located in their north-east. Lithological substrate composed of friable deposits, belonging to the Low Miocene (clay, marl, sandstone, poorly cemented conglomerate). The presence in this region of Bobâlna Hill, 693 m high, which is a part of the old structural Badenian surfaces, made of riodacitice tuffs (Dej tuff) induces a relatively high relief energy, due to the torrential rainfall character in summer and the relatively high slopes, and explains the frequency of modeling processes of relief through landslides. 10 delapsive landslides were discovered. Most of them are old slides, glimee type. To these there are added some other slides, which appeared due to other reasons than the periglacial modeling from the late Pleistocene and early Holocene. The formation of these landslides are due to exceptional amounts of rainfall from 1942, 1970, 1975, 1985.

Keywords: landslides, glimee, mounds, holoambe, acăstăi, Băbdiu stone

1. Introduction

Olpret Valley basin is an integral part of higher order relief unit Cluj and Dej Hills, located in the north-east of these hills. The limit of the basin is creeping on the turn and river system of Olpret Vad valley towards northwest, Şimişna valley on the west Codor valley on the southeast (Pop, 1967) and Luna, Lujerdului and Mărului valleys on the south (Fig. 1). Although the pool area is small, (138 square kilometers), the current and contemporary geomorphological processes are highlighted. By means of nowadays processes regarding the evolution of the system development, the reference is made on the late glacier period, the end of Pleistocene and early Holocen, while contemporary processes shaping the landscape scale are analyzed on human life scale.

Olpret Valley is one of the tributaries on the left of the Somes River, the confluence with the collector river being Dej town. It is a consistent valley type, its tributaries being subsequent valleys. The studied perimeter is characterized by the existence of a relief which is consistent to the monoclinal and tabulated structure (Pop, 2012).

2. Research methodology

The following steps have been taken:

a. Choosing the research theme.

b. Documentation Stage – this stage has been held in the library and consisted in reading the bibliography, and the necessary information from the Internet.

c. Field Research Stage – it consisted in supplementing information related to the landslides through direct observations, measurements and pictures landslides. A questionnaire was applied to a sample of people to assess their perception of the hazard they are exposed (based on the model provided by Surdeanu and Gotiu (2007).

d. Information Processing Stage – the legitimate manifestation of landslides has been analysed and interpreted by means of the data obtained from bibliographic sources, observations and measurements. Cartographic materials of Olpret Valley area have been elaborated.

Lithological substrate consists of loose deposits belonging to the Lower Miocene (clay, marl, sandstone, poorly cemented conglomerate). The presence in this area of a segment of the old structural Badenian surfaces (Bobâlna Hill, 693 m), consisting of riodacitice tuffs (Dej tuff, Ciupagea *et al.*, 1970) induces a relatively high relief energy (Fig. 2), taking into consideration the 240 m altitude at the confluence of Olpret Valley with Somes river, downstream of Dej. Gârbacea (1997) believes that the existence of volcanic tuff in western Transylvania Depression plays an important role in shaping of glimee slides, because "causes lasting stability of the slopes, before the trial slip, causing in this way an accumulation of tension in mass slope". The torrential rainfall in summer, the slopes of 10-15° which occupy about half of the studied area explain the frequency of slope modeling processes through landslides (Pop, 2007).

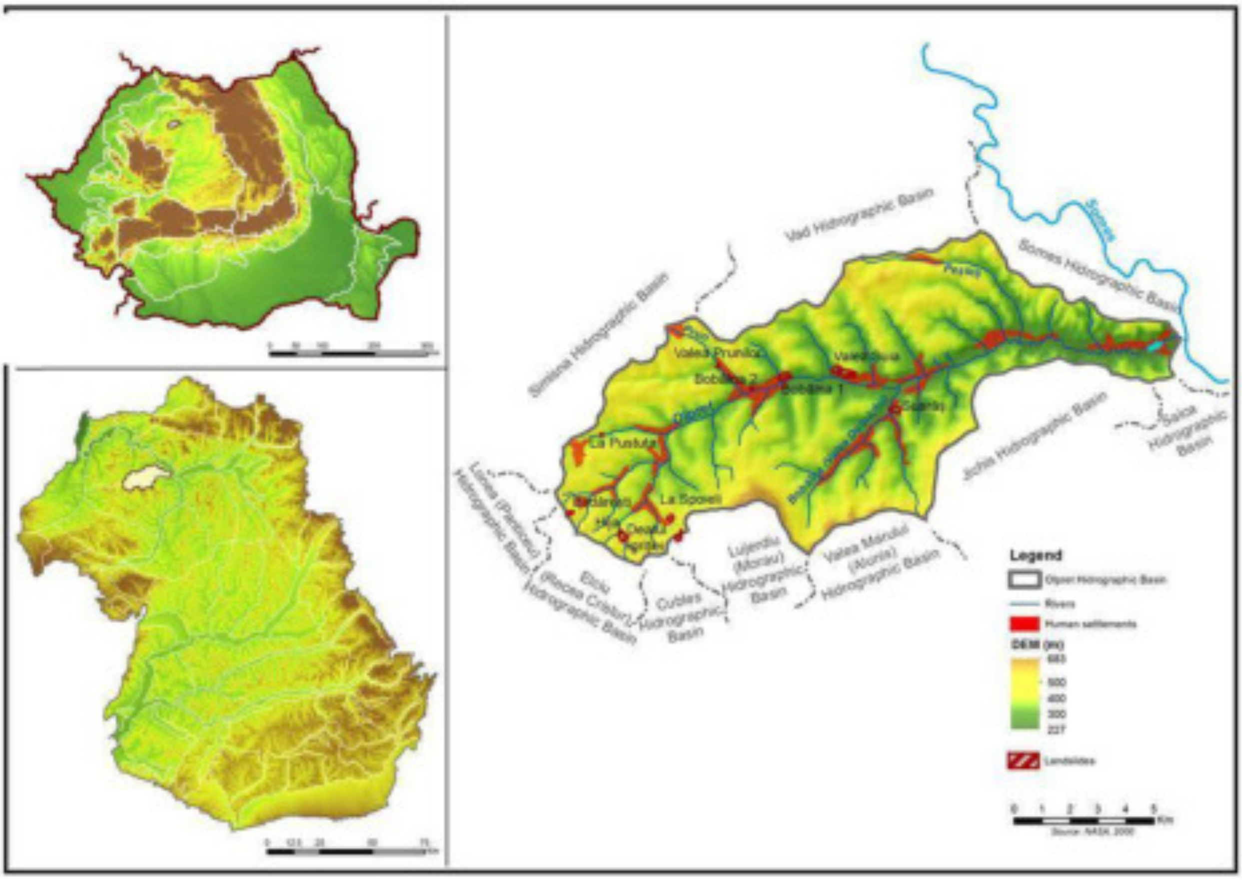

Fig.1. **Framing of the territorial Olpret morphohydrographic basin**

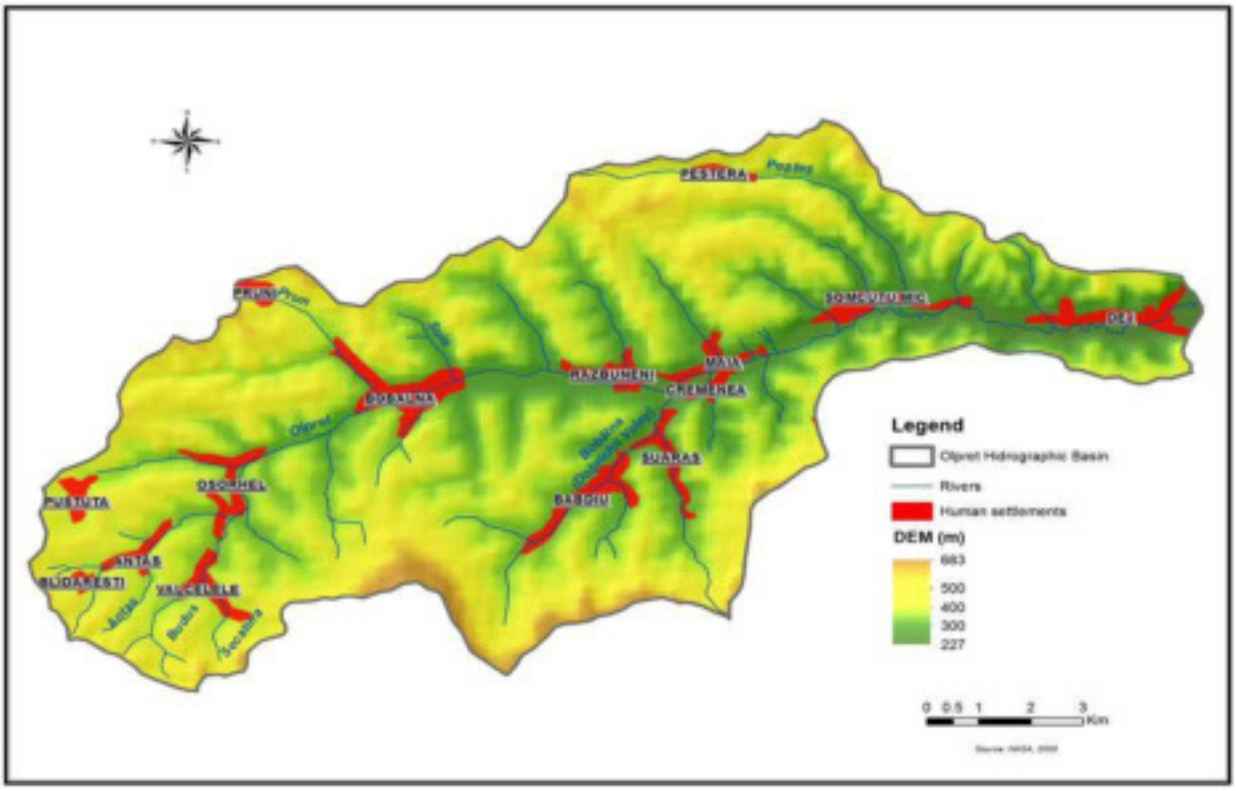

Fig.2. **Hypsometric map of the Olpret morphohydrographic basin**

Mac (1976-1980) classified the landslides into three categories, meaning slipped mass movement: the detrusor, delapsive and mixed. Of these types, the Olpret Valley meets delapsive and mixed slides. Gârbacea (2013), quoting Tufescu classifies landslides into four categories: 1. shallow landslides ; 2. lenticular slides ; 3. slides in mounds; 4. slides in pseudoterrace. Olpret basin`s most common are the old glimee type, locally known under the names of "holoambe" or "acăstăi". Some contemporary landslides are added to the above mentioned ones, which came into being due to other reasons different from the ones characteristic to late Pleistocene Slides and early Holocene. The initiation or reactivation of these landslides are due to large amounts of rainfall, the ones in 1942, 1970, 1975, 1985, similar to lenticular slips from Suarăş, on the right side of Băbdiului valley, the valley that is at the source of Antăş, as well as Pustuta landslide or the sliding slope from the source of Buduş valley (Fig. 3).

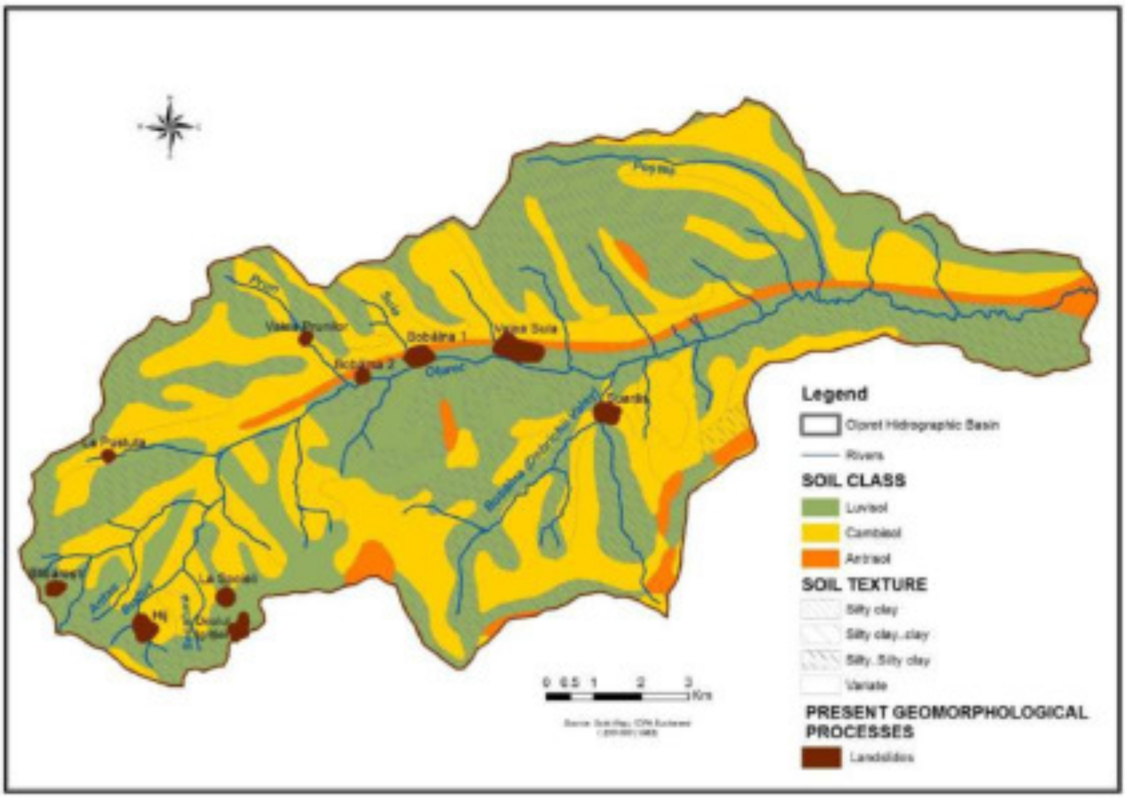

Fig. 3. **The map of active landslides in the Olpret morphohydrographic basin**

3. Results

3.1. Old landslides of glimee type

● Such a slip is the one on the left slope of the Suia valley, stabilized at the moment, due to the settling of a perimeter of pine, locust and buckthorn plantations in the period before 1989. This slide isthe largest in size, with a detachment front of about 1.500 meters.

● On the left of Olpret valley, in Bobâlna village there are three landslides, which are part of the old category of landslides. The first one is at the confluence of the Olpret valley with Prunilor valley (Photo 1). The ditch detachment has a front of 60 meters, where the presence of conglomerates with mollusc shells insertions and rough sandstone horizon could be observed. The length of the slip has a size of 170 meters and the difference in level between the ditch detachment and the sliding head is of 41 meters. The body of the slip is made of sandstone, sand and soil, and underbrush is planted in order to stabilize the slope.

● The second landslide in Bobâlna village is the one that affects the daily activity of most residents. The ditch detachment starts in the upper third part of the slope, as well as the slides mentioned above, and the body of the slip moved until the road embankment (Photo 2). Thus, the stability of 108 B county road is undermined. During the last 30 years and so, the road has deteriorated due to continuous sliding. A 230 m sector of the road has been affected by the slip and became bumpy compared to the rest and arched towards the stream. At the momen, works for drainage of excessive moisture from the sliding mass, as well as the reconstruction of the road embankment are executed. The sliding body has a length of 164 meters, and the difference in level between the ditch detachment and the sliding head is of 27 m. It is a sliding made of several waves, which are with grass. The ditch detachment is hardly noticeable, being covered by vegetation. The first work to stop slipping development occurred between 1953-1954 and consisted in constructing a retaining wall at the contact between the floodplain and terraces of the first head of "Băbdiu stone" the Tuff toponym of Dej. This action proved to be ineffective as the slope affected by this slip is northeast oriented.


Photo.1. **Landslide on Prunilor street, Bobâlna**


Photo.2. **DJ 108 B, the section affected by slip**

● The third landslide is located at the end of Bobâlna village on the left side of the Olpret valley (Photo 3). It is very similar to the one within the village under the following aspects. The ditch detachment is in the upper third of the slope, not interfluve. It is a glimee type sliding. The sliding body consists of superficial deposits on the slope. The difference in level between the ditch detachment and the sliding head is of 26 m. With a length of 165 m and a width of 180 m it does not occupy a large area, but the damage they cause are major because it is located within the village, as the last two landslides mentioned in heavily populated areas. Waves slip are covered by vegetation, especially wild plum, pine groves and underbrush. It undermines the stability of the road, the asphalt and embankment are pushed and broken, indicating the direction of travel of the sliding body. The versant affected by the sliding faces south-east.


Photo. 3. **Lansliding at the end of Bobâlna**


Photo. 4. **Slipping from Spoieli, Vâlcele village**

● One of the most developed is the landslide at the source of Buduș valley, on the right side, entering Vâlcele village (Photo 4). The ditch detachment is insinuated at the top of the slope, on interfluve, which indicates the direction of the landslide development towards slope withdrawal. The toponym of this slide is "vătaştină" or "at spoieli", a name which came from the geological embodiment of the slip body, whose surface is made of clays and the base is made of marls. The name derives from the rocks that were used locally in the early twentieth century, to paint houses. It is a deep slip developed in the rock of the place, of glimee type. The body of the slip is very explicit in the landscape. The difference in altitude between the slipping foot and its crest is of 65 m, with a length of 185 m and a width of 105 m, obviously occupying a larger area compared to the slides described above. The area where the slip lies, is bounded by wire fences. Pine trees were planted at the top of the ravine detachment and the sliding body. In addition to these, spontaneous vegetation consisting of hair and wild apple, wild rose and blackthorn also grew. Between the ditch detachment and slipping body, as well as the front part of the sliding body rush and reed grow, indicating the presence of water in the substrate. This slide does not affect the local community too much, being outside the precincts of the village, in an area used as pasture. On the left side of the slope the retreating slip is obvious by the appearance of saddles, used practically as a cattle trail. The versant affected by the sliding- faces southwest.

● The landslide that occupies the largest area in the Basin of Olpret Valley is located on the right valley Secătura, a left tributary of Buduş valley. It is a glimee type sliding developed under the edge of a hill called Hij (Photo 5). It is a reactivated slip, highlighting more multi-stage sliding, shaped by tougher horizons of sandstone. These steps are grassed and with bushes of wild rose, blackthorn and wild hair. The versant affected by the sliding faces southwest.

By taking these steps, we can talk about the emergence of a sliding slope. It covers a length of 306 m and a width of 154 m. The lake between the ditch detachment and the sliding body is clogged. In the southwestern end of the detachment ravine, the sliding is enabled. The detachment ditch in this sector is well illustrated, having layers of clay arranged homoclinely, with delluvials at its base. Only one landslide, a mound consisting of rock is present. The difference in level between the upper and lower parts of the slipped body is of 27 m. The lake behind the slipping wave is clogged. The composition of delluvials is dominated by the presence of sandstone, sand as well as Sarmatian sarsen stones. To stop the development of the slip, the base part was planted with underbrush. Although it occupies a noticeable area, the impact of this slide is minor, being outside the village precincts.

Photo.5. **Landslide from Hij, Vâlcele village**

Photo.6. **Ditch detachment of the landslide detachment from Suarăş.**

3.2. Recent Landslides

Shallow landslides were called those having a thickness of less than 2 m deposits affected (Surdeanu, 1998). The left side of the Olpret valley has frequent slope ruptures, early- shallow slope landslides derived from the cornice. Landslides affect mainly head cuestas tributary valleys of the Olpret oriented west-southwest. These valleys have subsequent character because of the general direction tilting strata, east-northeast. The left side slope of Olpret valley shows frequent breaks, early and shallow slips derived from the cornice of the slope. Because of the position, mainly southern, the insolation is stronger. The tilting of this slope, which is large enough, determined its terracing on numerous parts for planting fruit trees. The upper part of the terraces is affected by raindrop impact and deep erosion (gullies). The upper third of both slopes of the Olpret valley is generally wooded. Therefore, mass movements start on this part and they creep towards the base of the slopes. Early shallow slips are ubiquitous on the left side of the valley. In order to stop the development of these processes, in the period before 1989, the affected areas were planted with pine, spruce, locust and buckthorn. This aspect is obvious across the following villages: Maia, Răzbuneni, Bobâlna, Oşorhel, Vâlcele, Antăs or Pustuta.

● On the right side Suarăşului Valley, a tributary valley subsequent to Olpret valley, there is a lenticular, recent slip (Photo 6). The residents date the starting time of the slipping in the 1987-1988, after long rains in large quantities. The slipping started at the edge of the cuesta. The sizes of the slipping are smaller, measuring 72 m in length and 85 m width. Behind the sliding lens there is a small pond, partially covered by hydrophilic vegetation (coltsfoot, horsetail). The detachment ditch is developing, being heavily fragmented by processes of runoff and starting gullying. The rocks on which the lansliding developed are clays at the base and marls at the surface.

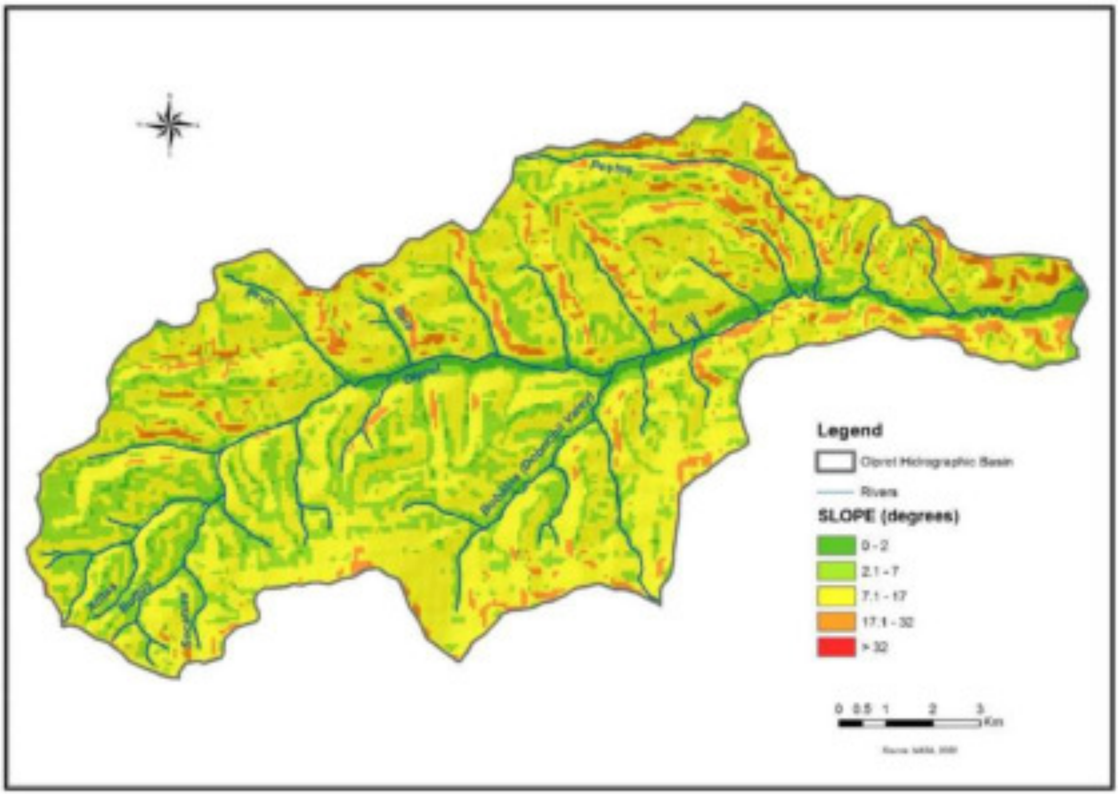

Fig. 4. **The map of gradient Olpret morphohydrographic basin**

● Another early slip is present at the head of the Antăş valley, a left tributary of Buduș valley, in the perimeter of the Blidăreşti village. The affected slope faces south-east. The difference in altitude between the top and the ditch detachment is of 35 m, its length of 179 m and its width of 52 m. It does not affect human activities, greatly being located outside the village, on land used for pasture. The territorial impact of these processes is very low because Blidăreşti village is one of the localities under stamping. Rural exodus in the years 1970-1980 was massive and it was not followed by return migration. Since the old agricultural economic structure fell apart, this territory became unattractive. Development opportunities are limited, so Blidăreşti village now has only six permanent residents.

● On the left side of Olpret valley, at the end of Pustuta village, there is a reactivated landslide. This sliding slope faces south-east. The length of the slip is of 210 m, the width of 200 m and the differences in level between the top slip and ditch detachment is of 34 m. The ditch detachment was formed in the lower half of the slope due to the higher slope and due to lithology. At the base the sliding body appears as a thin sandstone horizon over which thicker layers of clay, sand and sandstone overlapped. Although we tried to stabilize the sliding mass movement by planting acacia trees and underbrush, the slipping reactivated itself. The fact is demonstrated by the network of basins insinuated upstream of the ditch detachment.

On the steeply inclined slopes, used as pasture, furrows forming landslides are found, which affects only the grassy soil horizon, as it is the case of the left slope of Antăs valley.

● The base of Buduș valley is most likely to trigger new landslides, starting in the watershed of the Buduș valley and the Lujerdiului valley. The front detachment measures 400 m. The slope, facing north, favours the constant moisture maintainance in the substrate consisting of loose rocks. The slope is more than 15 degrees steeper (Fig. 4), and the use of land is low, being only used as pasture. Imminent formation of a landslide is given by the road layout. In some areas, at the top of the slope, the road enbankment is already uneven with approximately 10 cm. These ruptures are accompanied by downward movements of the terrain, on the low part of the fracture. Clearly, under conditions of high intensity rainfall on land soaked to saturation with water it is possible that a new landslide in this place to be triggered. Given the size of the ravine of detachment, we can say that this version will evolve as a sliding slope analogy Florina Grecu made in (2008) to describe this type of slopes.

4. Conclusions

There are two morphogenetic systems noticeable in Olpret Valley basin. The periglacial specific to Pleistocene, where the slopes were mostly shaped by processes of soil running (Ichim, *Geography of Romania, Physical Geography*, 1983). Frost and thaw alternation have favoured quasi-horizontal surfaces on structural surfaces on interfluvials or on higher structural surfaces, such as Bobâlna Hill. Its traces are present as eluvial deposits. The moving of mollisoll on the frozen substrate (permafrost) gave rise to a wavy or terraced relief, even on the slopes with low inclination. On slopes with higher inclinations, massive landslides were triggered.

With the warming of the early Holocene, the relief modeling system is temperate. On the surfaces which are slightly inclined by gelifluction processes, the later are replaced by those of wet-dry mechanical weathering (terms introduced by Mac, 1986). Weathering is no longer dominated by the disintegration, but chemical alteration represents a major part in the the creation of the alteration of the crust. Therefore, the Holocene eluvial deposits have a finer grain size. The transit of these materials in the production area (units 1, 2 the model of Dalrymple, Blong and Conacher, 1968, quoted by Grecu (2008) to the sedimentation (units 6, 7, 8, 9, the same authors) is no longer the preserve of gravitational processes mostly, but the river modeling. Old landslides develope, the trigger factor this time being dry periods alternating with extremely wet ones. Creeps of smaller dimensions than the periglacial ones are produced, but they show the same way of relief development. The overlap of the two morphogenetic and morphoclimatic systems are to be observed, offering this place a palimpsest character.

In conclusion, the processes of slopes development by mass movement of landslide type are significant in share in Olpret Valley basin. The lands used for agriculture occupy a much smaller area since 1990, so anthropogenic causes of slope development through slopes run-off, gullies, ravines, streams, are proportionaly diminished. However, detailed study of these processes, directly or indirectly linked to landslides, requires the use of the information gathered in the preparation of sustainable development projects.

REFERENCES

CIUPAGEA, D., PAUCĂ, M., ICHIM, TR., (1970), *Geologia Depresiunii Transilvaniei*, Editura Academiei Republicii Socialiste România, București, 256 p.

GÂRBACEA, V., (1997), *Remarques sur le relief de „glimée" en Roumanie*, Geografia fisica e Quaternaria, 19, 1996, Ed. Comitati Glaciologico Italiano, Torino, 279, 219-221.

GÂRBACEA, V. (2013), *Relieful de glimee*, Edit. Presa Universitară Clujeană, Cluj-Napoca, 259 p.

GOȚIU, DANA, SURDEANU, V., (2007), *Noțiuni fundamentale în studiul hazardelor naturale*, Editura Presa Universitară Clujeană, Cluj-Napoca, 142 p.

GRECU, FLORINA, (2008), *Geomorfologie dinamică*, Editura Tehnică, Bucureşti, 392 p.

MAC, I., (1986), *Elemente de geomorfologie dinamică*, Editura Academiei Republicii Socialiste România, Bucureşti, 215 p.

MAC, I., (1976-1980), *Geomorfologie:curs,* Cluj-Napoca, 341 p.

POP, P. GR., (1967) *Aspecte ale proceselor de versant în regiunea Dealurilor Şimişna –Dej*, Comunicări de Geografie, volumul IV, Bucureşti, 212, 114-123.

POP, P. GR., (2007), *Județele României. Județul Cluj*, Editura Academiei Române, Bucureşti, 277 p.

POP, P. GR., (2012), *Depresiunea Transilvaniei*, Editura Presa Universitară Clujeană, Cluj-Napoca, 289 p.

SURDEANU, V., (1998), *Geografia terenurilor degradate*, Editura Presa Universitară Clujeană, Cluj-Napoca, 274 p.

* * * (1983), *Geografia României, I, Geografia Fizică,* Editura Academiei R.S.R., Bucureşti, 662, 615-621.

[1] PhD student at the Faculty of Geography, Babeş-Bolyai University Cluj-Napoca
violetaretegan@yahoo.it

Landslides from the Apatiu, Meleş Basin (Transylvanian Plain)

Vasile Viorel POP

Abstract. Glimee-type landslides (rotational slumps) have been the subject of several papers published by geomorphologists from the Babeş-Bolyai University in Cluj-Napoca, among others. This paper aims to study this type of landform in the Meleş Valley basin. The paper focuses on presenting the conditions leading to these landslides, their triggering mechanisms, and their future development. Field observations indicated the existence of a massive glimee-type landslide affecting the right wall of the Apatiu Valley, in the proximity of the homonymous village. It is a complex landslide, extending from the upper third of the slope, where the scarp lies, to the Apatiu river meadow. Under the influence of later human intervention, such as levelling the toes to gain arable land, the slumps alignments kept their shape only in the median part of the slope. A proof for the extension of the landslide down to the Apatiu meadow is given by the river's deviation towards Apatiu.

The total area affected by mass wasting reaches 175 hectares, whereas the hills' toe surface extends over 9 hectares, given the agricultural transformed land. This area comprises 38 toes grouped in five parallel rows, while two of them are more isolated.

Keywords: landslides, rotational slumps, hillocks, Meleş Valley, glimee-type relief

1. Introduction

This paper aims to present the evolution of valley-slope systems from the Transylvanian Plain, where our study area is located. The Meleş Valley Basin is situated in the central part of the Someşan Plain, which is a subunit of the Transylvanian Plain. The Apatiu Valley belongs to the hydrographic basin of the Meleş River, a tributary of the Someşul Mare River. More precisely, according to the regionalisation made by Victor Tufescu (Tufescu, 1966), the Apatiu Valley lies in the Jâmborului Hills (Fig. 1).

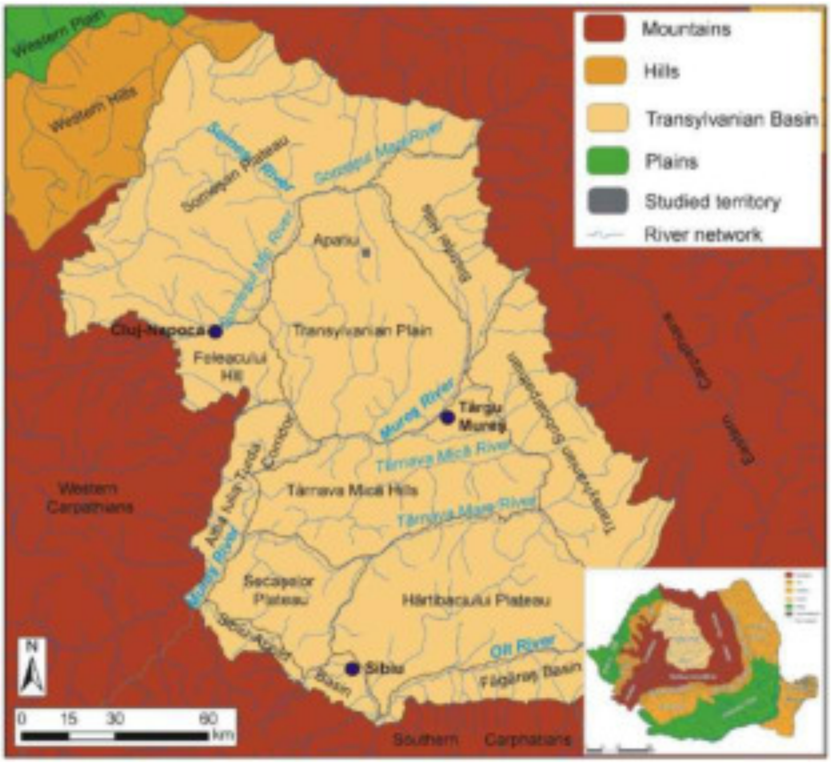

Fig. 1. **Geographical location of the studied area within the Transylvanian Plain**

Over the years, there was a wide interest in studying the problems regarding rotational slumps in the Transylvanian Plain (triggering mechanisms, evolution, age, etc.), which inhibited their detailed record. Among the researchers most preoccupied of this phenomenon, we can mention: Tövissi (1963), Gârbacea (1964, 1992, 1997); Gârbacea & Grecu (1981); Savu (1963); Morariu & Gârbacea (1968); Morariu *et al.* (1965); Mac (1970); Jakab (1981); Grecu (1993, 1985); Buzilă and Muntean (1997); Irimuş (1998); Pendea (2005); Roşian (2009); Moldovan (2011); Surdeanu (1982b, 1987, 1992, 1997b) etc.

In the profile of hillslopes in the Transylvanian Plain, rotational slumps are present at different levels; for example, the glimee-type landslides from Suatu are situated at the foot of the hillslope; those from Apold, Strugureni, Apatiu, Bozieş, and Romaneşti appear at the upper side of the slopes and on the watersheds, whereas those from Sălicea, Urmeniş, and Nuşeni cover the entire hillslope. Although these landslide type is characteristic for almost all of the depression subunits, there are some specific regional differences: the Transylvanian Plain has very many areas (over 500) affected by rotational slumping (Gârbacea, 1992), the Târnavelor Plateau (mainly in the Hârtibaciului Plateau) is known for the extension of the affected areas (Şaeş – 1500 ha, Movile – 900 ha, Saschiz 800 ha), while in the Someşan Plateau the slumping is linked not to the Sarmatian deposits, but to the occurrence of volcanic tuff (Dej tuff, Borşa tuff), the difference reflecting in the dynamics of the slumps, as the Sarmatian[1] deposits in the Transylvanian Plain comprise the complex of grey-purple marl with insertions of argillaceous mineral sands of the montmorillonite and illite class (Mac & Buzilă, 2003).

One of the main problems occurring in the study of rotational slumps is that of identifying their age and, in correlation to it, the climate conditions which inflicted such dramatic changes to the substratum. The studies mentioned above reveal several favourable time intervals for the triggering of glimee-type landslides, from the Late Glacial to the Sub-Atlantic period. According to Jakab, "*we cannot speak of a generally valid age for all glimees. In both the Pleistocene and the Holocene, moments – not periods – existed when favourable conditions were met for triggering large scale landslides*" (Jakab, 1981, p. 199).

2. Study area

Within the Meleş Valley basin, glimee-type landslides are characteristic for the upper third of the hillslopes, affecting both residual regolith and the bedrock. They are found at Apatiu, Chiochiş, Bozieş, Strugureni, Cheţiu, Manic, Nuşeni, Matei, etc. In the current paper, we will only elaborate the landslides from Apatiu.

The landslides from Apatiu are located within the perimeter of the homonymous village, on the right wall of the Apatiu Valley, in the Meleş Valley basin, which is in turn a tributary of the Someşul Mare River. Similarly to other slump areas in the Transylvanian Depression, the actual conditions that triggered the landslides seem to be linked to typical periglacial conditions, and in this particular case to crustal neo-tectonics.

3. Results

The key factor in the occurrence of the landslide is the geological structure. The slump site lies on Sarmatian strata formed of a succession of permeable and impermeable layers. The lithological structure of the site comes to light in a natural opening in the hillock: clay, volcanic tuff, sandstone and marl. Field observations revealed that the cause of the landslide was represented by some fissures in the tuff layer, which permitted the water to infiltrate down to the clay layer; by loading with water, this forms the slip plane. In the tuff fissures, a new precipitation mineral is observed to be forming. X-ray scans of the rock (Fig. 2.) sample from the Apatiu landslide reveal that it is part of the calcium carbonate family, being composed mostly of calcite ($CaCO_3$), and containing small particles of quartz (SiO_2).

It is a diagenetic carbonate crust formed through the precipitation of dissolved calcium carbonate (Fig. 3) deposited in the volcanic tuff fissures which developed during and after the landslide. Consequently, the cause of this landslide has to be of tectonic nature, as only these forces can create fissures in the mass of volcanic tuffs.

Another contributing factor can be the monocline structure of the site, which is situated on the west flank of the Strugureni dome. Given the fact that the slump mass covered the floodplain (slightly deviating the Apatiu River to the left), it appears possible that the landslide is more recent, probably dating from the Inferior Sub-Atlantic period, but in the absence of some precise dating, this remains only a speculation.

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[1] Late Serravallian – early Tortonian, cca. 13-9.

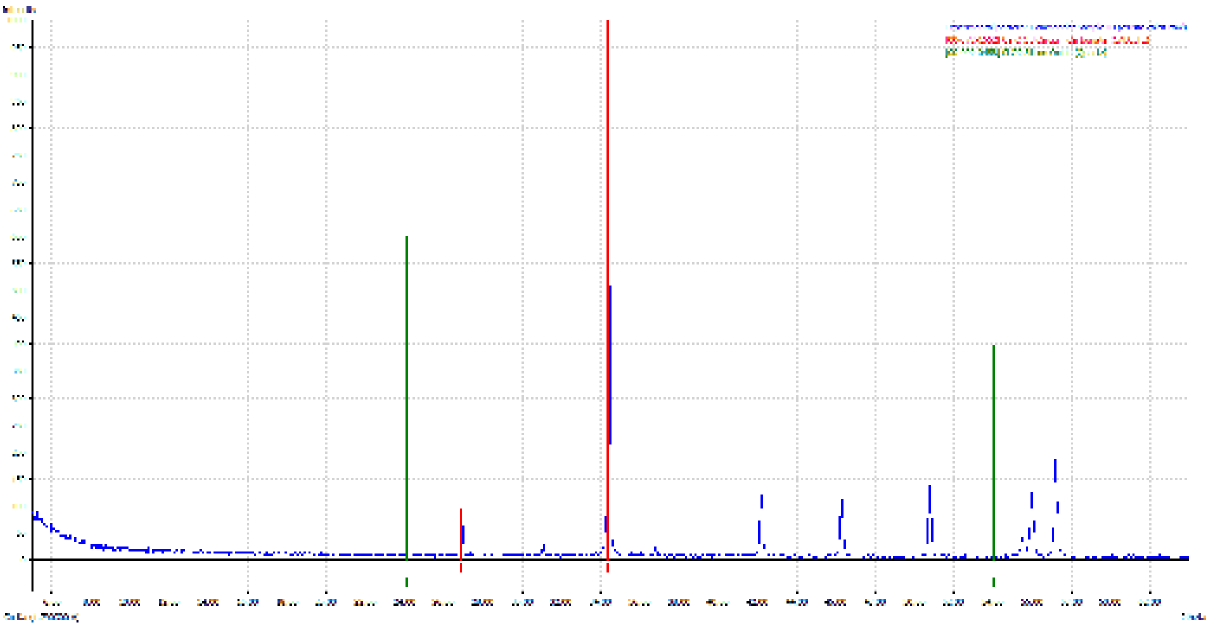

Fig. 2. **X-ray analysis of the precipitation rock formed in tuff fissures (Mineralogy Laboratory of the Babeş-Bolyai University)**

Fig. 3. **Diagenetic carbonate crust**

The landslide had at least three phases: a) in the first phase, the slope glided over the floodplain deposits, deviating the Apatiu River, leaving an approximately 50 m high escarpment; b) in the second phase, the three parallel walls are formed in the east part, continuing to the south for all the length of the slump; c) in the third phase, the hillock complex in the west is formed, standing out in the landscape through conical forms and high relative altitudes (15 – 25 m). The entire area (as measured on orthophotos by means of the ArcGIS application) covers 175 ha, but the active area is only 9 ha wide. Analysing older maps (1983, scale 1:25.000), we observed that the active area was much larger, with a greater number of rows and hillocks, but through the agricultural integration of the site, a large number of the rows and hillocks were destroyed and levelled.

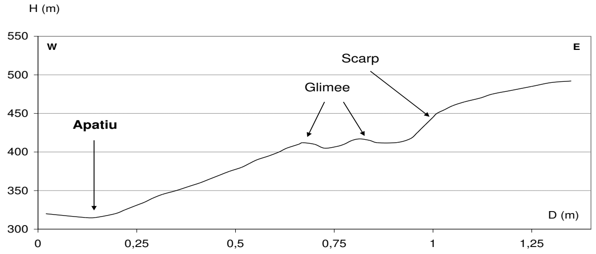

Fig. 4. **Profile of the Apatiu landslide**

The transverse section of the rotational slumps (Fig. 4) revealing three sectors with distinct morphological, morphometrical, and functional features: the scarp, the hillock (glimee) lines, and the front of the landslide.

Fig. 5. **Rows of glimee (hillocks) (photo: Pop Vasile)**

The main **scarp front** is 800 m long and presents an escarpment of 25 – 50 m. On most of its surface, the stratification of the Sarmatian deposits is visible, showing an alternation of massive marl strata and thin clay horizons, with a slight northward proclivity, which means that the landslide scarp formed perpendicularly to the geological layer inclination.

The scarp front remains active to the present day, and is still affected by new glimee-type landslides at the base of the escarpment, forming a transitional belt to the micro-depressions alignment; these landslides are in an embryonic state and at a smaller scale, as a result of present-day climatic conditions. The transition between the scarp front and the glimee lines is made through a depression alignment (Fig. 6) where the existence of a small, presently filled-up pond is traceable through the reed vegetation and the puddles that form during prolonged rainfall. Compared to the micro-depressions between the glimee lines (Fig. 5) this alignment is more pronounced and extended.

Fig. 6. **The depression alignment at the base of the scarp (photo: Pop Vasile)**

The glimee line complex. As a result of the landslide, five parallel rows of hillocks (glimee) formed at the base of the scarp. These formations started to dismantle already during the landslide. Even though some of them appear isolated, this is due to later rainwash, rilling, mudflow, etc.

Most hillocks are covered with grass vegetation, shrubs of whitethorn (*Crataegus monogyna*), dog rose (*Rosa canina*), and blackthorn (*Prunus spinosa*), and on some of them there is a small grove of hazel (*Coryllus avellana*), hornbeam (*Carpinus betulus*), oak (*Quercus robur*), and common dogwood (*Cornus sanguinea*). There is also a fauna comprising birds, like pheasant, and mammals such as wild boar, roe deer, rabbit, or fox, and in wetter areas frogs and lizards. The hillocks from the second line have the best preserved strata, which are almost horizontal. The four lines have different dimensions and are separated by micro-depressions, some larger, some barely observable. The largest hillocks are found in the second and third glimee lines, with a relative height of 20-25 m. Presently, the first line is affected by severe fragmentation (Fig. 7), and a new slump mass is separated from it, with the same length as the original hillock and closing a 3-4 m deep ditch, indicating an embryonic depression alignment (Fig. 7).

The front line of the landslide lies at the base of the hillslope, covering the river deposits with an alluvial fan, pushing the Apatiu River leftwards (Fig. 8). Their shape got them several names in the local toponymy: „dâlme”, „gâlme”, „movile”, „copârşaie”, all of which meaning small, elongated, rounded hill. Given their geological structure, most notably the presence of the horizon of volcanic tuffs, the locals from the surrounding villages use these hillocks to extract building blocks for their houses.

Fig. 7. **Secondary landslide on a glimee-type hillock**

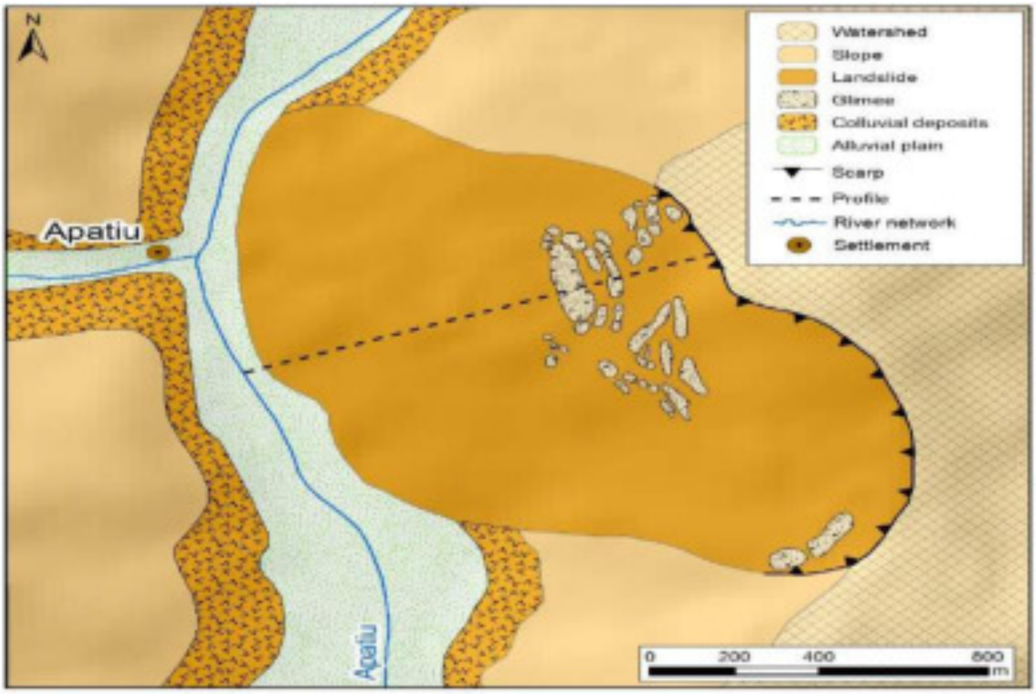

Fig. 8. **Geomorphological map of the landslide**

4. Conclusions

The impact of the glimee-type landslide on the right wall of the Apatiu Valley materialised in the retreat of the initial cuesta front toward the upper side of the hillslope, where it is visible as a bare scarp, while at the hill-foot, the slumped mass is continuously eroded by present-day geomorphological processes, tending to incorporate the alluvial fan at its base. The existence of a hillslope affected by older mass wasting processes generating several glimee lines (which, in turn, are affected by newer processes, such as soil creep, earth-slide and fall) only demonstrates the overlapping of different generations of landforms created by the same process, and which, through their relation of subordination, prove the existence of a holarchy of processes and landforms.

The hillslope affected by glimee-type landslides continues to evolve under present-day temperate climatic conditions, forming new slump fields and escarpments; due to current dynamics, the erosion process of the old hillocks and the scarp area continues.

The example presented above allows an insight on the role that geomorphological processes represented by massive, glimee-type landslides had in hillslope modelling in the Transylvanian Depression, processes oriented towards a dynamic equilibrium and generating a characteristic landform – the glimee relief (Gârbacea, 2013).

REFERENCES

BUZILĂ, L., MUNTEAN, L., (1997), “Alunecările de teren de la Saeş (Podişul Hârtibaciului)”, *Comunicări de geografie*, Ed. Universităţii din Bucureşti.

GÂRBACEA, V., (1964), “Alunecările de teren de la Saschiz (Podişul Hârtibaciului)”, *SUBB, Geol.-Geogr.,* I.

GÂRBACEA, V., (1992), *Harta glimeelor din Câmpia Transilvaniei*, Studia Univ. “Babeş- Bolyai”, Seria Geographia, vol. XXXVII, nr. 1-2, Cluj-Napoca.

GÂRBACEA, V., (1997), “Remarques sur le relief de „glimee” en Roumanie“, *Geogr. Fis. E Din. Quat.,* 19 (2), Torino.

GÂRBACEA, V., (2013), “*Releful de glimee*”, Ed. Presa Universitară Clujeană, Cluj-Napoca.

GÂRBACEA, V., GRECU, F., (1981), ”Relieful de glimee din Podişul Transilvaniei şi potenţialul lui economic”, *Memoriile secţiilor ştiinţifice*, Seria IV, tom. IV, nr. 2, Bucureşti.

GRECU, F., (1985), “Clasificări şi tipuri de alunecări de teren din Depresiunea Transilvaniei“, *Terra*, anul XVII (XXXVII), nr. 2, Bucureşti.

GRECU F., (1993), “Tipuri de evoluţie a versanţilor din Podişul Transilvaniei de Sud; 1. Evoluţia versanţilor afectaţi de glimee“, *An. Univ. „Ştefan cel Mare”, Suceava, Geol.-geogr.*, II, 2.

IRIMUŞ, I. A., (1998), “Alunecările de teren de la Corunca şi implicaţiile în organizarea spaţiului geografic“, *Analele Univiversităţii „D. Cantemir”, Ştiinţe Socio-umane,* II.

JAKAB, S., (1981), "Modelarea versanţilor din Dealurile Târnavelor prin alunecări de teren", *Lucrările Conferinţei Naţionale pentru Ştiinţa Solului Braşov, Publicaţiile Societăţii Naţionale Române pentru Ştiinţa Solului*, Bucureşti. MAC, I., (1970), "*Massive Landslides in the Transylvanian Basin*", SUBB, Geographia, Cluj-Napoca.

MAC, I., BUZILĂ, L., (2003), "Corelaţii între stratele de argilă şi procesele geomorfologice din România", *Studia Univ. „Babeş-Bolyai", Seria Geographia*, XLVIII, nr. 1, Cluj-Napoca.

MOLDOVAN, M.L., (2011), *Glimeele din transilvania- studiu geomorfologic*, Teză de doctorat.

MORARIU, T., GÂRBACEA, V., (1968), "Deplacements massifs de terrain de type glimée en Roumanie", *Revue Roumaine de Geologie, Geographie, Geophisique, Série de Geographie*, t. 12, nr. 1-2, Edit. Academiei, Bucureşti.

MORARIU, T., GÂRBACEA, V., CĂLINESCU, M., (1965), "Alunecările de la Bozieş (Câmpia Transilavaniei)", Com. de Geogr. III.

PENDEA, Fl., (2005), *Paleomediile geomorfologice ale Cuaternarului superior în Depresiunea Transilvaniei (Eemian-Weicheselian-Holocen)*, Teză de doctorat, Facultatea de Geografie, Univ. "Babeş-Bolyai", Cluj-Napoca.

ROŞIAN, Gh., (2009), "Evoluţia versanţilor afectaţi de alunecări masive de tip glimee. Studiu de caz: Versantul drept al Văii Secaşului Mic (sectorul Tău-Secăşel) ", *Geographia Napocensis, Anul III.*, nr. 1.

SAVU, Al., (1963), *Podişul Someşan. Studiu geomorfologic*, Teză de disertaţie, Universitatea"Babeş-Bolyai" Cluj-Napoca, Facultatea de Şt. Naturale-Geografie.

SURDEANU, V., (1982), "Cercetări experimentale de teren asupra alunecărilor", *Bul. Soc. Şt. Geogr.*, VI, Bucureşti.

SURDEANU, V., (1987), "Continuitate şi ciclicitate în procesul de alunecare", *Lucrările Seminarului de Geografie „Dimitrie Cantemir"*, 8, Iaşi.

SURDEANU, V., (1992), "Corelaţii între alunecările de teren şi alte procese denudaţionale", SUBB, XXXVII, 1-2.

SURDEANU, V., (1997), "Studiul alunecărilor de teren", *Probleme de Geomorfologie*, I.

TOVISSI, I., (1963), "Alunecările de teren în regiunea comunei Măgherani", *SUBB, Geologie.-Geografie*, I.

TUFESCU, V., (1966), *Modelarea naturală a reliefului şi eroziunea accelerată*. Editura Academiei Republicii Socialiste România, 619 p.

"Babes Bolyai" University, Faculty of Geography,
Department of Physical and Technical Geography
5-7 Clinicilor str., 410087, Cluj-Napoca, Cluj
vassypop@gmail.com

Multidisciplinary Analysis of the Bălteni Landslide (Romania)

Andreea ANDRA-TOPÂRCEANU[1], Mihai MAFTEIU[2], Mihaela VERGA[1],
Mircea ANDRA-TOPÂRCEANU[3], Sanda BUGIU[4], DENIS MIHĂILESCU[5]

Abstract On the right side of the Topolog River, an old landslide was reactivated in June 2005 affecting the entire pasture area of Bălteni village, which belongs to Tigveni commune (the Argeş County). The landslide occurred because of the existence of several discontinuous sliding planes situated at various depths. At the same time, it was also encouraged by the saturation degree of the sliding mass, by the lithological structure and by the existence of faults and fractures in the middle and lower sections of the failure planes.

The sliding mechanisms are active even in the case of morphological areas with declivity values (2^0-5^0), in the conditions of relatively low precipitation, because the physical-mechanical properties of the rocks and the structural accidents. The uccessive alterations are resuled by the displacement of the mass of cohesive earths and because of the moisture along a fault plane.

The aim of the research was finding the complex sliding mechanism, the geomechanical parameters and hydrological conditions of the geomorphological process and the conditions of low values declivity even if the rainfall were not significant.

Keywords Bălteni landslide, geomorphological mapping, vertical electrical soundings (VES), self-potential (SP), fault, geotechnical parameters.

1. Introduction

Landslides are morphodynamic processes affecting over 70% of the 550-450m hypsometric step of contact area between the Getic Subcarpathians and Piedmont Plateau, in the Topolog basin. Scientific interest was determined by the risk quality of these processes, especially of Bălteni landslide to local community, occurred in 2005.

The study hypothesis was defined by probability triggering factor consisted in rainfalls (either rapid rainfall, even long period intense rainfall), hanging in rainy year 2005 and their role in maintaining the sliding mechanism. In the first stage, the central aim of this work was to demonstrate the sensitive relation between rainfall (from 2005 rainy year) and Bălteni landslide. Much of our survey was based by rainfall events analysis related with monitoring of mass movement. We observed that landslide is not often triggered by rainfalls or antecedent rainfall (Tan *et al.*, 2007). After, reconsidering the triggering roll of rainfall on Bălteni landslide, and because of lot of moisture in slide mass even in dry periods, the main question was changed and was: Can exist an ascending vertical water circulation which overfill the mass movement from lower strata?

The Bălteni landslide is trending NW-SE along the entire length of the right side of the Topolog River. It sets in motion the deposits of the lower terraces, wiping them gradually from the landscape morphology. The area affected by the investigated landslide belongs to a transition strip of land separating the Topolog Sub-Carpathians (Getic Sub-Carpathians) and the Cotmeana Piedmont, a sub-unit of the Getic Piedmont (Figure 1). The SSE part of this sector has a monoclinal structure consisting of plastic clays, marly clays, sands, and clays (Dragos, 1950, 1952, Dragoş, 1959), which generate a specific morphology, with cuestas exhibiting linear or angular fronts, oriented to the N, NE and NW, and dip slopes shaped by hydrodynamic and gravitational processes (Andra, 2008).

Because of the heavy rainfall (2005) and the high discharges of the Topolog River in its upper course lying in the Făgăraş Mountains, large amounts of water were evacuated from the upstream reservoirs, which generated a liquid and solid surplus in the river channel. Thus, the lateral cutting of the right bank of the river affected the thin sands alternating with Dacian marls and clays.

Consequently, in June 2006 the landslide reactivated, which setting in motion the Pontian deposits (marls, clays and sands) stretching as far as the interfluve.

In the vicinity of Bălteni village, the lateral erosion undermined the old sliding front, imposing chain rotational movements to the upper part of the slope. The immediate effect of this process was the natural damming of the Topolog channel for about 24 hours and the formation of a temporary lake in its channel, which posed a high hydrological risk for the households lying in the proximity of the channel.

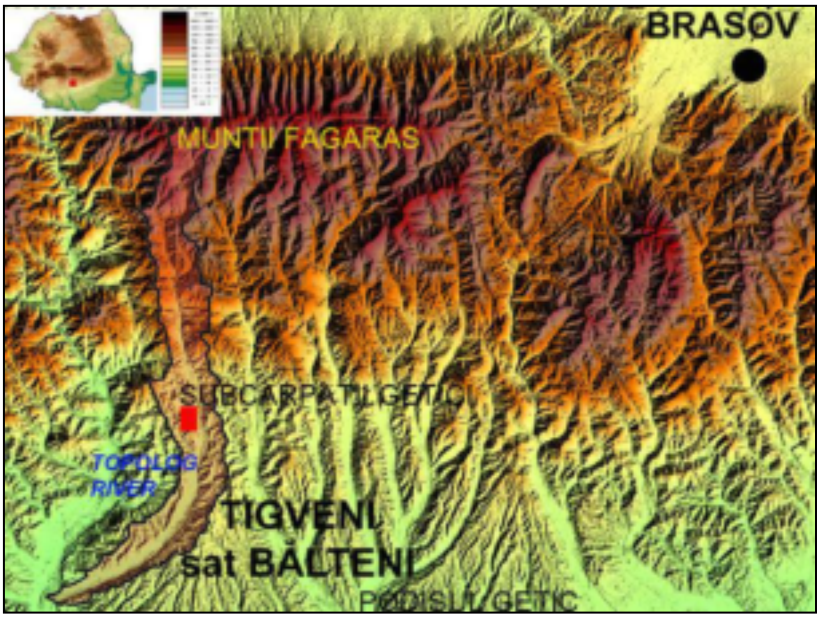

Fig. 1. **The Bălteni landslide location**

2. Field methods

The field investigation consisted in land surveying performed in 2006 (Sokkia 610), geomorphological mapping (in 2006, 2008, 2014 and 2015), geoelectrical measurements consisting in vertical electrosoundings (15 in 2006, 6 in 2008), as well as measurements of self (natural) potential (SP in 2015 on a cross profile of about 100 m) and geotechnical survey (4 drillings in 2015 with soil analyses). The geomorphological mappings were undertaken based on topographic maps of scale 1:25000 (1980), topographical plans of scale 1:10000 (1968) and orthophotoplans (2011). They aimed at highlighting the specific features of the landslide parts, their dynamics, and implicitly the way in which the landslide expands. The geoelectrical measurements were accomplished by using the Schlumberger symmetric quadruple device with high resolution, resistivimeter Supersting R1 (AGI - USA) and SAS 300 for identifying the lithology, the hydrostatic levels, the failure planes, and the structural accidents (Mărunțeanu *et al.*, 2003). The 21 VESs, deployed in the field in a grid with a cell of about 200/100 meters, have a maximum investigation depth of 20 m. The self (natural) potential geophysical method (SP) is useful for studying the buried structures, the geological borders and especially the groundwater flow directions and the water stagnation areas. The maximum values of the self (natural) potential indicate water emerging areas, while the minimum values point at water losses through seepage. In order to measure the difference of potential (in mV) along the profile a bipolar device was used (N static and M mobile). The measurements of the ground's natural potential in cross section in order to determine the hydrogeological (flow direction) and structural (dip) parameters were done every meter on an investigation depth of 15 m. The borings were made using the manual drill for removing geotechnical samples with a view to analyzing the specific parameters. The maximum depth of the borings was 6 m, where a friction plane was encountered.

Additional data were provided by meteorological analyses and filling up questionnaires.

3. Rainfall data

In this study we used daily value rainfall from 3 meteorological stations (Rm. Vâlcea, Morărești, Curtea de Arges), since 2005 until 2014 (Fig. 2). The goal of rainfall data analysis is to find the maximum of rapid or heavy rainfall or the maximum amount of cumulative precipitations which might be corresponding with movement of Bălteni landslide (Brunetti *et al.*, 2015). The most precipitations occurred every year since March-April until September, and the most intensive rainfall events were recorded in 2005 in April (< 30mm/day, and 45 mm/5 day), in June, when slippage was reactivated (< 25 mm/day and >50 mm in 6 days), July (over 30 mm/day and 70 mm/4 days amount) September (over 90 mm/day and 160 mm/8 days). In the next years, 2006 and 2008, once or twice in the annual period, the rainfall value was not more than 50 mm/day and the number of rainy days was lower.

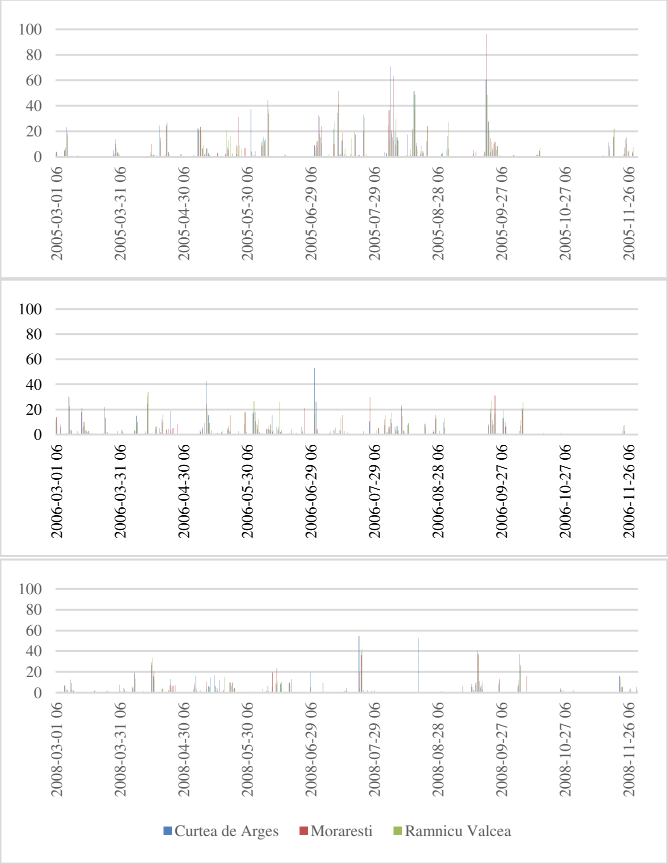

Fig. 2. **Rainfall analysis (mm/day)**

Even in the driest year, 2007, the landslide was characterized by a high water content, which meant that its water supply was underground.

4. Morphographical and morphometric analysis

This complex and subsequent landslide lies to the northeast of a cuesta front with a relative altitude of about 30 m and slope gradients of more than 40-50º (Table 1). The geodeclivity of the sliding mass ranges from 2º-3º, values that are very common, to more than 20°, as in the case of the slip ridges' fronts. Likewise, the values varying between 8º and 12° are very frequent (Fig. 3); they characterize the areas where the dynamics is more complex (Table 1). Thus, with regard to appearance and dynamics, the landslide is made up of three distinct sections (Fig. 4).

4.1. The upper section is tangent to a sliding saddle lying between two outliers detached by selective erosion. It shows marks of detrusive sliding triggered by expansion mechanisms along a failure plane made of silty clayey. The outliers are in fact older sliding masses detached from the dip slope lying to the north (South Chiciora Hill, 523 m). By analyzing the geoelectrical cross sections, we were able to identify several conformal failure planes, having hydrostatic levels.

The morphology of this section is intricate because of the various sliding mechanisms that have acted over the time. The main scarp is discontinuous and irregular, generally responding to the structural features of the basement. Usually, it mirrors the morphology of the cuestas, but on the dip slopes, it shows distension areas affecting only soil and vegetation.

The presence of a semipermeable bedding plane encourages the sliding of the rock mass and its overlying vegetation, which either leaves the trees undisturbed or makes them tilt a little bit, because of the differential rotational movement.

Downstream, the sliding mechanisms become more intricate, as the meteoric waters percolate the displaced material. The complexity is further enhanced by the old slip ridges, which have been recently reactivated. Water seeps into the ground through the fissures and cracks created by the compressive stress generated by the upstream detrusive landslide. The lithological change from the upper layer (silty clay) to the immediate lower one (compact clays), which underlies the dip slope, is responsible for the alterations of the features of the landslide developing in the middle-upper section. The transition between the two sections is marked by a three-meter high threshold, with a relative altitude of about 15 m, located obliquely on the main body.

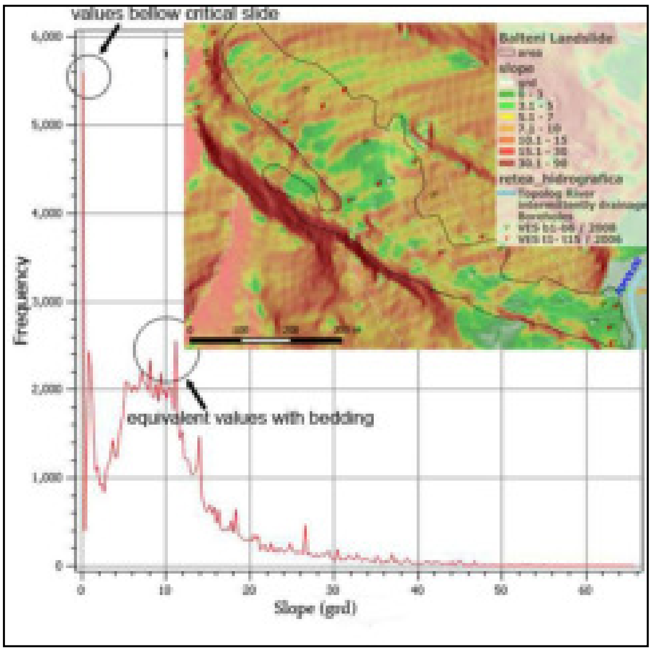

Fig. 3. **Variation and frequency values of the slopes in the adjacent Bălteni landslide area**

Table 1. **Morphometric data**

Parameters	The upper section	The middle section	The lower section	Landslide
Area (m2)	36536.3	70491.4	32130.2	139157.9
Length (m)	230	405	390	1025
Wide (m)	45-230	70-170	70-120	185
Slope (°)	7-10	15-20	3-5	8-12
Elevation (m)	510-477	477-415	415-393	ΔH = 120

4.2. The middle section has an intense and chaotic dynamics, highlighted by the mosaic appearance of the surfaces having slope gradients ranging from 0^0 to 20^0 (Fig. 3).

These create a landscape where the quasi-horizontal areas, sometimes with reverse slopes, fed by rains and ground waters, alternate with stronger inclined surfaces, as is the case of the slip ridges, which are heavily dissected by erosion. This section exhibits the largest number of water pockets, which feed the rock mass lying downstream; as a matter of fact, the reactivation of 2006 stretched from the bottom of the slope up to this middle section. The surface catchment area is situated in the final part of this section, where the fissure and cracks are denser. In other train of thoughts, analyzing in the field the surrounding area of this section we ascertained the discontinuities and the sharp drop of the elevations of the cuesta lying on the right hand side of the landslide. Downstream of it, follows a dip slope developing on layer ends and having lower amounts of local relief. The geological maps of the area do not show local fractures, but the geomorphological and geophysical analyses suggest their existence. For instance, the geoelectrical sections reveal a great variety of sliding mechanisms, in the sense that the middle-upper section has at least two failure planes. The lower one partly overlaps the basement (SW) and the old displaced material (NE), composed of clays and sands, while the upper one, lying at small depth, suggests a shallow landslide, highlighted by the lateral cracks, which may trigger in future a new landsliding process. ***The middle-upper section*** consists in a poorly defined landslide body that morphologically combines with the old slip ridges leveled through sheet and rill erosion. The slump process partly reactivates and dissects the old slip ridges. The novelty of this section is the formation of secondary detachment scarps, perpendicular to the direction of the main body. They affect the sides of the dip slope lying above the left hand side of the landslide, which will be affected by the future evolution of this area. Because of the lateral fractures and secondary scarps, the cuesta situated north of the left hand side of the landslide, merely 50-70 m away, will be dissected by the lateral development of the process and by the appearance of sliding saddles. ***The middle-lower section***, characterized by waterlogging, shows an active dynamics due both to the significant amounts of groundwater that reach the surface on the layer ends and the upstream intake, which soak the displaced material. Under the circumstances, the vegetal cover is not broken, but only strongly distorted. As a matter of fact, the mudflow-type sliding resembles a conveyor that is subjected to compressive forces, which warp the clay layer and the soil cover by 1 to 1.5 m. The middle-upper section is influenced by the sliding occurring along the bedding planes, which will be responsible for future reactivations and lateral expansions of the existing landslide. In its turn, the middle-lower section is determined by the relation with the cuesta-type slope, by the ground waters that are lying within the second terrace of the Topolog River, and by the excess material coming from the steep slope of the cuesta. The mudflow plane overlaps the lithological contact between the wet clays and sands, on the one hand, and the marls lying at the bottom, on the other hand.

4.3. The lower section is represented by the toe, which through an intake of matter and energy interacted with the river system, temporary damming the Topolog River. From the point of view of its consistence, one can ascertain a clear differentiation in relation to the upstream sections:

- the failure plane has a low gradient, which suggests the sliding was triggered by the displaced materials pressing from upstream;
- the rocks making up the toe of the landslide are almost completely depleted of water, as the dense network of cracks produced by mass compression drain it to the river channel;
- under the circumstances, the toe appears as multiple fragments located in different positions relative to one another, which are shaped at the bottom through fluvial erosion – the mass of the toe is mixed with deposits of sand and gravel belonging to the lower terrace of the Topolog, which make the ground more pervious;
- the landslide advancement into the channel led not only to the temporary damming of the river, but also to the alteration of the channel landforms in the respective area and upstream. The changes occurring in front of the landslide toe consisted in pushing the river to the left and in the reversal of erosion and accumulation areas between the two banks (the right, concave bank, supporting the displaced materials was protected against erosion, while the left, convex bank formed by fluvial accumulation, was subjected to lateral cutting and undermining). Likewise, we noticed that the abandoned channels with “fresh” sedimentary deposits were reactivated (under the circumstances of critical threshold), being able to drain the water surplus during the time when stream channel was dammed. The process develops regressively and monolaterally (to the right, *i.e.* to the north), with successive reactivations on various sections, especially during the wet periods.

5. Geophysical and geotechnical analysis

From the lithological standpoint, the Pontian (upstream) and Dacian (downstream) deposits are the formations underlying the Bălteni landslide. The first ones appear as a strip of land oriented WSW-ENE, and developing between Bădislava and Tigveni, on a mean width of 2.5 km. They are made up of marls and clays with thin intercalations of sands (sometimes marly), coals, compact grey-green marls and coarse sands. The Dacian deposits consist of bluish marls (few-decimeters thick), clays and sands, having a mean width of 2.5 km and a maximum one of 6 km. These formations slope down to SE and SSE with gradients of about 12^0 (Mihăilă, 1970, 1971) and form outcrops along the valleys and in the landslide scarps.

Lithostratigraphically speaking, the deposits are made up of clays, sometimes sandy, with intercalations of coals (on a depth of about 40 m), mica sands and gravel with torrential structure, alternating with grey-green marls on tens of meters.

The mechanical and hydrogeological features of these deposits are responsible for the large-scale morpho-hydro-dynamic processes affecting the slopes, which have complex socio-economic effects at local and regional level.

5.1. The network of SEVs and borings allowed the geophysical interpolation of data in the form of 10 profiles, of which five are cross profiles, which are located in every section of the landslide and along the borderlines between them, and four are long profiles. Of the last ones, three were performed in 2006, in the southern, middle and northern sections, while the fourth was accomplished in 2008 in the central-northern section, after the process increased in intensity.

The interpretation of geophysical data reveals that the displaced material and the failure plane have a complex structure, with a number of discontinuous and small-size percolation and hydrostatic levels (0.6-1 m thick). These are found as low as 6-8 m, under the form of clayey sands with intercalations of clays, marly clays and clayey marls (2.5 m, 5 m, 7 or 8 m), of which the last ones make up the failure planes. The strata have been subjected to fracture, dislocation and slip, which explain the wetting and drying cycles and the presence of deep failure planes. Outside the borderlines of this area, there are strata that have not been set in motion by sliding. The fractures and dislocations have locally led to the appearance of lens-shaped strata, while the several failure planes that came to light under the form of layer ends, were driven away by the motion of the displaced material.

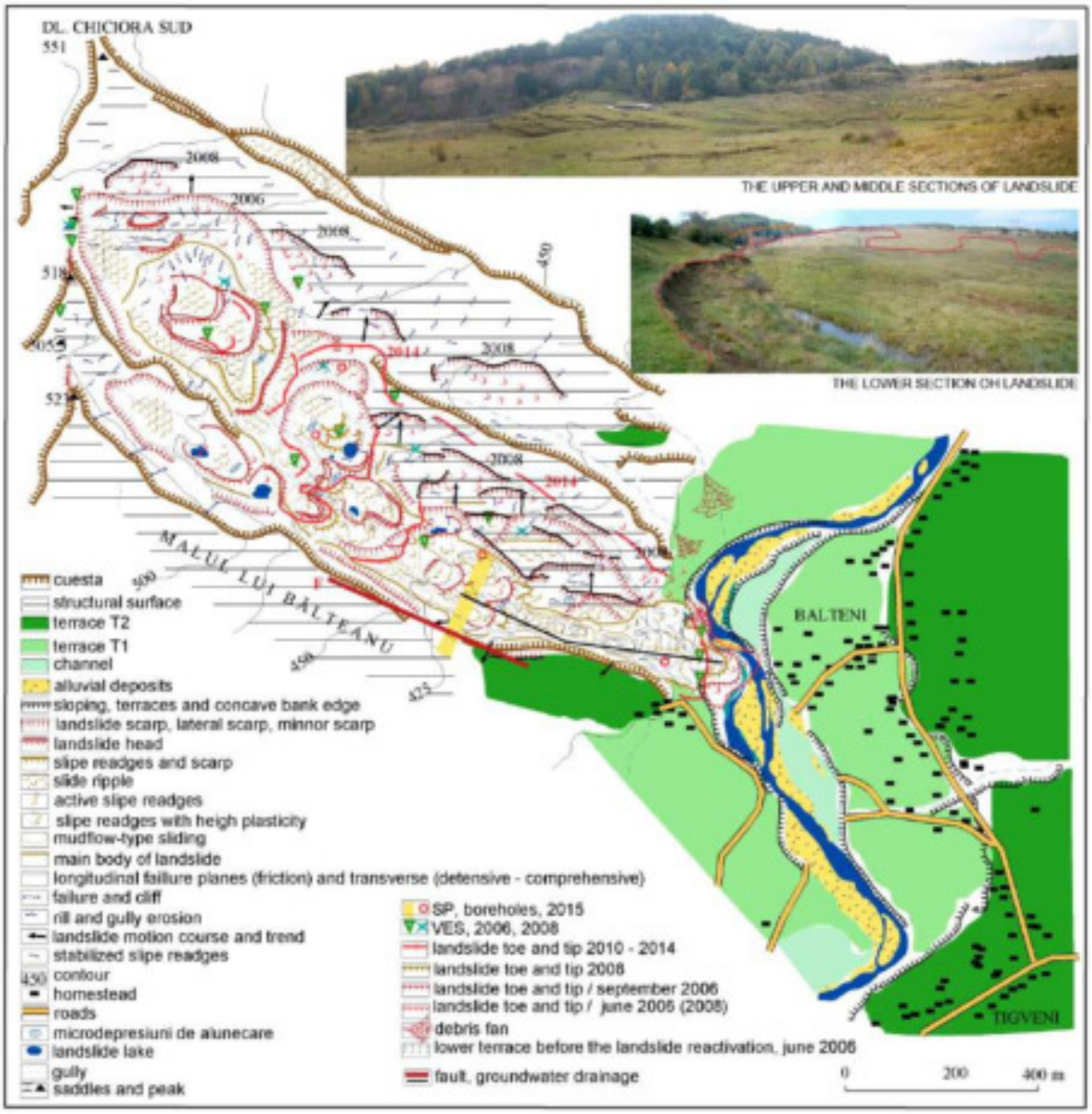

Fig. 4. **Geomorphological map of Bălteni landslide**

At different depths (levels) geoelectrical images (Fig. 5) reveals:

- the distribution of minimum resistivity values in the central part of the landslide (where deposits are more sandy than the surrounding) indicate the heads strata resulted by fracture layers. In their slipping, determined by water saturation train clay deposit, creating mass sliding. This is the area where the reactivation of ancient landslides occurred;
- the separation of heterogeneous stratifications (lens form) as the depth increases is reflected in slipping morphology through the obvious sliding and puddle steps;
- the existence of areas where colloidal clay is deposited, which requires crossing water circulation in landslide mass;
- the landslide is divide into 4 sections separated by thresholds with higher resistivity (dry areas).

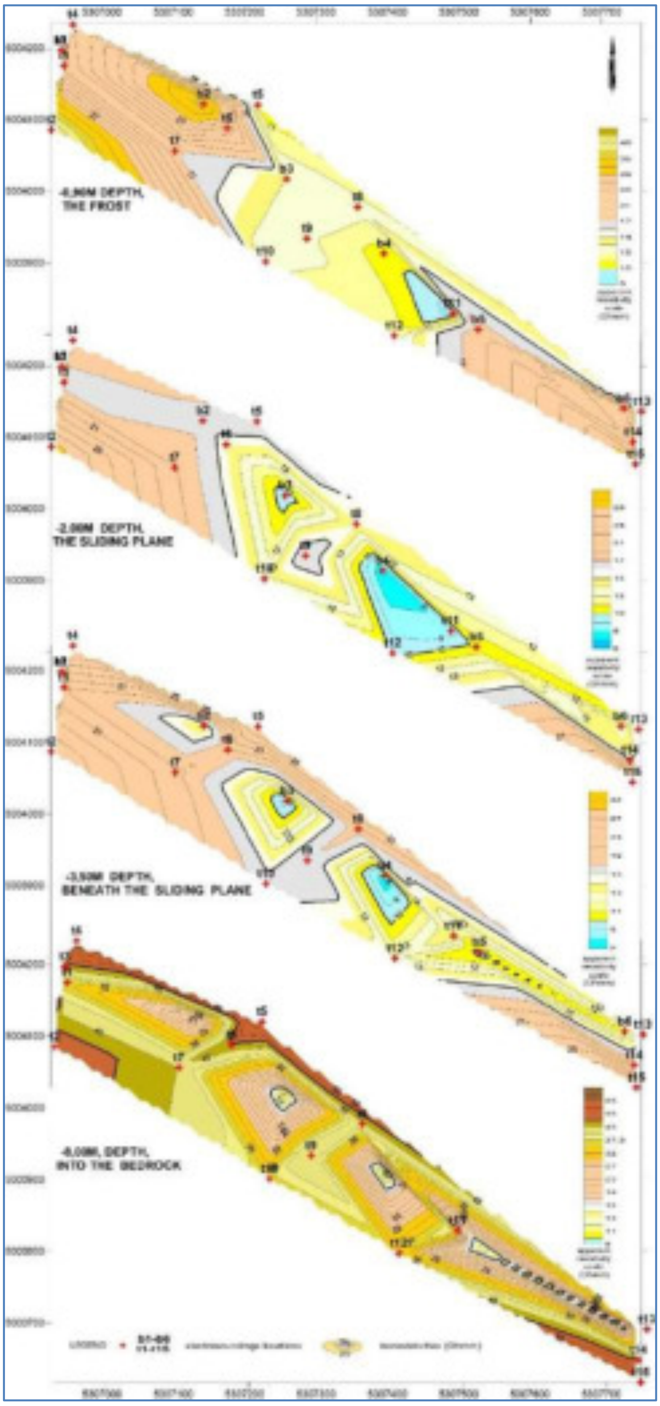

Fig. 5. **Geoelectrical maps at different depth**

The cross profile S1-1 points at the existence of an old landslide in the form of an old slide outlier that migrated 60-80 m to the south by breaking a layer of sand with small amounts of clay belonging to the layer surface lying to the north. Likewise, an obvious lithological discordance has turned into a supply path for the strata that make up the failure plane. The displacement material tends to accumulate to the south, at the bottom of the cuesta, which requires a minimum thickness of at least 2 m in comparison with the friction planes at the northern side of the landslide, which come to light. At the same time, one can note an increase of the depth of the first failure plane from 6 m in the north to 7 m in the center and 8 m in the south. The geoelectrical interpretative profile in the south (S8- 8, t2-t15, at SEV t12) (Fig. 6) reveals three dislodged and rotational sliding masses, of which the most striking is situated in the central section (485 m). Along the central axis of the landslide, which was analyzed with the S6-6 (t1-t14) profile (Fig. 7), the morphological surface intersects four failure planes, while the mass of rocks that make up that surface gets thinner downstream. The northern side of the landslide has a complex dynamics. In this area, the geoelectrical profile S7-7 (t4-t13) (Fig. 7) highlights the following: the bedrock appears to surface (on more than 75 m) and the old failure planes have been reactivated. The slip ridges are characterized, especially in the central section, by rotational movements, which downstream give rise to local unevenness, with relative heights of 5-7 m, while upstream they encourage the formation of sliding pools. Laterally (to the north), these ridges thrust over the structural slope surface, recently dislodged. In the lower section, the sliding mass reaches 10 m thick and exhibits five failure planes. The last one, the newest and the deepest, was highlighted starting with the measurements undertaken in 2008. In the same year, we noted an increase of rock moisture, which in fact was an increase by 2.5 of the geophysical values of apparent resistivity of 2006 (14-25 Ohm.m) in comparison with 2008 (6-10 Ohm.m), while the geotechnical values are characterized by a moisture of only 30%. Some abnormalities were traced concerning the correlation among the amount of precipitation, the landslide dynamics, the geophysical and structural features, and the geotechnical parameters. As long as the amount and the type of precipitation were not always enough for ensuring the moisture content and for triggering the mechanisms of fracture, dislodging and sliding of the displaced material, we came out with the hypothesis of structural accidents, which might explain the existence of hydrogeological supply sources within the displaced material. Thus, the self-potential (SP) profile aimed at detecting *a possible structural discordance on the southern side of the landslide (Bălteni fault)*. At meter number 85 of the profile, we were able to determine, by a maximum-minimum pair of abnormalities, *a longitudinal fracture with vertical displacement* (the southern cuesta being the high compartment) (Fig. 6).

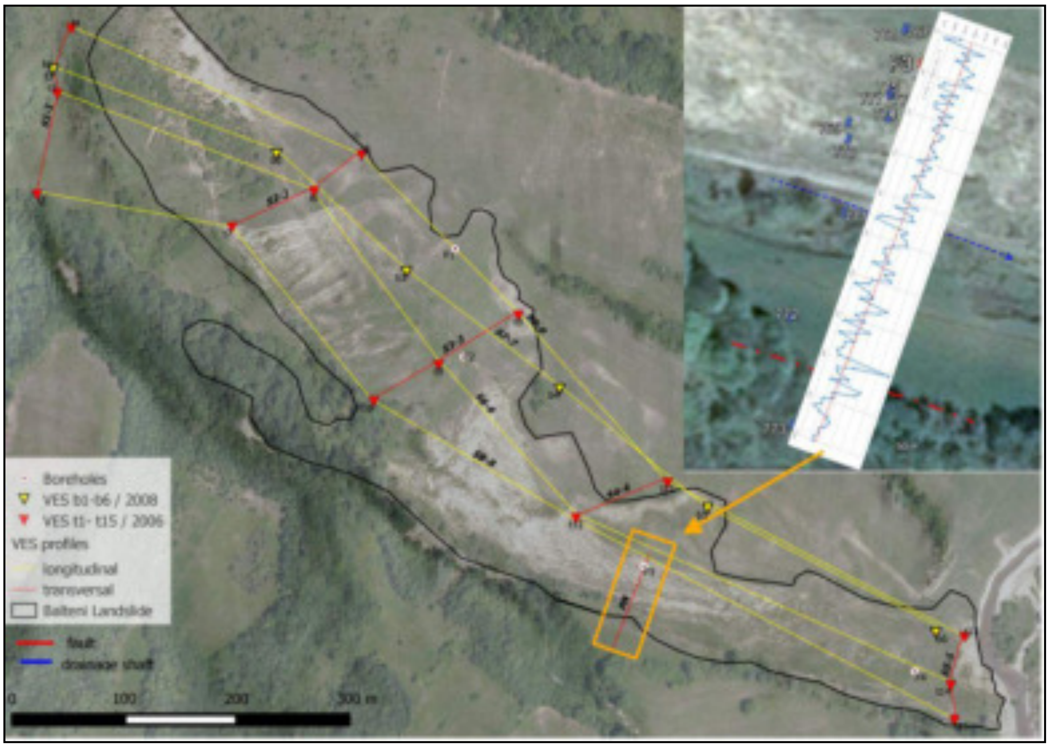

Fig. 6. **VES network and boreholes achieve on mass sliding and adjacent area. Geoelectrical longitudinal profiles: (S6-6 – S8-8 (2006) and S9–9, and transverse S1–1–S5–5 (2006). SP variations of minimum and maximum values indicate the leakage and exfiltration / emergence lines, also the fault plane**

The maximum natural potential identified mirrors an exfiltration/emergence that penetrates directly into the stratification, being responsible for the breaking and sliding of the materials, including the failure planes, which also explains the very low slip angle (Table 1). The minimum potential recorded at meter 45 of the profile is the effect of a sewer that drains the ground waters stored in the displaced material.

The statistical values of 2008 are about two times lower in comparison with those of 2006 because of the water excess in the sliding mass, even though the measurements were undertaken in October 2006 and September 2008, two months characterized by rather similar amounts of precipitation (Table 2). From the mean pluriannual amounts of rainfall (1961-1990) at Râmnicu Vâlcea weather station (lying about 15 km away) one can ascertain a minor difference, of 1.3 mm/month, between the months of September (49.8 mm) and October (47.5) (source: National Meteorological Administration, 2015).

Comparing from the statistical point of view the cross profiles 1-5/2006 with the longitudinal ones 6-8/2006, we were able to note that the values drop along the long axis of the slide by about 15% in comparison with its northern and southern edges. More obvious is the drop by 50% of the resistivity values along the middle part of the slide (S3-4-trans) in comparison with the bordering areas (S1-2 and S5-trans). This phenomenon is due to the continuous water stagnation (low transmissivity) in the prevailing clayey-marl deposits of the displaced material.

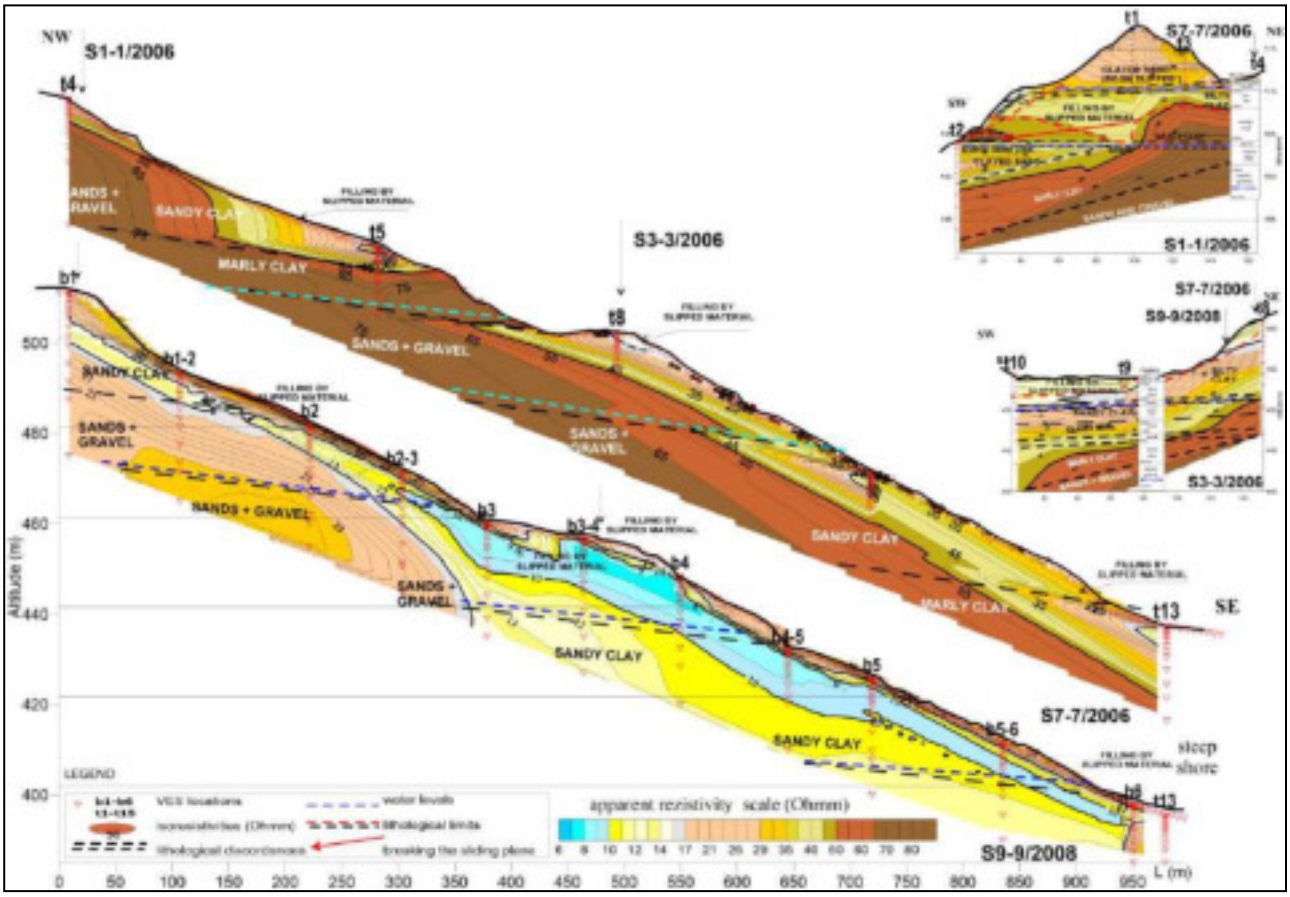

Fig. 7. **Interpretative geoelectrical sections, Bălteni, Arges county S7–7(2006), S9-9 (2008) longitudinal, S1–1, S3–3(2006) transverse.**

Table 2. **Table of resistivity statistics surveys 2006-2008**

profiles	data	sum	min	max	mean	Stand dev.
S1-1	52	2008,2	14	83,1	38,6	19,3
S2-2	39	1305,4	8,7	83,1	33,5	21,6
S3-3	39	1001,7	11,1	67,8	25,7	16,7
S4-4	39	924,8	8,3	66,5	23,7	17,5
S5-5	39	1423,8	9,4	124,6	36,3	25,5
S6-6M	65	1828,0	8,3	95,5	28,1	18,9
S7-7 N	78	2459	8,7	83,1	31,5	21,4
S8-8 S	78	2590	9,4	124,6	33,2	22,2
S9-9	165	2789	6,8	67	16,9	10,4

5.2. The preliminary field investigations of the geotechnical features of the cohesive earths that make up the upper failure planes, namely the marly clays, envisaged the natural appearance (grains and invisible pores), the invisible non-clay components (invisible limestone), the fracture appearance (irregular and mat), the appearance in fresh cut (slightly shiny), the color (grey-greenish), the touch sensation (slightly greasy), the consistency (high), the plasticity (high), and the adhesion to metals (poor).

When the moisture is high, these earths show mean detachment values. The rocks overlying the failure planes make up an irregular surface

In the presence of water, *the silts, which are one of the components of the marly and silty clays, are rapidly removed,* so that *the structure and the properties of the initial rock alter in time*. The proof is the high percentage of silt that can be found in the composition of the earths: in marly clays, the fraction ranging from 0.002 to 0.063 accounts for 57%, while in the silty clays it is 71% (Table 3). Lab analyses certified that the rocks forming the failure plane – grey and hard marly clays with disseminated limestone – are characterized by **very high plasticity** (according to STAS 1243-88) (I_p >35%) and are sensitive to freeze-thaw cycles. From the moisture standpoint they belong to the **practically saturated earths** (S>0,90), and are considered **hard earths** (I_c = 1,). According to the oedometric deformation module (M), they are included in the category of **medium compressibility** (M=10000-20000), while in the boring M= 12500kPa. Consequently, they are **active or very active earths**. The angle of internal friction of the undrained and unconsolidated material that slides down gravitationally along an inclined plane is 10^0.

5.3. Discussions and solutions for slope rehabilitation

The stability factor (SF) calculation using the Bishop Method revealed a very small amount of SF = 0.568 related to morphometric values of slope and geotechnical parameters. *Accordingly*, the slope beneath 8° values (maximum values of the terminal slip) with lengths of over 250 m slope (referring also to the last sector of slipping) *the land should be stable.*

Once again confirming that landslide is not occurs as a reflex of the slope degree, breaking the equilibrium state of the slope by its own weight, but by wetting of layers near the sliding planes from underground water sources, even during the driest periods.

Geotechnical solutions envisage the execution of drains (with temporary character, until the land gets dry) as deep as 2-2.5 m; the digging of a gravitational sewer on south part of the landslide, and the reinforcement of Topolog River banks with stone-fill dykes. As soon as the moisture in the ground is reduced, it will require afforestation.

Table 3. **Table of geotechnical parameters**

Clay [%]	Granulometric composition Fine silt [%]	Medium silt [%]	Coarse silt [%]	Fine sand [%]	Natural moisture W [%]	Plasticity index Ip [%]	Consistency index Ic [%]	Oedometric deformation modulus M [kPa]	Cohesion C [Pa]
23	24	28	19	6	25,8	> 35%		12500	-
Borehole 3, depth 2,50m: material from landslide – silty clay, yellow gray, with plastic consistency, with disseminated limestone, with FeO_3									
39	19	23	15	4	23,7	43,2	0,95	12500	55
Borehole 4, depth 3,50m : marly clay, gray, plastic and stiff, with disseminated limestone									

Conclusions

By corroborating all geotechnical, geophysical, hydrogeological, meteorological and geomorphological data we ascertained that *the sliding mechanisms are active even in the case of morphological areas with low declivity values (2°-5°), in conditions of relatively low precipitation*, because the granularity, the physical-mechanical properties of the rocks and the structural-tectonic accidents lead to the following:

- soil moisture due to the **temporary pore water pressure increase**, which turns the materials from a solid into a liquid state;
- successive alterations of the structure and physical-chemical properties of the earths;
- the displacement of the mass of cohesive earths when the silt fraction of the rocks is soaked due to the morphological, tectonic and structural context;
- moisture increase due to the water surplus that enters the sliding mass and the adjacent slope along a number of fractures.

Acknowledgement

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REFERENCES

ANDRA, A., MAFTEIU, M., TOPÂRCEANU, M., (2007), *Tigveni – Bălteni Landslide. Geomorphologic and Vertical electrical Sounding Field Investigations and Analysis*, Volum de abstracte al Simpozionului internaţional "Alunecările de teren – impactul asupra mediului şi societăţii", Bucureşti, ISBN 978-973-0-05257-2.

ANDRA, A., 2008, *Bazinul hidrografic Topolog.Studiu geomorfologic,* PhD Thesis, Bucureşti ISBN 978-973-0-06260-1.

BRUNETTI, M., T., PERUCCACCI, S., ANTRONICO, L., BARTOLINI, D., DEGANUTTI, A. M., GARIANO, S. L., IOVINE, G., LUCIANI, S., LUINO, F., MELILLO, M., PALLADINO, M.R., PARISE, M., ROSSI, M., TURCONI, L., VENNARI, C., VESSIA, G., VIERO, A., GUZZETTI, F., (2015), *Catalogue of Rainfall Events with Shallow Landslides and New Rainfall Thresholds in Italy*, Engineering Geology for Society and Territory – Volume 2, G. Lollino *et al.* (eds.), Springer International Publishing Switzerland, **280**, 1575-1579.

CRUDEN, D. M, VARNES, D.J, (1995), *Landslides: Investigation and Mitigation: Transportation Research Board, Landslide types and processes*, Turner, A. Keith, and Schuster, Robert L. eds., Special report no. 247, National Research Council, National Academy Press, Washington, D.C., p. 36-75.

DRAGOŞ, V., (1950), *Cercetări geologice asupra regiunii dintre râurile Topolog şi Olt*, (comunicare preliminară, D.S. ale şedinţelor, vol XXXVII (1949-1950), Comitetul Geologic, Bucureşti, p. 55- 76.

DRAGOŞ, V., 1952, *Asupra structurii geologice a regiunii dintre Rîul Topolog şi Valea Olăneşti,* D.S. ale şedinţelor, vol XXXIX (1951-1952), Comitetul Geologic, Bucureşti.

DRAGOŞ, GH, (1959), *Recherches geologiques concernant la region Topolog et Olt,* în "C.R. com. Geol. ", XXXVII – XXXIX, Bucureşti.

FLOREA, M., (1979), *Alunecări de teren şi taluze*, , Ed. Tehnică, Bucuresti.

KELLY, W.E. MAREŞ, S., (1993), *Applied Geophysics in Hydrogeological and Engineering Practice*, Elsevier.

MĂRUNŢEANU, C, MAFTEIU, M., NICULESCU, V., (2003), *Metodologie privind utilizarea măsurătorilor geoelectrice în zone de extindere urbană pe terenuri în pantă în vederea evaluării riscului de alunecări de teren*, Reglementare tehnică MLPTL – Bucureşti.

MALAMUD, B. D., TURCOTTE, D. L., GUZZETTI, F., REICHENBACH, P., (2004), *Landslide Inventories and Their Statistical Properties*, Earth Surf. Process. Landforms 29, p. 687-711.

MIHAILA, N., (1970), *Deplasările de teren din interfluviul Olt – Vâlsan şi locul lor în clasificarea actuală*, St. de Geol tehnică, seria F, nr. 8, IG.

MIHAILA, N., (1971), *Stratigrafia depozitelor pliocene şi cuaternare dintre Valea Oltului şi Valea Vîlsanului (sectorul Rîmnicu Vîlcea – Curtea de Argeş – Vîlsăneşti)*, Studii tehnice şi economice, seria 3, Stratigrafie, nr. 7, IG., Bucureşti.

MURGEANU, G., 1953, *Cercetări geologice asupra regiunii dintre Rîurile Topolog şi Olt,* D.S. ale şedinţelor, vol XXXVII (1949 – 1950) Comitetul Geologic, Bucureşti.

TAN, S-A, TOLL, D, PHOON, K.-K., (2007), *Rainfall Induced Landslides – Why they occur*, Latsis Symposium by CCES at ETH-Z Zurich, Switzerland, 17-19 Sep 2007, ht*tp://www.cces.ethz.ch/latsis2007/program/CCES_Latsis_extended_abstract_Siew_Ann_Tan.pdf*

VARNES, D. J., (1984), *Landslide hazard zonation: a review of principles and practice* / Commission on Landslides and Other Mass Movements on Slopes Educational, Scientific and Cultural Organization, Paris.

*** 1968, *Harta geologică a R. S. R., 34. Piteşti, 1 : 200 000*, Comitetul de stat al Geologiei, Institutul Geologic, Bucureşti.

1) **University of Bucharest, Faculty of Geography, Department of Geomorphology–Pedology–Geomatics; Romania**
2) **MM Georesearch; Romania**
3) **ISC; Bucharest, Romania**
4) SamiConsult; Rm Valcea, Romania
5) **National Meteorology Administration, Romania**
University of Bucharest, Faculty of Geography, Department of Geomorphology–Pedology–Geomatics;
1 N. Balcesxu Blvd. 010074, Sect 1, Bucharest, Romania
andreea.andra@geo.unibuc.ro

Cartographic analysis on the morphology of Prut river plan, downstream Stânca – Costeşti Reservoir (Româneşti – Sculeni sector) in the last 100 years

Ştefan GRĂMADĂ[1]

Abstract. One of the most important hydraulic mega structures in Romania, classified as the third largest in Europe, is Stânca Costești reservoir, on Prut River. After Stânca Costeşti reservoir construction, hydrological parameters of Prut river (for example liquid and solid discharges) severely modified. This study quantifies some of the geomorphic effects on the river's active channel and plan form, in the context of the overall changes occurring in the last century (1915-2005 period).

The analysis was based on the different editions of the available topographic maps and aerial photos, which have recorded historical configurations of the Prut river channel. For each time period, several morphometric indices, such as minor riverbed width, major riverbed width, sinuosity index and meander curvature, were measured using GIS and further interpreted. The preliminary conclusions indicate that once Stânca Costești reservoir was built, the morphometric indices evolved in a different manner downstream of Stânca Costești reservoir.

Keywords: river channels, historical maps, aerial photos/orthophotos, plan form, morphometric methods.

1. Introduction

One of the main principles of fluvial geomorphology, is the principle of free course. This principle would mean, that a river channel drain is course so that, power consumption can be lowered by much as possible through self-regulation, (Chang, 1988). Depending by some factors such as fluid and solid flow, local geology and speeds flowing, rivers are channelling their course.

Human intervention is another important factor, which determine in time, the dynamics of the rivers. Regarding dams construction on rivers, this has an important influence on the rivers through detention of sediments. In Prut river case, once Stânca – Costești dam was built, determined an accumulation of sediments behind the dam in proportion of 95% (Rădoane et. al., 2009). In this situation, in downstream of the Stânca-Costești dam, in the absence of solid flow occurs the phenomenon of riverbed washing.

In Romania, those preoccupations had results in series studies like (Rădoane *et al.* 2006; Dumitriu, 2007; Cristea, 2009; Ioana-Toroimac, 2009; Grecu *et al.*, 2010; Rădoane *et al.*, 2010; Perşoiu & Rădoane, 2011; Chiriloaei, 2012; Zaharia *et al.*, 2011, Rădoane *et al.* 2013, Grecu *et al.*, 2014).

This paper aims to demonstrate the dynamics of a river downstream a reservoir dam, based on the example of the Prut River, downstream of Stânca Costești reservoir, based on historical documents available for such studies.

2. Methodology

2.1. Materials and methods for Prut river channel morphometry

The materials required for this study were historical maps, based on topographic maps and aerial photos, which have surprised the configuration of Prut river channel, between 1915 and 2005. For the Prut valley area, the oldest available cartographic documents are from 1915.

Table 1 presents the available historical maps from Romania that are covering Prut river area, and which have been used to study fluvial geomorphology of this river, with properly characteristics.

Also, it is important to specify that those maps were selected to be comparable by scale, resolution and projection. Details to identify those documents are available on dedicated website www.geospatial.org.

Table 1. **Cartographic documents employed for the analysis of the plan form shape of Prut river**

Name of the map	Date of survey	Publishing year	Scale	Projection	Institution	Resolution
Topographic plans	1915	1959	1:20 000	Lambert Gauss - Kruger	Romanian Military Topographic Service	1.68m/pixel
Topographic maps	1977	1980	1:25000	Gauss - Krüger Pulkovo, Cylindrical Projection 1942	Military Topographic Department	2 m/pixel
Orthophotos	2005		1:5000	Stereographic projection Stereo 70 ellipsoid Krasovschi	National Agency for Cadastre and Land RegSItration	0.5 m/pixel

2.2. Methods used to determine morphometric variables of Prut river channel

At first, it was necessary to delimit the floodplain of Prut river as development limit of morphometric variability in time. For Prut floodplain, the central axis was determined, and was sectioned from 2 to 2 km, in this way generating the cross sections of Prut river floodplain.

Cross transversal sections are useful to calculate the morphometric variability in time, of Prut river channel, especially for ***sinuosity index,*** and ***minor bank width***.

Prut river presents a sinuous channel and, in consequence it is necessary to determine the principal morphometric unit that is the ***meander loop***. A meander is formed by two successive ***meander loops***. The principal characteristic for meander loop morphometry, are ***wavelength*** which is the distance between the ends of the two successive loops and ***meander amplitude*** which is characterised as the perpendicular line to the meander length, between lateral extremities of meander loop, also can be characterised, as the line that shows the meandering strip (Fig. 2).

Curvature radius is the radius of the circle circumscribed into the meander loop, curvature radius helps to delimitate each meander in part, from river channel. For calculating the wavelength and meander amplitude, meanders were incorporated into rectangular frames, based by length and width of rectangles, as dimensions of wavelength and meander amplitude.

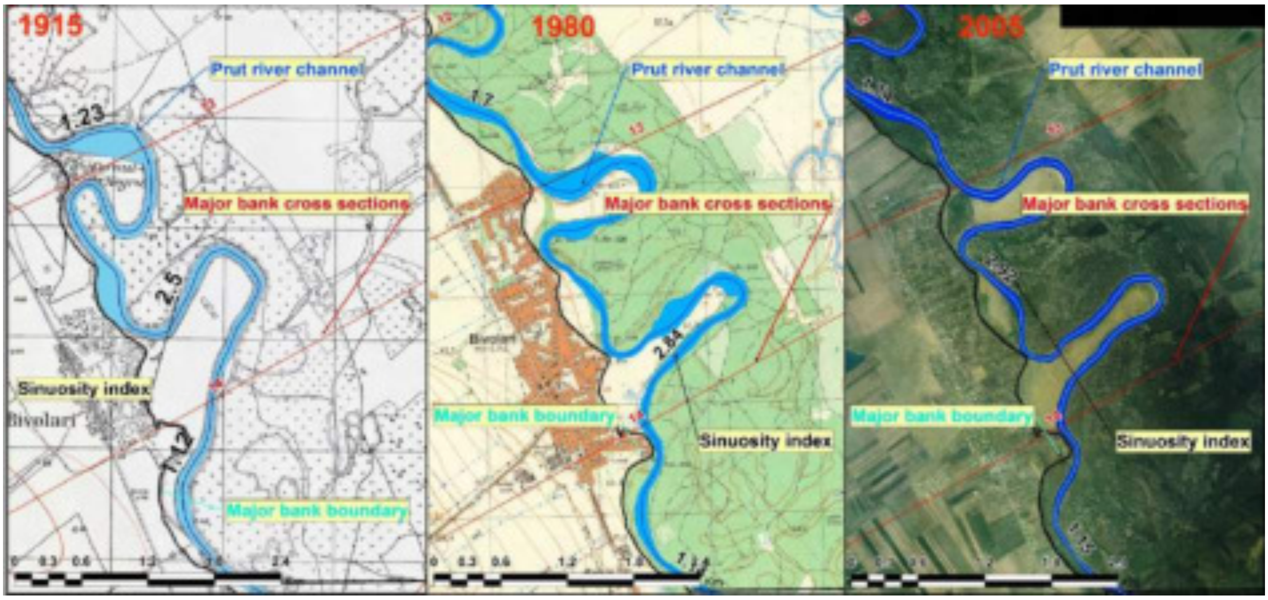


Fig. 1. **Model of cross sections of Prut river channel, in three periods of analysing between 1915 and 2005**

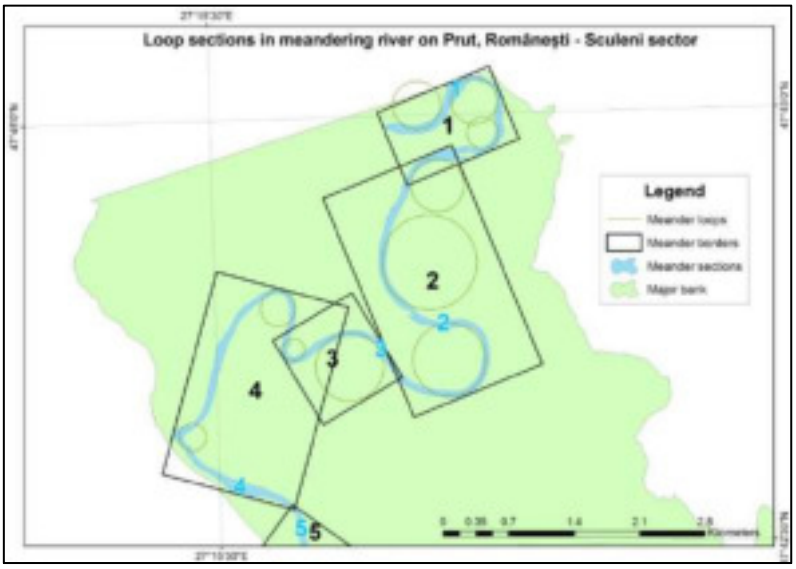


Fig.2. **Method of measuring meander morphometry**

3. Area of study

Prut river in Românești – Sculeni sector is disposed to the Botoșani and Iași counties (România) and Glodeni, Fălești and Ungheni counties (Rp Moldova). The Prut river has its origin in the Carpathians mountains in Ukraine. Up to Oroftiana, Prut river has a length of 235.7 km, with an average slope of 6.4m/km and a hydrographic basin of 8241 km^2. Between Oroftiana and the confluence with the Danube, Prut river has a length of 946 km, which represents the border between Romania and Ukraine and Romania with Republic of Moldova. The area of Prut River basin measures 28 463 km^2. To the Romania territory it measures 10 999 km^2.

About the geology, Prut river overlaps an area which was characterised by brittle rocks of riverbed, corresponding to the Moldavian Platform. The petrographic constitution is composed in generally by clay and marls formations.

The morphometric parameters of study area are: 254 km^2 floodplain surface, 53 km of floodplain length, and transversal width between 2467 m as minimum and maximum to 6854 m. The relief of studied area is characterised by floodplain of Prut river, with a lower altimetry, between 63 m to Românești and 40 m to Sculeni (Fig. 3).

About Stânca-Costești dam, it was built in 1978, considered as one of the mega structure of communism period in Romania. With a 43 m high and over 300 m width, it is considered as the third in Europe by dimensions. Behind the dam it can be accumulate 1.4 billion m^3 of water.

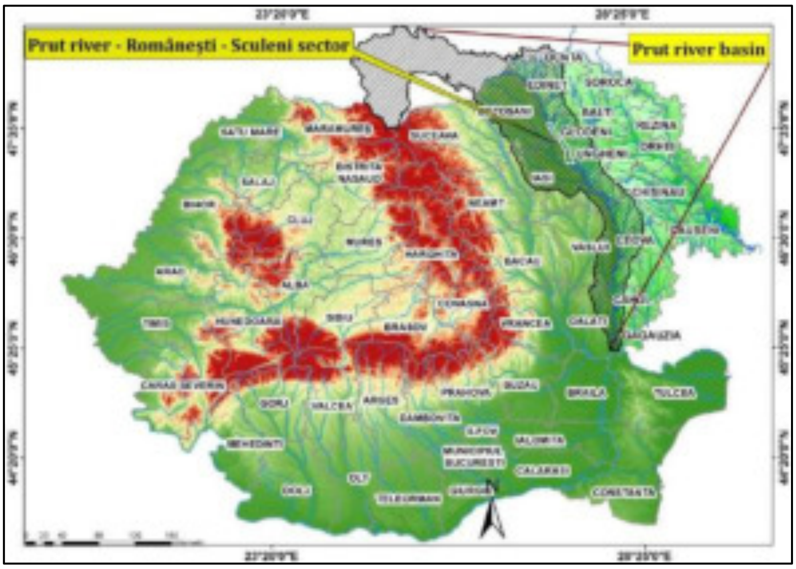


Fig. 3. **Cartographic representation of Prut river in Românești – Sculeni sector**

4. Results

4.1. Typological classification of Prut river channel

The earliest classification of river channels were made by Leopold & Wolman, 1957. The types of river channel configurations can be *straight, sinuous, meandering, anastomosed*, and *wandering.* Prut river is classified as ***meandering river*** (***SI*** ≥ 1.5) (Fig. 1).

Overall, Prut river presents a meandering type, but analysed in sections parts, we can observe transition of channel type in the same river channel.

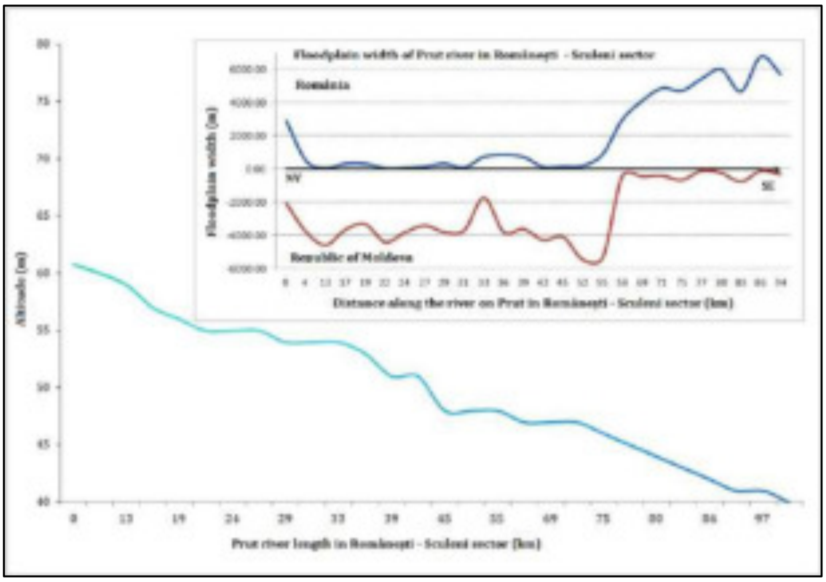


Fig. 4. **Longitudinal profile and floodplain width of Prut river in Româneşti – Sculeni sector**

In Prut river case, in Româneşti – Sculeni sector, we can find, river section parts, characterised by sinuous type and channel with high meandering type, as maximum value determined on sinuosity index (*SI*=4.2).

The sector of Prut river in this paper, between Româneşti – Sculeni (downstream to Stânca Costeşti reservoir), is disposed to a 97 km length, with a morphometric variability, that present an altitudinal amplitude of 26 m (63 m to Româneşti, 40 m to Sculeni) to floodplain.

Regarding morphometric variability of floodplain width, the amplitude between maximum and minimum width, of Prut floodplain in this sector, attains 4 387 m. Minimum width of floodplain measures 2 467 m in the 11th section, and maximum width measures 6 854 m in the 25th section.

The floodplain was determined as the flooding area of Prut channel, up to terrace of 5 m. In Prut river case, if the river channel has a meandering character, also the floodplain presents the same characteristics.

For example, the change of the Prut river in time, to the left or to the right, the floodplain was created accordingly with the river flow and it can be observed in Figure 4.

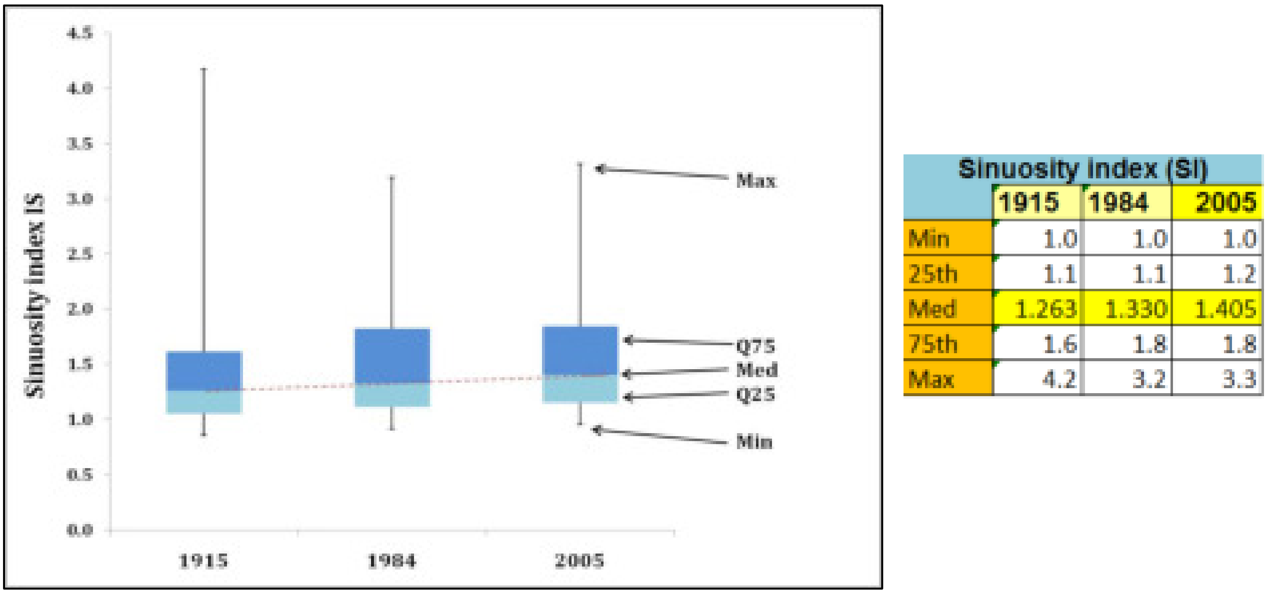
About the slope values on the Prut river sector, analysed, its measures 0.23m/km. That's an important factor which has influence to the *SI* index.

One of the principal aspects of river channel morphology is represented by sinuosity index (*SI*). Sinuosity index is calculates by ratio between the length of channel, along central axis and the length of the aerial distance between two floodplain sections cross.

Prut River presents a meandering channel, but in some sections *SI* reach's low values like 1.01, for example, in the 19th cross section, in 1915 period. The average of sinuosity index across the Prut river channel, reaches values over 1.5, which means minimum value, as a river to be considered meandering type (Leopold & Wolman, 1957).

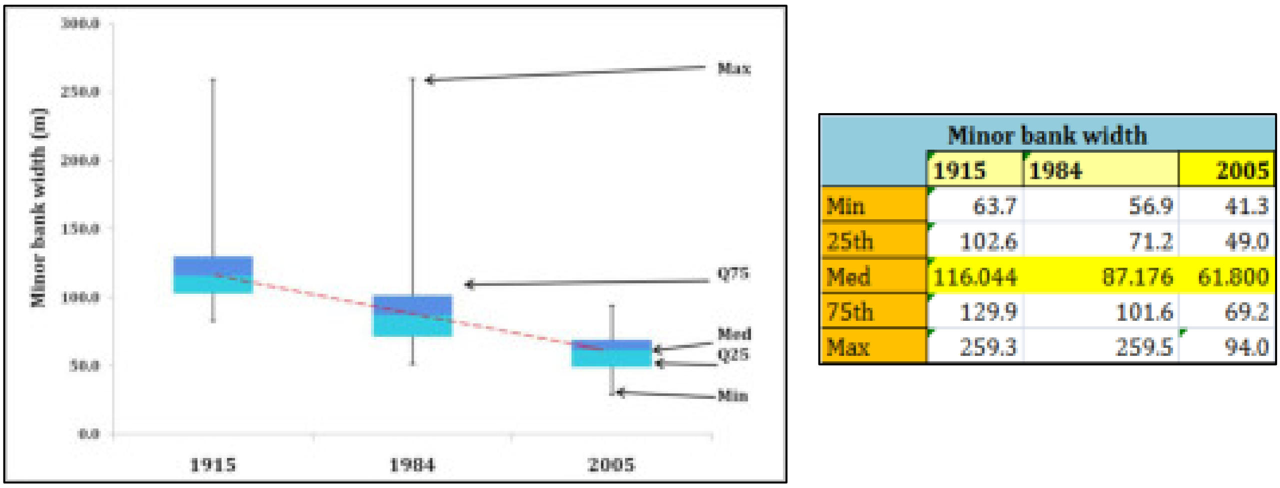
Following Arc GIS processing of Prut river channel, it can be observe that across the years, especially in late 30 years, *SI* values has known an ascending tendency about the frequency of high sinuosity values.

The variability of *SI* in time, can be attributed to the solid and liquid flow regime, and the modifications caused by human intervention, especially by construction of Stânca – Costeşti reservoir (Fig. 5).



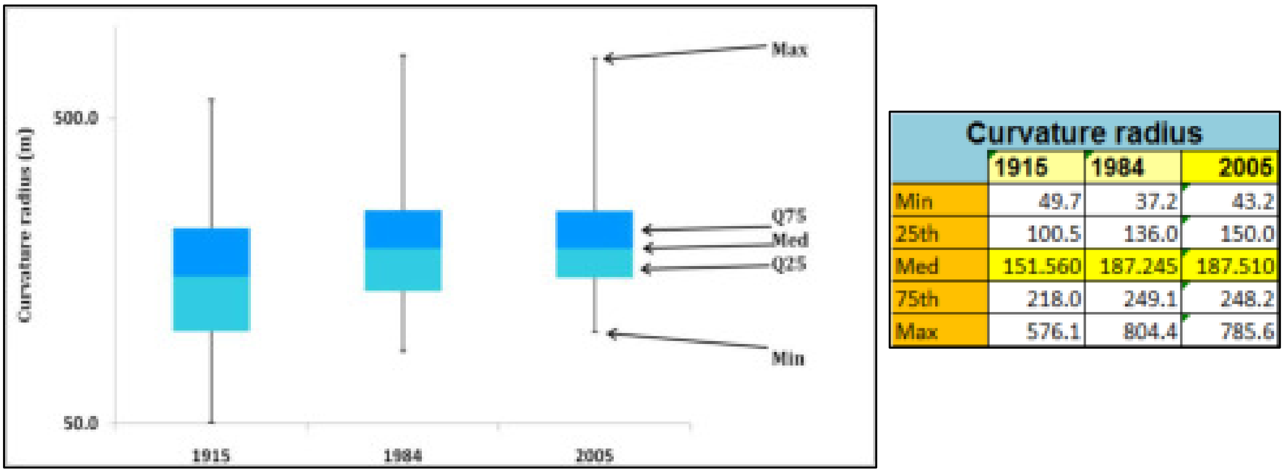
Sinuosity index (SI)			
	1915	1984	2005
Min	1.0	1.0	1.0
25th	1.1	1.1	1.2
Med	1.263	1.330	1.405
75th	1.6	1.8	1.8
Max	4.2	3.2	3.3

Fig. 5. **Sinuosity index variability on Prut river between 1915 and 2005**



Minor bank width			
	1915	1984	2005
Min	63.7	56.9	41.3
25th	102.6	71.2	49.0
Med	116.044	87.176	61.800
75th	129.9	101.6	69.2
Max	259.3	259.5	94.0

Fig. 6. **Variability of minor bank width between 1915 – 2005 in Româneşti – Sculeni sector on Prut river**



Curvature radius			
	1915	1984	2005
Min	49.7	37.2	43.2
25th	100.5	136.0	150.0
Med	151.560	187.245	187.510
75th	218.0	249.1	248.2
Max	576.1	804.4	785.6

Fig.7. **Variability of curvature radius on Prut river Româneşti – Sculeni sector, between 1915 – 2005**

In close correlation with the sinuosity index, is the minor bank width of Prut river. So as the variability of sinuosity index of Prut channel, between upstream and downstream of Stânca – Costeşti reservoir, the minor bank width, presents different characteristics in upstream toward downstream of the reservoir.

If in upstream of reservoir minor bank width of Prut river channel, measures 60 to 180 m, with a sinuous character, (Rădoane *et al.* 2008), in downstream to the reservoir in Româneşti – Sculeni sector, Prut river channel presents changes through a strong sinuosity up to 3.3, with minor bank dimensions that measures 41 to 94 m.

That situation was possible after the Stânca – Costeşti reservoir was built in the 70's, which caused an important retention of the solid flow.

The processes of riverbed washing, determined in time the decreasing of riverbed level. Through the degradation of riverbed, succeed the decreasing of minor bank width (Fig. 6).

On Prut river channel, in Româneşti – Sculeni sector, was identified a number of 97 meanders. After their identification it was necessary to measure them by wavelength and amplitude of it.

The results of wavelength and amplitude on Prut channel, in next hundred kilometres after Stânca Costeşti reservoir, presents high values, from 586.5 m to 6604.5 m. Also it must be specified that downstream to Stânca Costeşti reservoir, Prut river channel is characterized by free meanders.

An interesting situation was observed to the medium values of wavelength and meander amplitude on Prut river, between 1915 and 2005. So, if in the late 30 years wavelength presents decreasing values as 1956 m in 1980 and 1750 m in 2005, for the meander amplitude was registered an increasing medium values form 1029 m in 1980 to 1118 m in 2005.

In the last hundred years, the curvature radius of Prut has known the same tendency as the morphometric variability of meanders.

In the 1915 period curvature radius, has values between 49.7 and 576.1 m. After the construction of Stânca – Costeşti reservoir, in 1980 and 2005 analysed periods, values of curvature radius have known an ascending trend, up to 804.4 and 785.6, as maximum dimensions of curvature radius on Prut river channel loop. Regarding medium values of curvature radius, it can be observed a rising of measurements by 151 m in 1915 up to 187.5 m in 2005 period. That situation is in contradictory with other studies regarding rivers form Europe, Hernad river in Hungary, for example (Kiss & Blanka, 2012), who presents this river having a decreasing trend of curvature radius. In Prut river case, downstream to Stânca – Costeşti reservoir, the discharge is increasing, from medium values Q = 80.97 m/s to Stânca, to Q = 86.81 m/s to Ungheni in downstream to Stânca – Costeşti reservoir.

Regarding solid debit, it can observed a strongly decreasing in upstream of Stânca – Costeşti reservoir, Qs = 55.06 kg/s, in downstream to the reservoir Qs = 2.28 kg/s, which means a reduction of Qs with 95%.

So, if the Q is increasing and Qs is decreasing on Prut River, downstream of Stânca – Costeşti reservoir, we can say that is a strongly anthropogenic alteration of the river debits.

If in upstream of Stânca – Costeşti reservoir, radius curvature values, of Prut channel, are higher to the cuffed meanders than free meanders (Rădoane *et al.*, 2008), in downstream to Stânca – Costeşti reservoir which is characterised by free meanders, values of radius curvature in this sector, are higher than values of cuffed meanders from upstream Stânca – Costeşti (Fig. 7).

7. Discussion

Meandering process is very complex depending on the local characteristics, like liquid and solid flow, floodplain slope, human intervention and the geological particularities of the banks. For example Siret River meandering, was induced in time by neotectonics particularities of subsidence area in Romanian Plain (Grecu *et. al*., 2010).

For Bârlad river, in Moldavian Platform, the human intervention occurred through cut-off meanders, drainage and damming, but the tendency of meandering in time, was the same with a slight decreasing (Rădoane *et. al*., 2003).

For Prut river case, in nearest 100 km after Stânca - Costeşti dam (Româneşti – Sculeni sector), the tendency of meandering in time (last hundred years) was induced, through the rettain of sediments behind Stânca – Costeşti dam, washing of Prut riverbed through its own waters, and bank erosion in time.

Also, for Buzău river the channel dynamic appears to be partially influenced by climatic factors acting on short term. The human induced factors are like in Prut river case, mostly dams and mining to the thalweg (Grecu et. al., 2014).

8. Conclusions

The anthropic intervention to the Prut river natural state, through Stânca – Costeşti reservoir construction, was the most important factor, concerning dynamics of Prut river channel in time.

Upstream to Stânca – Costeşti reservoir, Prut river channel, has known lower values of sinuosity index, from SI = 2 to the SI ≥ 1, (from meandering to sinuous).

Downstream to Stânca – Costeşti reservoir, the sinuosity index of Prut river channel, presents an ascending tendency up to SI = 3.3, with medium values increasing from SI = 1.2 (1915 period) to SI = 1.4 (2005 period) as a response to decreasing of solid flow over 65% after 1970 period, once Stânca – Costeşti reservoir was build.

Also an interesting tendency it can be observed to the curvature radius of Prut river especially in last 30 years, about meander morphometry. So, it's about an evident tendency to meandering by decreasing values of wavelength, increasing of meander amplitude, increasing of curvature radius, conditioned by decreasing of solid flow and increasing of liquid flow.

Decreasing of solid flow in suspension, and river hydraulic (based by principle of dynamic stability through self-regulation) determined in time changes through lateral erosion and intensifying of meander in late 30 years.

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REFERENCES

CHANG, H.H., (1988), *Fluvial processes in river engineering*. Wiley Interscience, 432 pp.

CRISTEA, I., (2009), *Aspects in the evolution of the hydrographical network from the Lower Siret Plain reflected in cartographic materials*, ANALELE Universităţii „Ştefan cel Mare" Suceava SECŢIUNEA GEOGRAFIE ANUL XVIII – 2009;

CHIRILOAEI, FRANCISCA, RĂDOANE, MARIA, PERŞOIU, I, POPA, I., (2012), *Late Holocene history of the Moldova River Valley, Romania,* Catena, 93, 64-77.

DUMITRIU, D., (2007), *Sediment System of the Trotuş Drainage Basin.* Editura Universităţii Suceava, 259 p. (in Romanian).

GRECU, FLORINA, GHIŢĂ, CRISTINA, SĂCRIERU, R., (2010), *Relation between tectonics and meandering of river channels channels in theRomanian Plain. Preliminary observation,* Revista de Geomorfologie, vol. 12, p. 97-104.

GRECU, FLORINA, TOROIMAC, GABRIELA, IOANA, MOLIN, PAOLA, DRAMIS, F., (2014), *River channel dynamics in the contact area between the Romanian Plain and the Curvature Subcarpathians,* Revista de Geomorfologie, vol. 16, p. 5-16.

IOANA-TOROIMAC, G., (2009), *La dynamique hydrogeomorphologique de la riviere Prahova (Roumanie)*, PhD thesis in Geography, University of Lille and University of Bucarest, 341 p.

KISS, T., BLANKA, V., (2012), *River channel response to climate and human induced hydrological changes: Case study on the meandering Hernad River, Hungary*. Geomorphology, 175-176:115-125.

LEOPOLD, L.B., WOLMAN, (1957), *River Channel Patterns - Braided, Meandering and Straight*, United States Geological Survey, Professional Paper 282B.

RĂDOANE, MARIA, RĂDOANE, N., (2003), *Morfologia albiei râului Bârlad şi variabilitatea depozitelor actuale,* Revista de Geomorfologie, a Universităţii Bucureşti. (in Romanian)

RĂDOANE, MARIA, RĂDOANE, N., DUMITRIU, D., CRISTEA, I., (2006), *Granulometria depozitelor de albie ale râului Prut între Orofteana si Galaţi*, Revista de Geomorfologie, a Universităţii Bucureşti. (in Romanian)

RĂDOANE, MARIA, RĂDOANE, N., DUMITRIU, D., CRISTEA, I., (2007), *Granulometria depozitelor de albie ale râurlui Prut între Orofteana şi Galaţi,* Revista de Geomorfologie, Bucureşti; (in Romanian)

RĂDOANE, MARIA RĂDOANE, N. CRISTEA, I. GANCEVICI-OPREA, D., (2008) *Evaluarea modificărilor contemporane ale albiei râului Prut pe graniţa românească*, Revista de Geomorfologie, a Universităţii Bucureşti. (in Romanian)

RĂDOANE, MARIA, RĂDOANE, N., (2009) *Procese fluviale,* Revista Monografia Carpatica. (in Romanian)

RĂDOANE, MARIA, PERŞOIU, IOANA, CRISTEA, I., CHIRILOAIEI, FRANCISCA, (2013), *River channel planform changes based on successive cartographic data. A methodological approach.* Revista de Geomorfologie, nr. 15, 2013, 69-88.

ZAHARIA, L., GRECU, F., IOANA-TOROIMAC, G., NECULAU, G., (2011), *Sediment Transport and River Channel Dynamics in Romania – Variability and Control Factors, in Sediment Transport in Aquatic Environments*, Andrew J. Manning (Ed), 293-316.

[1] **"Ştefan cel Mare" University of Suceava,**
Faculty of History and Geography, Department of Geography
13 Universităţii Street, 720229, Suceava, Romania.

The Impact of Large-Scale Atmospheric Forcing on the Dynamics of Water Turbidity in the Danube Delta Coastal Area

Sorin CONSTANTIN[1,2,*], Florina GRECU[1], Ştefan CONSTANTINESCU[1]

Abstract. Large scale climatic changes can have important impacts on regional and local environments, especially on fragile ecosystems like wetlands and coastal areas. In order to better quantify the magnitude of such impacts on marine areas in front of Danube Delta, specific indicators can be correlated with locally determined parameters. The analyzed climatic indicators within this study are the North Atlantic Oscillation (NAO) and the East Atlantic / West Russia (EAWR) indices. Their dynamics are linked to local processes (waves and currents), which can influence the variability of total suspended matter in the water column, crucial for all the geomorphological processes that take place in coastal areas. In this context, turbidity products derived from long time series of satellite data are used as an expression of sediment loads in the upper water layers. Analyzing 12 years of remote sensed turbidity values shows the relationship between large-scale atmospheric forcing systems and regional dynamics of suspended sediments. The results show a medium degree of correlation between the two parameters during winter seasons, while for the rest of the year no such relationship is to be found.

Keywords: turbidity, MODIS, Danube Delta, NAO, EAWR

1. Introduction

Coastal areas are fragile ecosystems that require intense monitoring in order to obtain the necessary information for proper management action plans to be conducted. Out of all the techniques available today, remote sensing represents the only way to have a synoptic overview for large study areas, like wetlands or marine basins (IOCCG, 2000). Multiple oceanographic parameters can be quantified using remote sensing data, such as chlorophyll concentration, water turbidity or total suspended matter. The last two can be used in order to monitor and analyze the evolution of sediment dynamics in coastal areas, since both are strongly linked to such processes. Availability of sediments is the first order concern for delta maintenance (Giosan *et al.*, 2013). Turbidity represents an optical property of the water, determined by the scattering (and to a lesser degree by absorption) of light by suspended particles inside the water column (Anderson, 2005). By comparison, the amount of total suspended matter (TSM) represents an exact quantitative measure of the solid matter per unit of volume (Kemker, 2014). For coastal areas dominated by the river's solid discharge, the relationship between turbidity and TSM is a very strong one. Although the optical properties of water (turbidity) can also be influenced by other factors, such as chlorophyll concentration or colored dissolved organic matter, in coastal areas dominated by river's input (such as the deltaic coastal zone) the main cause for large turbidity units is represented by inorganic matter from river particulate discharge or caused by resuspension processes (IOCCG, 2000).

It can be therefore concluded that both turbidity and TSM can be used as parameters based on which the evolution of sediment dynamics can be evaluated. Detailed knowledge of this type of processes is crucial for understanding the mechanisms that govern specific geomorphological characteristics, such as formation and evolution of barrier islands or submerged bars. The sedimentary balance also dictates the evolution of the entire delta shoreline, through appearance of erosion/ accumulative sectors, mainly depending on the amount of solid particulates at specific time periods and locations. The spatial distribution of turbid waters has also an influence on the primary production, by modifying the characteristics and vertical extension of the photic zone.

The goal of this study is to investigate if there is any correlation between water turbidity and teleconnection patterns in the Danube Delta coastal area, at monthly time scale. The main index involved in the analysis is NAO (North-Atlantic Oscillation), but also EAWR (East Atlantic / West Russia) was taken into consideration. This hypothetical relationship between coastal turbidity and large-scale atmospheric forcing was tested for different spatial extents and for multiple time intervals (for all the months and also only for specific seasons - winter).

For the Black Sea basin, the effects of climatic teleconnection on the marine environment were studied mainly taking into consideration parameters such as chlorophyll concentration or sea surface temperature (Oguz, 2005). For the Danube Delta coastal areas, NAO influence was accounted for in terms of shoreline dynamics (Vespremeanu-Stroe *et al.*, 2007) or in correlation with the overall Danube hydrological status (by determining the precipitation anomalies in the drainage basin), that must be considered when analyzing the geomorphological changes that occur at river mouths and in the delta plain (Giosan *et al.*, 2005).

NAO is defined as the difference in air pressure at sea level between the Icelandic low and Azores high pressure centers (Van Loon & Rogers, 1978). EAWR pattern consists of four main anomaly centers. Positive height anomalies over Europe and northern China and negative height anomalies located over the central North Atlantic and north of the Caspian Sea correspond to a positive phase. Both patterns affect their influence area throughout year.

Although NAO has the general tendency to vary from one year to another, periods of several years without any shifts between positive and negative phase were recorded. For the Romanian deltaic coastal area, a strong inverse relationship exists between NAO and the occurrence of storms, together with high wave and wind energy. This is defined by a correlation coefficient of R=-0,76 for meteorological data (wind) recorded at Sulina station and R=-0.77 for Sfântu Gheorghe (Vespremeanu-Stroe *et al.*, 2007). All this translates in a higher probability for storms to occur during periods with strong negative NAO values, which can lead to high impact on the shoreline by increasing the expansion of erosive sectors. Such changes are heavily dictated on decadal scales by NAO phases (Vespremeanu-Stroe *et al.*, 2007). Also, the resuspension processes in shallow waters are favored by strong winds, waves and currents. This indirectly affects the values of turbidity by increasing the sources for suspended sediments in the water column. Changes in wind energy can contribute not only to higher resuspension processes and shoreline erosion, but also to a larger spatial distribution of sediment plume at the surface of the water column, thus leading to a much wider area with high turbidity values observed from space.

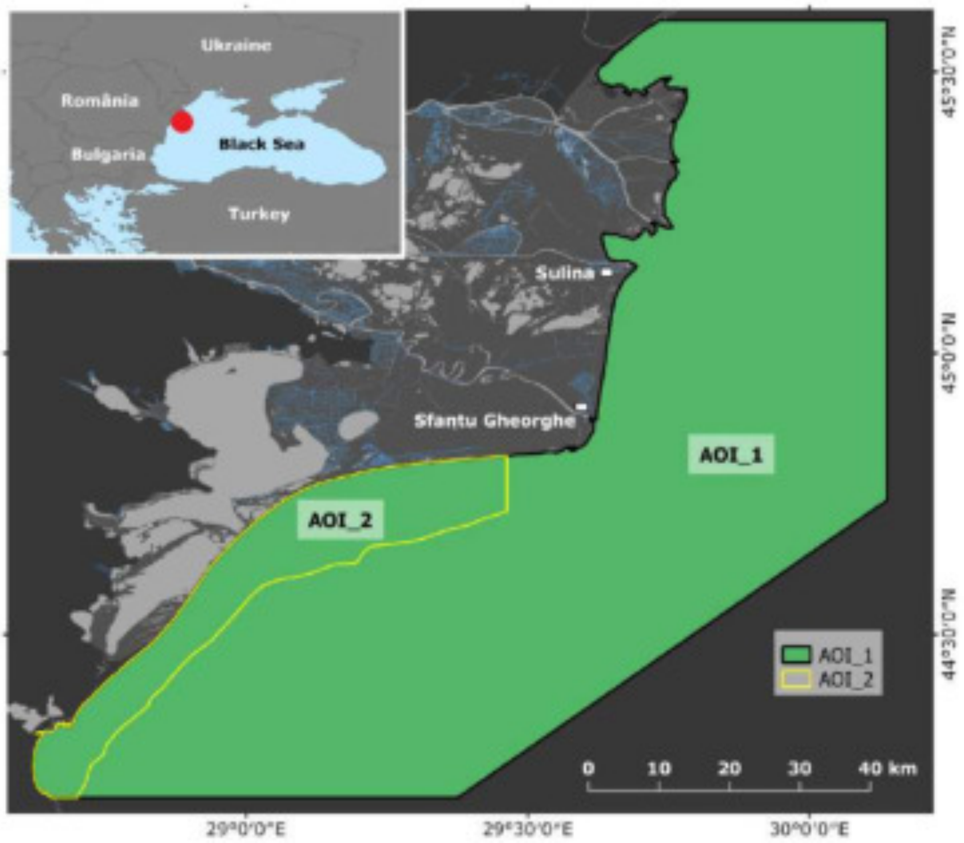

Fig. 1. **Location of the study area; two distinct Areas of Interest (AOI_1 and AOI_2) were selected**

The study area covers 8125 km^2 in front of Danube Delta (Fig. 1), overlapping a shelf zone with low depths, up to maximum approximately -60 m. The large interest area was noted as AOI_1, and it encompasses a smaller one, noted AOI_2, situated South-West of Sfântu Gheorghe mouth, and delimited by the 0 and -20 m isobaths. The main reason for choosing two AOIs was to capture the turbidity patterns in areas dominated by distinct factors. While for AOI_1 the turbidity is determined mainly by the Danube solid input, in AOI_2 the resuspension processes can play a more important role. Statistics were computed for each of the two AOIs.

2. Methodology and used datasets

Large volumes of archived satellite data can now be used to analyze trends of the impact that large-scale atmospheric forcing can have on specific local ecosystems, like coastal environments. In the near future, climatic observations will also be possible to be tackled based on the same input information type (Earth Observation data), but this will most probably require solid and validated processing schemes, especially in terms of sensor inter-calibration. This is mainly due to the fact that long periods of time are usually covered by data coming from different satellites with sensors that have distinct radiometric and spectral characteristics. For this specific study, only data coming from one sensor, MODIS, mounted on two platforms, Terra and Aqua, were used. The period of time for which the analysis was performed is covering 12 years, from 2003 up to 2014.

Level 1A satellite data was acquired from NASA Ocean Biology Processing Group. Using SeaDAS 7.1 software, Level 2 reflectance products were computed, using the MUMM algorithm for atmospheric corrections (Ruddick *et al.*, 2000). These products were translated into turbidity maps based on a local determined relationship between satellite reflectance and turbidity (Constantin *et al.*, 2015). For every month during the 2003-2014 period, composite products were processed by averaging all the available turbidity maps from that specific time interval. NAO and EAWR monthly index values were available from NOAA Climate Prediction Center.

3. Results and discussions

The location of AOI_1 (Fig. 1) was set as to cover all the area with overall high turbidity values. In what concerns AOI_2, its extension was chosen in order to have more information on how the turbidity varies as a result of resuspension processes alone. After analyzing all the monthly turbidity maps, it was observed that the shallow waters South-West of Sfântu Gheorghe mouth are more prone to such events than others, during winter periods, when storm occurrence is higher and also the wind and wave energy are grater. Although some spring months are characterized by an overall higher turbidity average (for AOI_1), the suspended sediment load in AOI_2 is much lower than in winter (Fig. 2). This is mainly because the turbidity plume extension is more influenced now by the river discharge than during winter, when resuspension plays a key role in the close proximity of the coast.

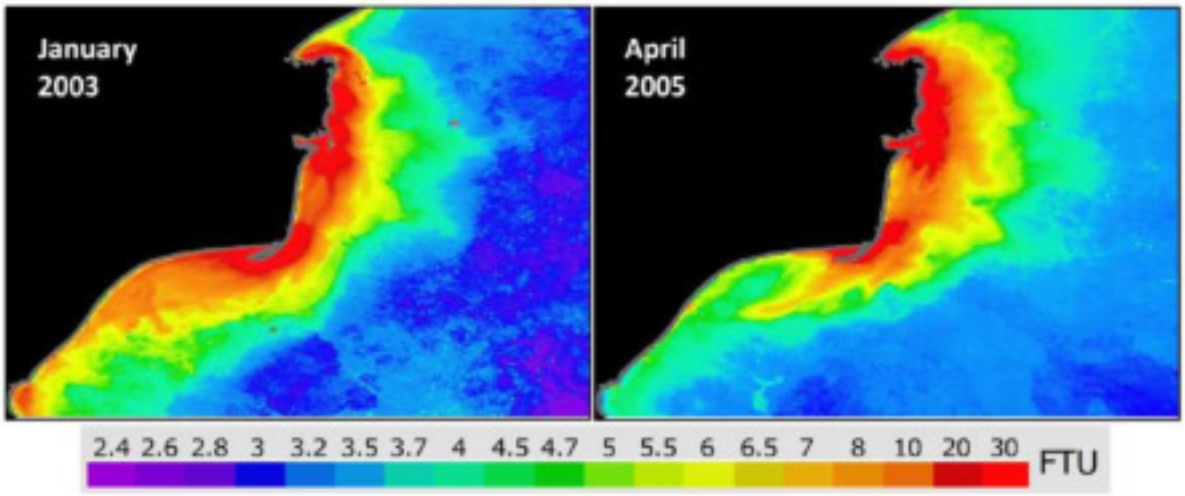

Fig. 2. **Different distribution of high turbidity values between winter and spring months, especially in the South-Western part of the AOI_1**

For the analyzed time period, a high oscillation of NAO index was observed, with some long intervals with negative values, such as the one between the end of 2009 and beginning of 2011 (more than one year). EAWR is mostly negative, with short periods when positive values are recorded. The relationship between NAO and EAWR is not a strong one, with a correlation coefficient of just R=0.106.

One of the first steps in our analysis was to determine if and how coastal water turbidity alternates in parallel with NAO and EAWR. For this specific purpose, the correlation coefficients between the two parameters of interest for AOI_1 and AOI_2 were computed, for all the 144 months taken into consideration. A synthetic overview is given in table 1. All the values are lower than ±0.06, which strongly indicates that there is no evident relationship between turbidity and climatic teleconnection patterns for all year round in the Danube Delta coastal area.

Since this low correlation is mainly caused by the fact that turbidity is influenced by river discharge more than by resuspension (due to strong winds and waves), when all seasons are considered, the next step was to choose only those time periods when NAO and EAWR are supposed to have a more significant impact. Therefore, we performed the same analysis taking into consideration only winter months (December, January and February). For EAWR, the correlation coefficients were found still to be very low (R=-0.159 for AOI_1 and R=-0.189 for AOI_2), which clearly shows that turbidity dynamics are not directly influenced by changes that occur in EAWR behavior.

Regarding NAO, it was found out that the same correlation coefficients are increasing considerably during winter (R=-0.50 for AOI_1 and R=-0.57 for AOI_2) (Fig. 3). High negative NAO values correspond to significant increase of turbidity units. This is the case during December 2009 and the winter of 2010, when the turbidity monthly averages were the highest one recorded, of more than 10 FTU in average for AOI_1 (maximum of 13.2 FTU), and more than 15.2 FTU for AOI_2 (maximum 19.9 FTU). The average turbidity values for all winter months are 6.3 FTU for AOI_1 and 8 FTU for AOI_2. During time periods when NAO has the highest positive recordings (December 2011), the values of turbidity are also some of the lowest ones (3.5 and 3.7 FTU for AOI_1, respectively AOI_2). The graphic from figure 3 shows an evident larger fluctuation for turbidity in AOI_2 than in AOI_1 when NAO index drops to negative values, which proves that our initial hypothesis concerning different magnitudes on resuspension processes inside the two AOIs (grater in AOI_2) is correct.

	R (NAO vs TURBIDITY)	R (EAWR vs TURBIDITY)
AOI_1	-0.058	0.040
AOI_2	-0.012	-0.020

Table 1. **Correlation coefficients between turbidity and large-scale atmospheric forcing indices**

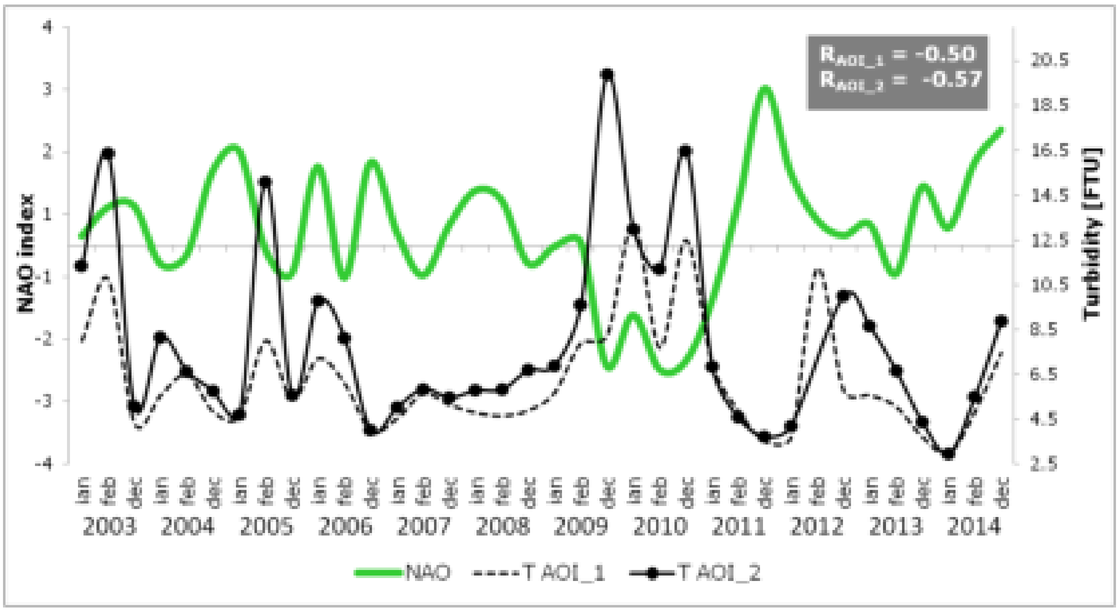

Fig. 3. **Relationship between turbidity (T, in AOI_1 and AOI_2) and NAO index**

This moderately strong relationship between turbidity and NAO shows that the large-scale atmospheric forcing phenomenon can have an indirect impact on sediment dynamics, but other factors must be accounted for when trying to understand the turbidity spatial extension and magnitude. In this context, not only winds and waves are to be considered, but also Danube discharge rates, marine currents behavior or even algal bloom events. The correlation between the two analyzed parameters might increase if only months with high prevalence of storms should be considered, out of the selected period.

4. Conclusions

This current study must be considered as a first attempt to use remote sensed oceanographic parameters (turbidity) in order to establish a connection between climatic and meteorological patterns and geomorphological processes at local scales in the Danube Delta coastal area. Of course, longer periods of time should be taken into consideration in order to have a better understanding of the phenomenon, which is one of our main directions of research for the future. Also, these results must be treated with caution since during winter, because of high cloud cover over the AOIs, the number of satellite data decreases compared to the rest of the year and therefore less information is available for analysis. These observations remain to be further augmented by other similar studies that might introduce into analysis also modeled datasets.

Nevertheless, it is obvious that changes in atmospheric conditions at larger scales can have an indirect impact on the distribution and dynamics of the sediments in the coastal areas. But, as already mentioned, other factors (such as river discharge or algal blooms) might have more significance in specific areas. For the entire year, NAO cannot be hold responsible for turbidity spatial distributions, although it influences the precipitation rates within Danube hydrographic basin which in turn reflects into higher discharge rates at river mouths. Only for winter periods, the coefficient correlation was found to be R=-0.50 (AOI_1) and R=-0.57 (AOI_2) between turbidity averages and NAO, which indicates a moderate relationship between the two parameters during seasons with high resuspension occurrence.

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Remote sensing information: NASA Ocean Biology (OB.DAAC). MODIS Ocean Color Data. Accessed on 2015/03/25.

REFERENCES

ANDERSON, C. W., (2005), "USGS Handbook for Water-Resources Investigations. Chapter 6 - Field Measurements. Section 6.7 - Turbidity", Available online at http://water.usgs.gov/owq/FieldManual/Chapter6/Ch6_contents.html.

CONSTANTIN, S., DOXARAN, D., CONSTANTINESCU, Ș., (2015), "Estimation of water turbidity and analysis of its spatio-temporal variability in the Danube River plume (Black Sea) using MODIS satellite data". Continental Shelf Research, accepted for publication, doi: 10.1016/j.csr.2015.11.009.

GIOSAN, L., DONNELLY, J.P., VESPREMEANU, E., BHATTACHARYA, J.P., OLARIU, C., BUONAIUTO, F.S., (2005), "River delta morphodynamics: examples from the Danube Delta", *SEPM Spec. Publ.*, **83**, 393–411, doi:10.2110/pec.05.83.0393

GIOSAN, L., CONSTANTINESCU, Ș., FILIP, F., DENG, B., (2013), "Maintenance of large deltas through channelization: Nature vs. humans in the Danube delta", *Anthropocene* **1**, 35–45, doi:10.1016/j.ancene.2013.09.001.

IOCCG, (2000), "Report 3 - Remote Sensing of Ocean Colour in Coastal and Other Optically-Complex Waters", available online at http://www.ioccg.org/reports_ioccg.html

KEMKER, C., (2014), "Turbidity, Total Suspended Solids and Water Clarity", *Fundamentals of Environmental Measurements,* Fondriest Environmental, Web. < http://www.fondriest.com/environmental-measurements/parameters/water-quality/turbidity-total-suspended-solids-water-clarity/.

OGUZ, T., (2005), "Black Sea Ecosystem Response to Climatic Teleconnections", *Oceanography*, **18**, 122–133.

RUDDICK, K.G., OVIDIO, F., RIJKEBOER, M., (2000), "Atmospheric Correction of SeaWiFS Imagery for Turbid Coastal and Inland Waters", *Applied Optics*, **39 (6)**, 897–912, doi:10.1364/AO.42.000893.

VAN LOON, H., ROGERS, J.C., (1978), "The Seesaw in Winter Temperatures between Greenland and Northern Europe. Part I: General Description", *Mon. Wea. Rev.*, **106**, 296–310.

VESPREMEANU-STROE, A., CONSTANTINESCU, S., TATUI, F., GIOSAN, L., (2007), "Multi-decadal Evolution and North Atlantic Oscillation Influences on the Dynamics of the Danube Delta Shoreline". *J. Coast. Res.*, ICS2007 Pr, 157–162.

[1] **University of Bucharest, Faculty of Geography, Romania**
[2] **TERRASIGNA, Bucharest, Romania**
4 Verii Street, 020723, Bucharest, Romania
*sorin.c.geo@gmail.com, Tel. +40 727 34 34 71

Relief suitability for developing a macro ski area between Predeal and Azuga Resorts

Mădălina TEODOR[1], Robert DOBRE[1]

Abstract: This study represents a complex analysis of favorable and restrictive factors created in order to identify the suitable areas for a macro ski development on Prahova Valley, Romania. Our goal is to integrate the solutions in the existent touristic infrastructure for practicing winter sports (ski, snowboard, etc.). The work represents an analysis of applied geomorphology and it can be very useful for the policy makers and the local authorities in order to access funded projects.

The methodology aims two aspects: relief parameters analysis (slope, aspect, soil texture) and climatic factors analysis (snow depth, solid rainfall, wind). Each parameter is analyzed and classified according to common characteristics, reclassified into the suitability categories and plugged into a formula. The result is the suitability map for ski area development.

The target of this study is to analyze, develop and propose in Romania, a complete system such as the international ones.

Key words: suitability, ski area, applied geomorphology, touristic infrastructure

1. Introduction

Applied geomorphology is a new discipline developed in the last century. Detailed researches have been carried out recently. Internationally speaking, applied geomorphology studies have been focused on the relationship between man and the environment and also on the access mode of the sustainable development projects**.** We can notice following studies. (Cendrero, 1991; Chardon, Thouret, 1994; Panizza, 2000; Beniston, 2005; Reynard *et al.*, 2004).

In Romania, this type of studies was generally focused on mountainous areas with increased anthropic pressure. In Prahova Valley area, important researches were carried out by: Mihai, 2003 – Timiş Mountain Basin, geomorphological study regarding current morphodynamics and spatial planning; Oprea, 2004 – Prahova Mountain Basin, natural potential and landscape assessment and Dobre, 2011a, 2011b – Terrain to be suitable for constructions on Prahova Valley Corridor. Relevant terrain analysis of this area was made by Orghidan, 1932; Ielenicz, 1984, 2004; Rădoane, 2003, 2011; Surdeanu, 1990, 1997, 1998; Mac, Râpeanu, 1995; Grecu Florina, 1997, 2002, 2003, 2009; Mihai *et al.* 2001, 2004, 2009; Mihai 2003; Şandric, 2001, 2004, 2008; Oprea, 2004; Dobre, 2007, 2011, Irimuş, 2006; Bălteanu *et al.*, 2008, 2010, Voiculescu, 2009, 2011, 2013; and climatic and tourism researches: Bălteanu *et al.*, 2008, 2010.

2. Studied area

Prahova Valley presents itself as a genuine geographical system interconnected between natural and anthropogenic components. It has defined and created authenticity in Carpathians (Dobre, 2011). The area is represented by the mountain sector of Prahova Valley between Predeal town in the north sector and Azuga town in the south (Fig. 1). Baiului Mountains are part of Curvature Carpathians. The maximum altitude is 1519.6 m reached in Clăbucetul Taurului Peak (Mihai & Şandric, 2004).

3. Methodology

Relief suitability is achieved by analyzing parameters and characteristics of the terrain and the climatic parameters. For Predeal-Azuga area we have considered the following factors: slope, aspect, snow depth and soil texture. The parameters were weighted and plugged into a formula.

To these factors were assigned values from 1 to 100 based on their influence on the suitability of the ski area development. The highest values were given high suitability. Once the values have been assigned into a reclassification, the four factors were weighted by importance using the following formula:

$$P = \frac{\mathbf{F1} * \mathbf{2} + \mathbf{F2} * \mathbf{2} + \mathbf{F3} + \mathbf{F4}}{\mathbf{6}}$$

Where:
P – Relief suitability for developing the ski area
F1 – factor 1 = slope
F2 – factor 2 = aspect
F3 – factor 3 = snow depth –altitudinal gradient
F4 – factor 4 = soil texture

The result of this formula generates suitability classes for Predeal-Azuga ski area.

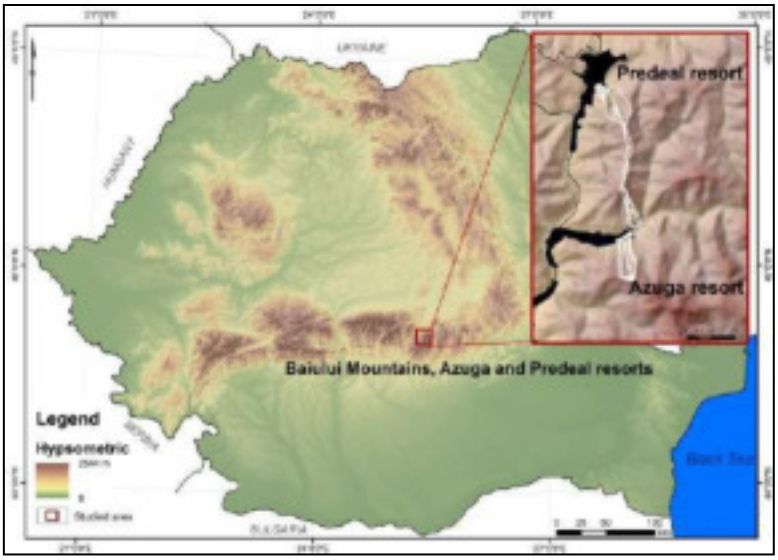

Fig. 1. **Study area location**

Factor 1: Slope – represents the tilt of the Earth's surface to the horizontal plane. Basically, it is given by the angle between the land surface plane and the horizontal plane. It is measured in sexagesimal or centesimos degrees by tilting the topographic surface (m/km), in percent (%) or per thousand (‰).

The Slope map (Fig. 2) was achieved by applying the function *Slope* from *Spatial Analyst Tools – Surface Analyst* in ArcGIS program. Slopes were calculated using numerical model altimetry.

The result was reclassified into five classes (*Symbology – Classified – Classes: 5 – Classify – Break Value: 5, 7, 30, 40 and the last value unchanged). The suitability relief map according to the slopes* was created by reclassification of the anterior result (*Arc Toolbox – Spatial Analyst Tools – Reclass – Reclassify)* in 3 classes (slopes: low, medium and high) which they were assigned values between 10-100 (Table 2).

Table 2.

Slope

Classes	Assigned values	Suitability classes
$0 - 5^0$	10	Low
$5^0 - 20^0$	90	High
$20^0 - 40^0$	100	High
$40^0 - 60^0$	90	High
$> 60^0$	10	Low

The result is a raster that was used in the final relief suitability formula for developing skiing areas. The next step was to change the raster color (*Symbology – Classified – Color Ramp*).

Fig. 2. **The suitability relief map according to the slopes**

The hydrographic network and the main geographic features were overlaid. The DEM was used to achieve the *Hill shade* or shadowing land for obtaining 3D effect (*ArcToolbox – Spatial Analyst Tools – Surface Analyst Tools – Hillshade* (*Input Surface: dem, Z factor: 1 or 2* – exaggerating relief). This hillshade may overlap with other layers after being given 50-60% transparency (*Display – Transparency: 50*).

The slope is a very important factor for the sky development. The different degrees of difficulty were assigned a value in the table below (Table 2).

We can observe the lowest suitability values overlapping with almost flat valley corridors or with the peaks.

Factor 2: Aspect – it is a very important factor that must be taken into account for developing a ski area. The aspect directly influences the amount of solar radiation that reaches the Earth's surface and causes snow melting. Due to the smaller quantity of solar radiation, the most favorable aspect is the northern orientation followed by northwest and northeast orientation.

A considerable caloric energy is recorded on the western and eastern slopes followed by the south-western slopes. South-eastern and southern slopes are warmer and drier.

The Aspect map was achieved by applying the function *Aspect* from *Arc Toolbox – Spatial Analyst Tools – Surface Analyst Tools* in ArcGIS. The first results were classified into 8 classes taking into account the orientation towards the cardinal points that is based on a 360^0circle (Fig. 3). Then *the grid* was reclassified by changing degree values from *Break Values (Symbology – Classified – Classes: 5, Classify)* with: 22.5, 67.5, 112.5, 202.5, 247.5, 292.5, 327.5 and the last was unchanged (Table 3). The result was a nine class grid.

Nine classes reclassification grid: The north previously represented in 2 classes (1 and 9) will be merged in a single class (1). *Arc Toolbox – Spatial Analyst Tools – Reclass – Reclassify*. Value 9 from *new values* (representing $337.5\text{-}360^0$) is replaced by the value of 1 for $0\text{-}22.5^0$ and $337.5\text{-}360^0$ classes.

Table 3.

Slope orientation degrees
1. north ($0^0 – 22.5^0$),
2. northeast ($22.5^0 – 67.5^0$),
3. east ($67.5^0 – 112.5^0$),
4. southeast ($112.5^0 – 157.5^0$),
5. south ($157.5^0 – 202.5^0$),
6. southwest ($202.5^0 – 247.5^0$),
7. west ($247.5^0 – 292.5^0$),
8. northeast ($292.5^0 – 337.5^0$),
9. north (337.5^0 -360^0).

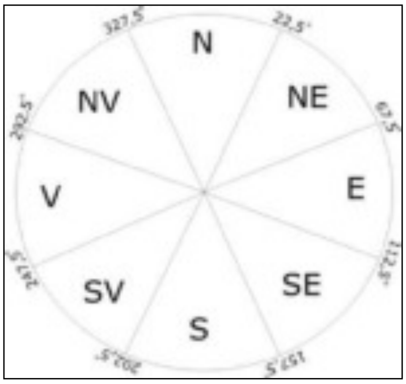

Fig. 3. **The cardinal point orientation based on a a 360^0circle**

The resulted grid has the values: 1, 2, 3, 4, 5, 6, 7 şi 8. These values must be assigned a role. Therefore, the specific name for the layout will change be changed (ex: 1 with north (337.5^0-22.5^0), 2 cu north-east (22.5^0-67.5^0), etc.).

Table 4.
Aspect

Classes	Assigned values	Suitability classes
north	100	High
northeast	90	High
east	40	Middle
southeast	20	Low
south	10	Low
southwest	30	Low- middle
east	50	Middle
northwest	90	High

Fig. 4. **The suitability map according to the aspect**

The suitability map according to the aspect resulted from the previous grid classification (*Arc Toolbox – Spatial Analyst Tools – Reclass – Reclassify*). The result was 3 suitability classes which were assigned values from 10 to 100 (Table 4). The result (Fig. 4) was used in the final relief suitability formula for developing skiing areas.

Factor 3: *Snow depth:* this factor was calculated by using snow data from 1961-2012 period from Predeal (1000 m) and Sinaia 1500 (1500 m) weather stations. The two weather stations are relevant to the studied are because of their position. There are recorded data from 900 m to 1650 m altitude. Snow data were interpolated by using a vertical gradient.

By analyzing the graph above (Fig. 5) we observe the increase of snow depth by altitude. Regarding Sinaia 1500 and Predeal weather stations, there is a relatively uniform distribution. Generally upward to data recorded at Predeal station with a relatively sharp increase in depth of snow in the period 2009-2012 from 120 centimeters to 172 centimeters. Sinaia station recorded data shows a downfall in 1500 is snow cover in the same period, from 180 cm to 143 cm.

Data recorded at Omu Peak during 1961-2012, from November to May; there is the existence of three growth poles in 1970, 1990 and 2014 and two degrees poles in the 1980 and 2000. These variations may be due to instability of the clouds. The greatest thickness of snow was recorded in 1990: 382.97 centimeters while the lowest layer of snow recorded at Omu Peak was 248 centimeters in 1980. At present there is a tendency of snow growing at all meteorological stations analyzed.

By analyzing the graph (Fig. 6) the smallest snow depth is recorded at Predeal meteorological station: 106.33 centimeters (period 1961-2012, from November to May), followed by Sinaia 1500: 146.51 centimeters (period 1961-2012, from November to May). The greatest snow depth was recorded at Omu Peak meteorological station: 281.91 centimeters (period 1961-2012 from November to May).

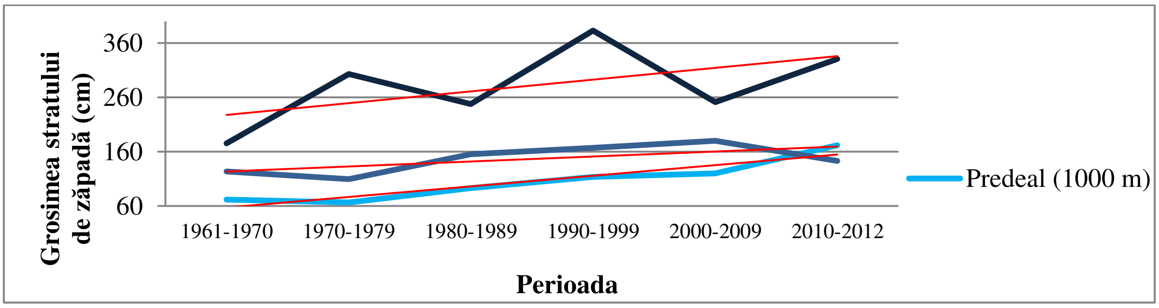

Fig. 5. **The graph of snow distribution in Predeal, Sinaia 1500 andOmu Peak during 1961-2014**

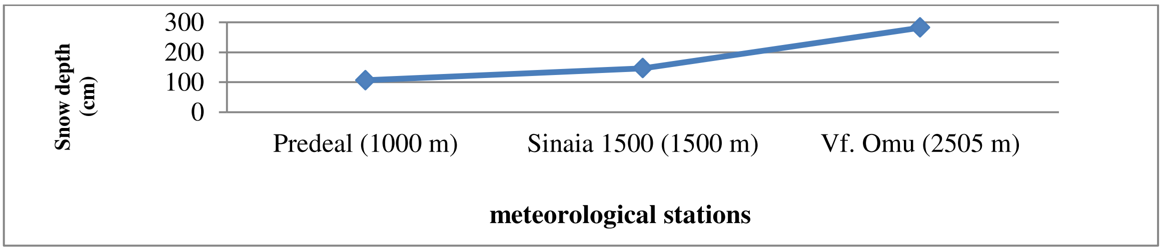

Fig. 6. **Snow depth - altitudinal distribution (1961-2012)**

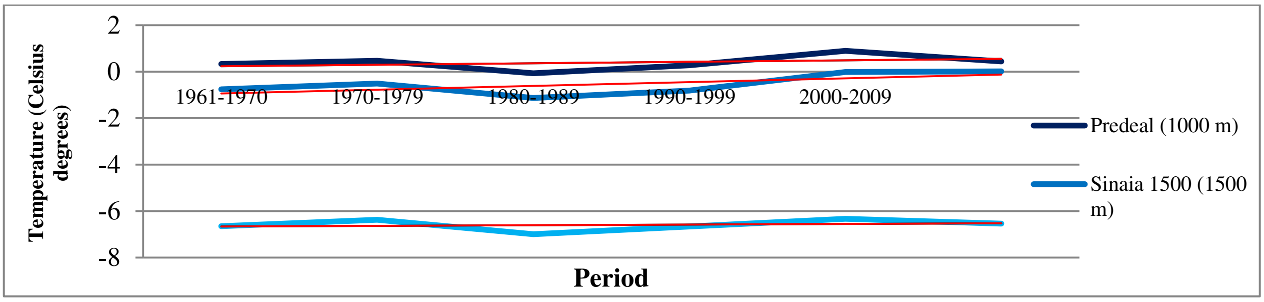

Fig. 7. **Average monthly temperature graph from November to May (1961-2012)**

By analyzing the graph above (Fig. 8) the average monthly temperature from November to May 1961-2012 is seen keeping the temperature below 0 ^{0}C at Omu Peak and Sinaia 1500 weather stations. Because of the altitude (1000 m) in Predeal weather station, the temperature fluctuated from 0.9 ^{0}C in 2000–2009 to 0.07 ^{0}C in 1980 – 1989. The graph (Fig. 7) shows a slight downward trend of monthly average temperatures during cold season.

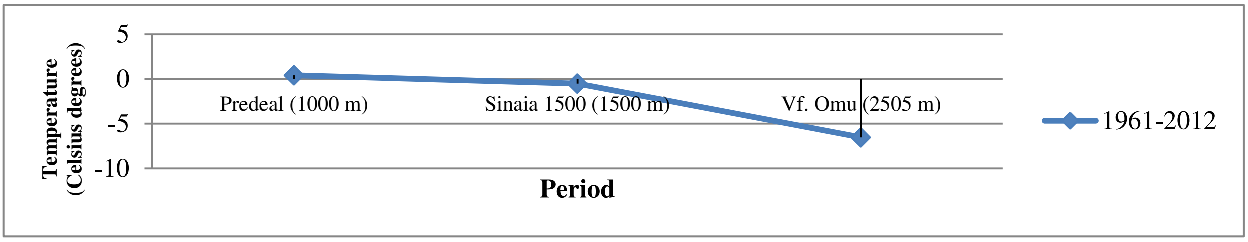

Fig. 8. **Average monthly temperature graph**

In conclusion, snow depth is very important. Its distribution is formed on a vertical gradient (Table 5) that introduces the relief altitude in the suitability formula.

Table 5.

Snow depth

Hypsometric steps (m)	*cm*	*Gradient (cm)*
900 - 1000	48.58	**7.26**
1000 - 1100	55.84	**7.26**
1100 - 1200	63.10	**7.26**
1200 - 1300	70.36	**7.26**
1300 - 1400	77.62	**7.26**
1400 - 1500	84.88	**7.26**
1500 - 1600	92.14	**7.26**

To achieve the *snow depth vertical gradient* (Fig. 9) we used *Reclass– Lookup* function from *ArcToolbox – Spațial Analyst.* Before applying this function, the Digital Elevation Model was reclassified (*ArcToolbox – Spatial Analyst – Reclass – Reclassify*). At *Input raster* we selected DEM by using values from Table 5. The result is the map of snow depth vertical gradient which will be granted on suitability classes by using the values from table 6. The final result is *the relief suitability map based on snow depth* (Fig. 9).

Table 6.

Snow depth (m)

Classes	**Assigned values**	**Suitability classes**
40 – 50 cm	40	Middle - low
50 – 60 cm	60	Middle
60 – 70 cm	80	High
70 – 100 cm	100	High

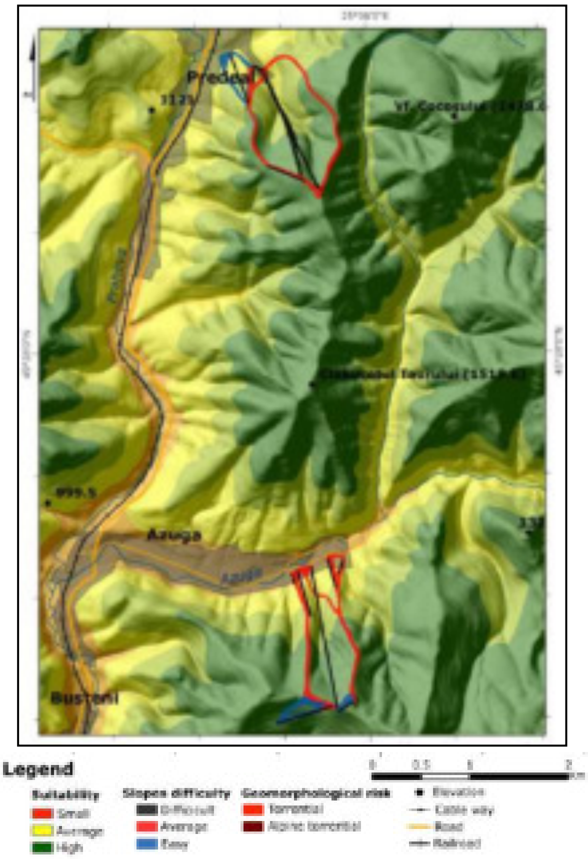

Fig. 9. **The relief suitability map based on snow depth**

Factor 4: *Soil texture:* the soil is a very important element to be taken into account when speaking about territorial planning (Săvulescu, 2011).

Relief suitability for developing a ski area must take into account the soil texture because the presence of clay soil can be a problem due to flushing of the ingredients by meteoric water. The occurrence of geomorphological processes could negatively affect the slopes (Fig. 10).

The soil map was achieved by using vector data extracted by soil map 1:200.000 scale.

To determine the soil suitability, the map is analyzed and classified into classes of soils.

Subsequently, we will determine for each class the degree of favorability for skiing area. It will assign values from the table below (Table 7) and we will develop a grid.

Table 7

Soil texture

Classes	Assigned values	Suitability classes
Sandy loam	100	High
Sandy loam - clayey	80	High
Varied texture	30	Middle
Sandy loam - silty clay	20	Low – Middle
Loamy - clay	10	Low
clay	1	Low

Fig. 10. **The relief suitability map based on soil texture**

Other important factors

The land use is very relevant regarding relief suitability for ski slopes development. In the analyzed area, 90% were forests of alpine meadows. Because of this, the land use has not been taken into account in the final formula for the relief suitability determination.

The geology is a very important factor, often restrictive (Mihai, 2003). In the studied area there is a geological homogeneity. Because of this, the geology has not been taken into consideration in the final formula for the relief suitability determination.

Geomorphological processes represent limiting factors when developing a ski area. To determine the suitability of a ski area development, it is very important to manage and inventorize the geomorphological processes. They can adversely affect skiing, tourism infrastructure but they can affect the safety of skiers (Grecu, 2009).

Wind and nebulosity: there are important elements that can limit factors of tourism activities.

Analyzing the chart above (Fig.11) we can observe a downward trend in wind speed at all the meteorological stations.

We also notice that the wind speed varies with altitude and according to local conditions (Fig. 12). The largest wind speeds are recorded at Omu Peak station: 12,03 m/s in 1961 followed by Predeal meteorological station at 1000 m elevation where the highest wind speed was 12.03 m/s also in 1961. At Sinaia at 1500 m altitude the highest wind speed is 2.4 m/s in 1961 gradually decreasing to 2.14 m/s in 2012 (Fig.12).

The cloud scan influences the ski areas position by preventing direct sunlight to reach and melt the snow.

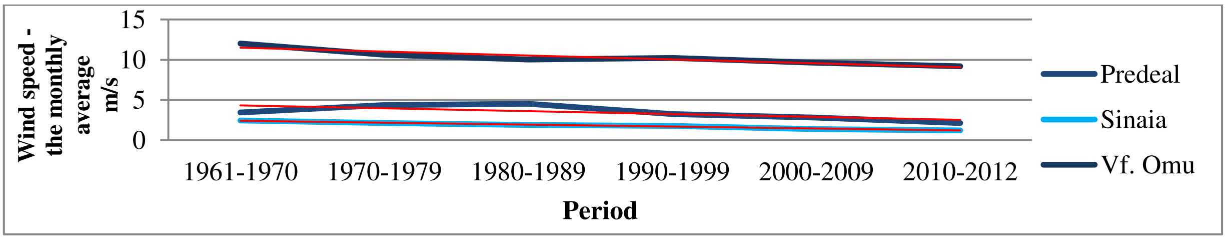

Fig. 11. **Wind speed – from November to May (1961-2012)**

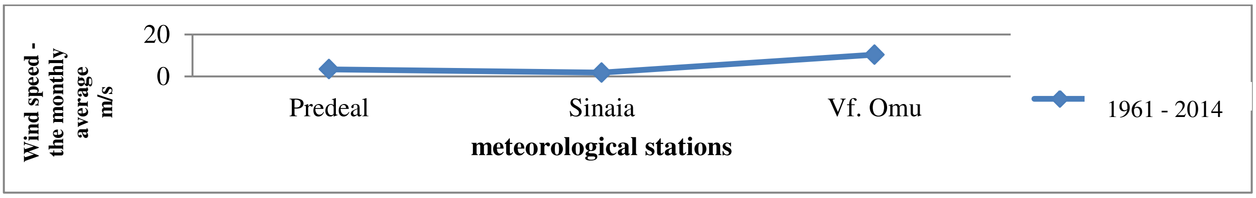

Fig. 12. **Wind speed – from November to May (1961-2012)**

4. Results

Suitability map (Fig. 13) was accomplished by applying the formula as follows the four factors related to the values represented by the raster of 10 to 100. *ArcToolbox – Spatial Anayst Tools – Map Algebra – Raster Caculator* was used to apply the formula [*(slope x 2 + aspect x 2 + snow depth + soil texture)]/6.*

By analyzing the map, we emphasize with green the favorable areas ski development (Fig. 13). The middle suitable areas are represented with yellow and the unsuitable areas with red.

Fig. 13. **Relief suitability map for sky areas development**

Proposals for the Azuga – Predeal macro ski area development

By analyzing the relief suitability map, nine connecting slopes and four cable ways were proposed (Fig. 14, 15).

Nine ski runs have been proposed for suitable ski areas. They have different characteristics (Table 8) extending over a length of 11.39 km.

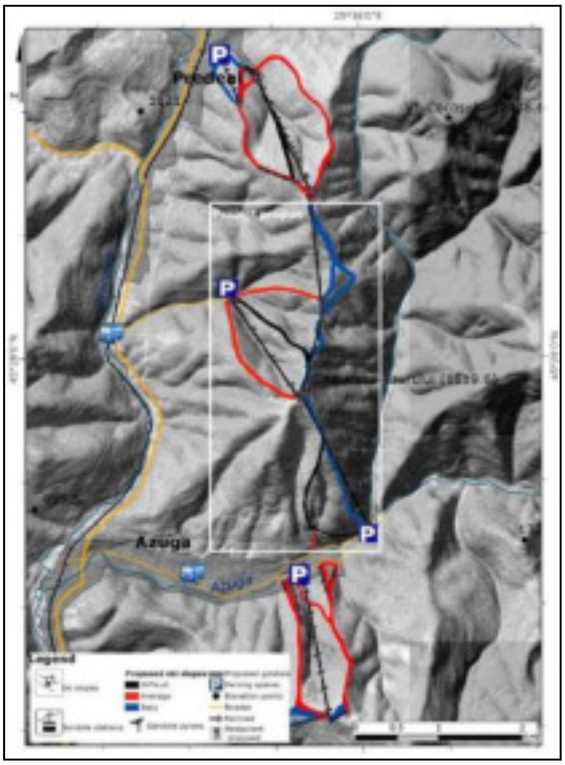

*Fig. 14***. Proposal for Predeal – Azuga project development**

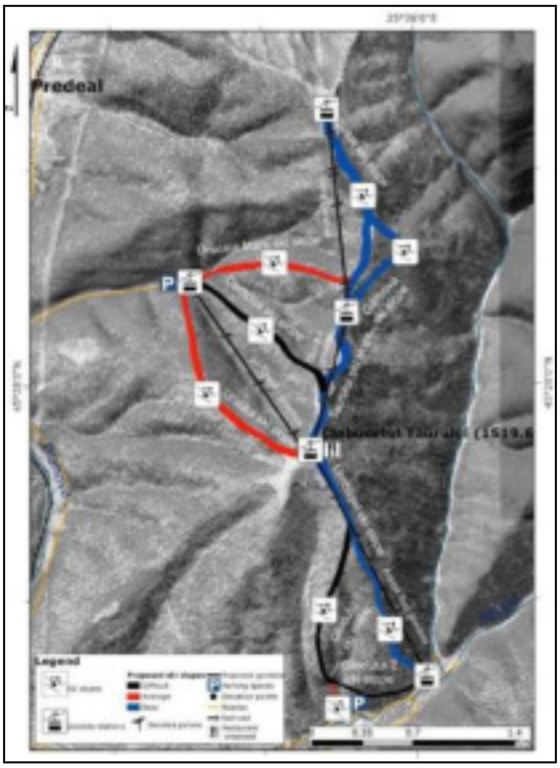

Fig. 15. **Touristic infrastructure and cable ways proposals**

Table 8. **Ski slopes characteristics**

Slope		Slope characteristics							
Name	**Difficulty**	**L** **m**	**l med** **m**	**Alt Pl** **m**	**Alt Sos** **m**	**i %** **med/max**	**i (^{0})** **med/max**	**Δh** **m**	**S** **ha**
Susaiului	**U**	1544	22.7	1324	1451	5/18.6	8.7/33.60	127	9.351
Taurului	**U**	960	59	1324	1519	12.5/21	22/38.4	195	5.67
Gârbovei	**U**	884	45.5	1324	1400	12.5/ 13	22/ 23.10	76	4.021
Ursoaia Mare	**M**	1193	33,8	1064	1519	21.5/28.6	37/54.5	455	4.035
Cerbului	**D**	1210	40	1064	1519	21.4/36.7	36.7/74.5	455	4.917
Ursului	**M**	1618	43.4	1064	1519	18/32.6	34.45/64	455	7.028
Limbășel	**U**	1792	40.9	950	1519	18.2/43.2	34.8/93.90	570	7.339
Glodului	**D**	1860	28	950	1410	21.5/26.6	37/50.10	460	5.214
Glodului variantă	**M**	329	15	950	1100	8.9/30.6	14/59	50	0.477

L – length, l med – average width, Alt Pl – departure altitude, Alt Sos –arrival altitude, i % med/max – average/maximum inclination in percent, i (0)average/maximum inclination in degrees, Δh – level difference, S – surface

Table 9. **Gondola proposals**

Gondola	Departure station (base)	Arrival station (top)	Capacity people /h	Number of pillars
Susai	1324	1451	900	11
Ursului	1064	1519	1724.8	9
Taurului	1324	1519	1700	9
Azuga Sud	950	1519	1750	12
	Total		**6074.8**	**41**

For the proposed slopes (Fig. 17) and proposed cable ways (Fig. 16) topographic profiles were made to identify their development in the longitudinal profile. These profiles were very useful for determining the degree of difficulty of the ski slopes (Table 8) and the need to choose from several types of cable way (cable car, gondola, chair lift, teleski).

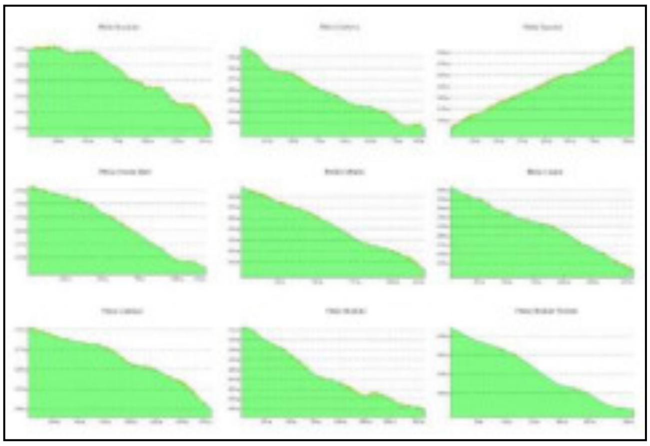

Fig. 16. **Proposal ski slopes profile**

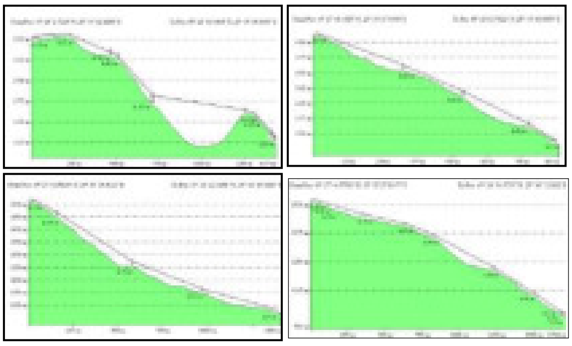

Fig. 17. **Proposal cableway profiles**

They calculated the capacities for the proposed ski slopes and touristic infrastructure (Table 9). They also calculated the surfaces that would change the type of use after the project implementation (Table 10).

Table 9. **Proposed capacities**

Gondola	ascent times	serviced slopes	length m	Average speed km/h
Susai	4.8 min	**Susaiului**	1544	25
		Gârbovei	884	25
Ursului	3.9 min	**Ursoaia Mare**	1193	25
		Cerbului	1210	25
		Ursului	1618	25
Taurului	2.9 min	**Taurului**	960	25
Azuga Sud	4.8 min	**Limbășel**	1792	25
		Glodului	1860	25
		Glodului variantă	329	25
Average	**4.1 min**			

8.45 downhill-boarding /h/people
6074,8 people/ascent

Optim maximum: 718.91 skiers/h
5.751 skiers/zi (8 h)

Table 10. **The surfaces that would change the type of use after the project implementation**

Proposal	**Surface (ha)**	**Land use**	**Relief unit**
Slopes	48,051	mixed forests	Clăbucetele Predealului
Gondolas	11,079		
Gondola outbuildings (departure stations, arrival station, deposit)	0.344		
annex building (restaurant, ticket offices)	0.143		
Parking place	1.099		
Pillars foundations (3x3x41)	0.0369		
Total permanent and temporary construction	56.079		
Total permanent constructions (structures)	1.62		

Analyzing the table above (Table 10) we can observe a land use change from mixed forests into permanent and temporary constructions and ski slope areas.

Analyzing the balances / imbalances report (Table 11) we notice the predominance of implementing this project (27 points). Some negative effects will diminish. Some ecosystems will rebalance after the execution of the project. Deforested area will regenerate because the activity of ski is in winter. Because solid constructions are not part of our proposal there will not be barriers to prevent movement of animal populations. Flora and fauna are readaptable and they will quickly find a balance.

Table 11. **Balance sheet of balances and imbalances**

Identified element	Positive (0-2)	Negative (0-2)
0 - unimportant, 1 – neutral, 2 – important		
Increase of the area attractiveness and competitiveness	2	0
Expanding the ski area	2	2
Satisfying the skiers' requirements	2	0
Long period tourists attraction	2	0
Attracting tourists from remote areas, including foreign tourists	2	0
Arrangement of new ski slopes (approved)	2	2
Achieving a modern cableway	2	2
Development of transport infrastructure and new parking places	2	1
The ecosystems and natural habits degradation and regeneration after work	1	1
Changing land use from mixed forest in recreational areas	2	2
Creating new work places	2	0
Economic and social development	2	0
Consumption of electricity, water, gas, oil, waste generation	0	2
Project implementation cost/benefit (costs amortization)	2	1
Active and healthy live system promotion	2	0
Accidents	0	1
Total	**27**	**14**

5. Conclusions

Analyzing the most important European mountain resorts there is a better use of the ski area shared between two or more resorts. There is good management and integrated management of tourist facilities and infrastructure used by skiers. The analysis reveals the relief suitability for developing a ski area between Predeal and Azuga resorts. The investment is to expand the ski area between Predeal and Azuga by developing new slopes (new and connection). The ski slopes will be approved under European law and certain related facilities to ensure their operation: touristic infrastructure, artificial snow facilities, provision of utilities and other services.

The benefits of implementing the project are:

- Creating a visible ski area of Prahova Valley as a tourist destination both internally and externally;
- Ensuring sustainable development of winter sports;
- Creating a network of tourist information centers coordinated in all resorts but also the internet to transmit the correct information in quick, uniform and organized time;
- Encouraging municipal and county authorities to develop integrated development macro ski area, including all infrastructure elements to avoid uncoordinated development;
- Stations and mountain areas developing to provide facilities and attractions to tourists throughout the year (in winter: skiing, snowboarding, spring; in summer and autumn: hiking, mountain biking, etc.).

REFERENCES

BĂLTEANU, D., DINCĂ, A.I., SURUGIU, C., DUMITRAŞCU, M., MICU, D., FELCIUC, M., (2008), *Ecotourism and Environmental Change in the Romanian Carpathians*, în *Global Environmental Research*, vol. 12, nr. 2, p. 161-172, ISSN: 1343-8808.

BENISTON, M., (2005), *Mountain Climates and Climatic Change: An Overview of Processes Focusing on the European Alps*, in Pure and Applied Geophysics, Pure appl. geophys. 162 (2005) 1587-1606, 0033 – 4553/05/091587–20, DOI 10.1007/s00024-005-2684-9.

CENDRERO, A., (1991), *Geology for environmental planning and management,* in Science International, 45-46: 35-36.

CHARDON, A. C.., THOURET, J.C., (1994), *Cartographie de la vulnérabilité d'une population citadine face aux risques naturels: le cas de Manizales*, Mappe Monde 4/1994, p. 37-40.

DINCĂ, A.I., MINCU, D., (2008), *Climate Variability and its Implications for Winter Mountain Tourism in the Prahova Valley – Poiana Braşov Area*, Proceedings PEEC 2008, Vol. I, Supplement of "Quality-access to success" Journal, CNCSIS recognized, Year 9, no. 94, p. 232-241, ISSN: 1582-2559.

DINCĂ, A.I., MINCU, D., (2010), *Tourism Destinations Vulnerable to Climate Changes: An Econometric Approach on Predeal Resort*, in Buletinul Universităţii Petrol-Gaze din Ploieşti, seria Ştiinţe Economice, vol. LXII, no 1, p. 111-120, ISSN 1224-6832.

DOBRE, R., (2007), *Pretabilitatea terenurilor pentru o legătură feroviară în sectorul Câmpina –Predeal*, Comunicări de Geografie, XI, Bucureşti.

DOBRE, R., (2011a), *Pretabilitatea reliefului pentru căi de comunicaţii şi transport în Culoaru Prahovei (sectoarele montan şi subcarpatic)*, Editura Universitară, Bucureşti, ISBN 978-606-591-235-9, 245 pagini – teza de doctorat .

DOBRE, R., (2011b), "Use of GIS techniques to identify areas to consider when designing the Posada – Sinaia motorway sector so as to meet sustainable development requirements", *Revista de Geomorfologie*, nr. 13, Bucuresti, ISSN 1453-5068, p. 131-139.

DOBRE, R., MIHAI, B., SĂVULESCU, I., (2011), "The Geomorphotechnical Map: a highly detailed geomorphic map for railroad infrastructure improvement. A case study for the Prahova River Defile (Curvature Carpathians, Romania)", *Journal of Maps,* v2011, 126-137. 10.4113/jom.2011.1155.

GRECU, F., (1997), *Fenomene naturale de risc geologice şi geomorfologice*. Editura Universităţii din Bucureşti, Bucureşti.

GRECU, F., (2002), *Risk prone lands in hilly regions: Mapping stages*, in R.J. Allison, ed. Applied Geomorphology, John Wiley and Sons. p. 49-64. Chichester.

GRECU, F., (2003), *Aspecte ale reprezentării cartografice a fenomenelor de risc geomorphic, Riscuri şi Catastrofe, II*, p. 323-31.

GRECU, F., (2009), *Hazarde şi riscuri naturale*, IV, Editura Universitară Bucureşti, Bucureşti.

GRECU, F., COMĂNESCU, L., (1998), *Studiul reliefului. Îndrumător pentru lucrări practice,* Edit.Universităţii din Bucureşti, 180 pag.

IELENICZ, M., (1984), *Munţii Ciucaş-Buzău: studiu geomorfolgic*, Editura Academiei Republicii Socialiste Române.

IELENICZ, M., (2004), *Geomorfologie*, Editura Universităţii, Bucureşti.

IELENICZ, M., POPESCU, N., NEDELEA, A., (2005), *Morphodynamic system of the Făgăraş mountains alpine crests*, Natural environment and civilization, Turkey, p. 55-70.

IOSUB, F., (2008), *Distribuţia şi Evoluţia Sistemelor Informaţionale Geografice,* [Available online] | URL: http://earth.unibuc.ro /articole/evoluia-sistemelorinformaionale-geografice-gis, Geospaţial.org, Bucureşti.

IRIMUŞ, I.A., (2006), *Hazarde şi riscuri asociate proceselor geomorfologice în aria cutelor diapire din Depresiunea Transilvaniei*, Casa Cărţii de Ştiinţă, Cluj-Napoca.

JENSON, S.K., DOMINIQUE, J.O., (1988), *Extracting topographic structure from digital elevation data for geographic information system*, Phogramm. Eng. Remote Semn, 54(11), 1593-1600.

MAC, I., RÂPEANU, M., (1995), *Premisele geomorfologice pentru localizarea şi dezvoltarea oraşului Predeal*. Studia Universitatis Babeş-Bolyai, Seria Geographia XL (1).

MIHAI, B., NEDELEA, A., (1999), *Câteva comparaţii geomorfologice între masivele înalte din Carpaţi. Studiu de caz: Munţii Făgăraş – Ţara Înaltă*, Comunicări de Geografie, vol. III, Bucureşti, p. 159-167.

MIHAI, B., OPREA, R., ŞANDRIC, I., (2001), *Aplicatii GIS in amenajarea domeniilor schiabile. Studiu de caz – domeniul schiabil Predeal-Clăbucet*, Comunicari de Geografie, V-VI, Editura Universităţii Bucureşti, Bucureşti.

MIHAI B., (2003), *Munţii din bazinul Timişului, studi geomorfologic cu privire specială asupra morfodinamicii actuale şi amenajării spaţiului*, Editura Universităţii, Bucureşti.

MIHAI, B., ŞANDRIC, I., (2004), "Relief accessibility mapping and analysis in middle mountain areas. A case study in the Postăvaru-Piatra Mare-Clăbucetele Predealului Mts. (Curvature Carpathians)", *Studia Geomorphologica Carpatho-Balcanica*, Vol. XXXVIII, Krakow.

MIHAI, B., ŞANDRIC, I., (2004), *Relief accessibility mapping and analysis in middle mountain areas. A case study in the Postăvaru-Piatra Mare-Clabucetele Predealului Mts. (Curvature Carpathians)*, Studia Geomorphologica Carpatho-Balcanica, Vol. XXXVIII, Krakow , 2004.

MIHAI, B., ŞANDRIC, I., CHIŢU, ZENAIDA, (2008), "Some contributions to the drawing of the general geomorphic map using GIS tools. An application to Timiş Mountains", *Revista de Geomorfologie*, 1453-5068.

MIHAI, B., REYNARD, E., WERREN, G., SAVULESCU, I., ŞANDRIC, I., CHIŢU, Z., (2009), *Impacts of tourism on geomorphological processes in the Bucegi Mountains in Romania*, Geographica Helvetica, Swiss Journal of Geography.

NIŢU, C., TUDOSE, C., VIŞAN, M., (2001), *Sisteme informaţionale geografice şi cartografie computerizată*, Editura Universităţii din Bucureşti, Bucureşti.

HUPPER, A., (2005), *Location Based Services – Fundamentals and Operation*, Ludwig Maximilian University Munich, Germany.

WOOD, J.D., (1996), *The Geomorphologycal Characterisation of Digital Elevation Models,* University of Leicester, UK, [Available online] | URL: http://www.soi.city.ac.uk/~jwo/phd/.

OPREA, R., (2004), *Bazinul montan al Prahovei, potenţial natural şi evaluarea peisajului,* Editura Universităţii, Bucureşti.

ORGHIDAN, N., (1932), *Observaţii morfologice în Bucegi*, Lucrările Institutului de Geografie ale Universităţii din Cluj, vol. IV.

PANIZZA, F., (2000), *Beyond 'delegative democracy': 'old politics' and 'new economics' in Latin America*, Journal of Latin American Studies, 32 (3). pp. 737-763. ISSN 0022-216X.

POSEA, Gr., GRIGORE, M., POPESCU, M., IELENICZ, M., (1976), *Geomorfologie*, Editura Ştiinţifică şi encliclopedică, Bucureşti.

RĂDOANE, M., CRISTEA, I., RĂDOANE, N., (2011), Cartografierea geomorfologică.Evoluţie şi tendinţe I, II, III [Available online] | URL:http://earth.unibuc.ro/articole/cartografierea-geomorfologica-i, Geospaţial.org, Bucureşti.

RĂDOANE, M., RĂDOANE, N., (2003), *Geomorphological evolution of river longitudinal profiles*, Geomorphology, vol. 50, Elsevier, Olanda, 293-306.

ROTAR, A., SIMON, L., URDEA, P., VOICULESCU, M., (2012), *A study of institutional stakeholders' views on biodiversity in Romania*, Carpathian Journal of Earth and Environmental Sciences, vol. 7, No. 2, p. 219-230.

SURDEANU, V., (1990), *Sistemul geomorfologic al alunecărilor de teren*. Studia Universitatis Babeş-Bolyai, XXXV(2).

SURDEANU, V., (1997), *La répartition des glissements de terrain dans les Carpates Orientales*, Geographia Fisica e Dinamica Quaternaria, 19.

SURDEANU, V., (1998), *Geografia terenurilor degradate.* Presa Universitară Clujeană, Cluj-Napoca.

REYNARD, N. S., CROOKS, S. M. and KAY, A. L., (2004), *Impact of climate change on flood flows in rive Catchments.* Final report for Defra / EA project W5B-01-050. 80 p.

SĂVULESCU, I., (2010), *Interrelaţiile dintre componentele fizico-geografice şi etajarea pădurii în Munţii Iezer*, Teză de doctorat, Unuversitatea din Bucureşti, Facultatea de Geografie, Bucureşti.

TUDOSE, C., OVEJANU, I., (2011), *Elemente de sisteme informaţionale geografice,* EdituraUniversitară, Bucureşti.

VELCEA-MICALEVICH, VALERIA, (1961), *Masivul Bucegi: Studiu geomorfologic*, Editura Academiei Republicii Populare Române, 152 p.

VOICULESCU, M., (2009), *The Present-Day Erosional Processes in the Alpine Level of the Bucegi Mountains – Southern Carpathians,* Forum geografic. Studii şi cercetări de geografie şi protecţia mediului, Year 8, No. 8, pp. 23-38.

VOICULESCU, M., POPESCU, F., (2011), The management of Snow avalanches in the Ski Areas in Southern Carpathians. Case study: *Făgăraş massif and Bucegi Mountains, in (edit. Zhelezov, G.) Sustainable Development in Mountain Regions: Southeastern Europe*", Springer, pp. 103-120, doi: 101007/978-94-007-0131_10.

VOICULESCU, M., ARDELEAN, F., ONACA, A., TÖRÖK-OANCE, M., (2011), *Analysis of snow avalanche potential in Bâlea glacial area – Făgăraş massif, (Southern Carpathians – Romanian Carpathians)*, Zeitschrift für Geomorphologie, Sttutgart, Volume: 55, Issue: 3, Pages: 291-316, doi: 10.1127/0372-8854/2011/0054.

VOICULESCU, M., POPESCU, F., TOROK-ONCE, M., OLARU, M., ONAC, A., (2011), Features of the Ski Area from the Romanian Banat, Forum geografic. Studii şi cercetări de geografie şi protecţia mediului Volume 10, Issue 1 / June 2011, pp. 58-69, (www.forumgeografic.ro) DOI: 10.5775/fg.2067-4635.2011.019.i.

VOICULESCU, M., ARDELEAN, F., (2012), *Snow avalanche – disturbance of high mountain environment. Case study – the Doamnei glacial valley the Făgăraş massif – Southern Carpathians, Romanian Carpathians*, Carpathian Journal of Earth and Environmental Sciences, vol. 7, no. 1, p. 95-108.

VOICULESCU, M., ONACA, A., (2013), *Snow avalanche assessment in the Sinaia ski area Bucegi Mountains, Southern Carpathians) using the dendrogeomorphology method*, Area 45.1, 109/122, doi: 10.1111/area.12003.

Surse internet:

AgenţiaEuropeană de Mediu, 2010, Corine Land Cover 2006, [Online] Available at: http://www.eea.europa.eu.

Earth Resources Observations and Sience Center (EROS), USGS Glabal Visualisation Viewer, URL: http://glovis.usgs.gov/AboutBrowse.shtml,

Global Land Cover Facility, Earth Sienece Data Interface, [Available online] | URL: http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp, imagini satelitare Landsat ETM+.

Ministerul Mediului şi Pădurilor, *Limitel parcurilor naţionale în format digital,* [Available online] | URL: http://mmediu.ro/protectia_naturii/protectia_naturii.htm.

*** (2004), *Dicţionar de geografie fizică*, EdituraCorint, Bucureşti.

*** (1967), Harta geologică a României, scara 1:200.000, Foaia 28 Braşov, L-35-XX, Institutul Geologic, Bucureşti.

*** (2006), Dezvoltarea turistică şi a domeniului schiabil, Zona Arieşeni, Judeţul Alba. Studiu, Transcablu S.A, Braşov.

*** (2009), Plan urbanistic zonal în ComunaVoineasa, Memoriu de prezentare, Aspro SRL, Râmnicu Vâlcea.

*** (2009), Raport privind evaluarea impactului asupra mediului pentru proiectul de investiţii: dezvoltarea infrastructurii de agrement în staţiunea turistică Voineasa, JudeţulVâlcea, Aspre SRL, Râmnicu Vâlcea.

*** (2010), Raport la studiul de evaluare a impactului asupra mediului, proiectul: Telescaun Vâlsan L=1.825 m, telescaun şi zonă de agrement cu bandă transportoare L= 400 m şi parcare, zonă servicii, clădire panoramică – Muntele Mic.

*** (2010), Studiu de evaluare a impactului asupra amediului pentru proiectul: Dezvoltarea şi relabilitarea domeniului schiabil în Poiana Braşov, SC Ecoanalitic SRL, Odorheiul Secuiesc.

[1] **University of Bucharest, Faculty of Geography,**
Department of Geomorphology, Pedology & Geomatics,
1 Nicolae Bălcescu Blvd, 010074, sect. 1, Bucharest, Romania

Miscellanea

National Geomorphology Symposium

31st Edition, Sfântul Gheorghe – Danube Delta, 21 st - 24 th May 2015

The 31st Edition of National Geomorphology Symposium was held in the Danube Delta at Geographical Marine Research Station (Faculty of Geography, University of Bucharest). The symposium was organized by the Romanian Geomorphology Association, Department of Regional Geography and Environment – Faculty of Geography, University of Bucharest and St. George Marina and River Research Station.

The symposium was deployed for four days (21 st - 24 th May 2015). Two days were dedicated to oral presentations and poster presentations and field trips and one day only for field applications. In this edition they have registered 51 papers including 27 oral presentations and 24 poster presentations. To encourage young geomorphologists they were awarded prizes for the best presentation (Francisca Chiriloaei, Maria Rădoane, Constantin Nechita, Nicolae Rădoane – The reconstitution of the Holocene fluvial activity. Case studies from NE Romania) and for the best poster presentation (Laurențiu Ilie, Tiberiu Iurea, Mădălina Teodor, Robert Dobre - Atlasul domeniilor schiabile din România).

On Friday, 22nd of May 2015, the meeting of the Romanian Geomorphology Association Council took place. Elections for new leadership were held On Saturday 23rd of May in the General Meeting Romanian Geomorphology Association.

- AGR president: Mrs. **Dr. Maria Rădoane**;
- Vice President – international relations, Mr. **Dr. Petru Urdea**;
- Vice President (with executive powers in the name and with the agreement of the President, strategy, international relations coordinator and website responsible), Mr. **Dr**. **Alfred Vespremeanu-Stroe**;
- Vice President (2016 National Geomorphology Symposium organizer), Mr. **Dr. Dan Dumitriu**;
- Vice President e (communication responsible, website administration, finance, young geomorphologists), Mr. **Dr. Mihai Micu;**
- Vice President, the Geomorphology Journal editor assistant al (UBB, Oradea, Valahia website maintenance), Mr. **Dr. Olimpiu Pop**;
- General Secretary (The Geomorphology Journal managing editor), Mr. Dr. **Sandu Boengiu**;
- Treasurer, USV website maintenance, Mrs. **Dr. Francisca Chiriloaei**;

Members:

- **Dr. Mircea Voiculescu**, UVT website maintenance responsible;
- **Dr. Marta Jurchescu**, communication with youth geomorphologists, website maintenance on Institute of Geography and possible other institutions members;
- **Dr. Nicu Cruceru**, Geomorphology Journal editor assistant, private universities and other institutions website maintenance;
- **Dr. Robert Dobre**, UB website maintenance responsible, relation with economic, engineering, law fields;
- **Dr. Ciprian Mărgărint**, UAIC website maintenance responsible.

During the symposium there were organized two fields trip. The first one was held in 23rd of May on the St. George Black Sea shore. The second one was held on Sunday 24th of May on the Danube River and Caraorman maritime field.

Every day, the organizers were able to present the local traditions by organizing tastings of local products, some specific meals, or by specific Saint George Cooks Choir repertoire and the repertoire of the Delphine 90 band.

The Romanian Geomorphology Association new website was launched after this edition of this year. The new website can be accessed at the following link: http://www.geomorfologie. ro/.

Mădălina TEODOR

Authors' instructions

Title page information

• Title. Concise and informative. Use Sentence case, Times New Roman, Font 14, bold.
• Author names. Please indicate the first name with a Sentence case and the last name(s) with an Uppercase. Use Times New Roman, font 12. Please insert a superscript Arabic number for linking the affiliation provided at the end of the article. Example:
Petronela DARIE (CHELARU)^1, Ion IONITA^1

Abstract

A concise abstract of 150-250 words is required. The abstract should state the purpose of the research, the main results and conclusions. References should be avoided, but if essential, then cite the author(s) and year(s). Also, non-standard or uncommon abbreviations should be avoided, but if essential they must be defined at their first mention in the abstract itself.
Use Times New Roman, font 10, followed by a dot and by the abstract text, without indentation. Example:
Abstract. From a morphological point of view, the Ialomița Upper Valley represents a typical mountain valley. This feature frequently determines the appearance of torrential geomorphological processes (runoff, gulling, and torrent). The goal of this article is to highlight the occurrence of soil erosion using a bivariate analysis in the Ilwis 3.4 software.

Statistical approaches are indirect methods for assessing susceptibility, involving statistical determinations by combining variables that determined the known processes. The weights of evidence modeling for torrential erosion is based on overlapping the erosion map with parameter maps (slope, aspect, geology, land use, soil, etc.),which aims at obtaining the susceptibility map and the final prediction map (success rate map).

Keywords

Immediately after the abstract, provide a maximum of 6 keywords, avoiding multiple concepts (avoid, for example, 'and', 'of'). Only abbreviations firmly established in the field may be eligible. These keywords will be used for indexing purposes.
Example:
Keywords: erosion, susceptibility, maps, statistical analysis, Ialomița Upper Valley.

Text information

Manuscripts should be submitted in Word. Please save files in the .docx format for Word2007 or higher or .doc format for older versions of Word. Use a normal font of 11 point Times New Roman.
Use italics for emphasis.

Article structure

Subdivision - numbered sections

Divide your article into clearly defined and numbered sections. If subsections exist, these should be numbered (1.1., then 1.1.1, 1.1.2, ...; then 1.2 etc). The abstract is not included in the section numbering). Use this numbering also for internal cross-referencing: do not just refer to 'the text'. Any subsection may be given a brief heading. Each heading should appear on its own separate line, distanced by one line from the text above and below.
Examples for sections that should not miss:

1. Introduction

State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.

Conclusions

The main conclusions of the study may be presented in a short Conclusions section, which may stand alone or form a subsection of a **Discussion** or **Results and Discussion** section.

For first subsections' headings use Bold italic. Example:
3.1. Relief
For second subsections' headings use italic only. Example:
2.1.1. Un secteur dominé par des jebels aux versants raides avec une lithologie favorable au ruissellement
First paragraph of each section/subsection should have no indentation.

Acknowledgements

Collate acknowledgements in a separate section at the end of the article before the references. List here people, grants, funds, etc.

Abbreviations

Abbreviations must be defined at their first mention. Ensure consistency of abbreviations throughout the article.

Math formulae

Use the equation editor for equations.

Footnotes

Footnotes can be used to give additional information, which may include the citation of a reference included in the reference list. They should not consist solely of a reference citation, and they should never include the bibliographic details of a reference. They should also not contain any figures or tables.
Footnotes to the text are numbered consecutively; those to tables should be indicated by superscript lower-case letters (or asterisks for significance values and other statistical data).
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Figures

If there is text in the figures, please keep it consistently sized throughout all the figures in the article.
Do not include titles or captions within your illustrations.
All the figures are to be numbered using Arabic numbers.

Each figure should have a concise caption describing its content (Bold, Font 9), not in the figure itself, but beneath the figure. The captions should be preceded by the term "Fig." (italic font 9) and the figure number and dot (italic font 9).

Example:
Fig. 1. **Landslides**
Photo 1. **The Ialomița Valley**

Figures should be cited in the text respecting their order of appearance. Figure parts have to be signaled by lower-case letters (a, b, c etc.).
Examples:
Figure 2
Figure 11b
(Fig. 3)
(Figs. 3 and 4)

Previously published figure material should be cited by giving the original source in the form of a citation at the end of the figure caption. Additionally, if the figures have been published before elsewhere, you are obliged to obtain permission from the copyright owners for both the print and the online format. If these rights are not granted for free, you need to use other material from other sources.

Tables

All tables should be numbered using Arabic numbers. Each table should have a table caption above (centered) explaining its content.

Published material should be cited with the original source in the form of a reference at the end of the table caption. Footnotes to tables (for significance values or other statistical data) should be indicated by superscript lower-case letters and put beneath the table body.

Example:

Table 1. **Index classification on categories of fluvial vulnerability**

All tables should be cited in the text in the order of their appearance.

Example:
Table 2
(Table 5)

References

Citations inside the text

Cite references in the text by name and year in parentheses. Consider the following examples:

- This results in the displacement of soil and/or rock particles by rainsplash and runoff as dispersed and concentrated flow (Moțoc, 1963).
- Changes in land cover can lead to significant changes in leaf area index, evapotranspiration (Mao & Cherkauer, 2009)
- As to gully development in the Bârlad Plateau, the long term findings obtained by Ionita (1998, 2000, 2007) and Ionita *et al.* (2006) are as follows
- The analysis proves the fact that this frequency is strongly influenced by the resistance degree of the rock types from the hydrographical basins (Zăvoianu *et al.*, 2004).
- …further into the sea sediments can be redistributed under the influence of waves, with a subsequent phase of mouth asymmetry, with the bar anchored on one of the shores (Bhattacharya, 2003; Giosan, 2005).

Reference list

References section (3 lines distanced from the text, 1 line between the title **REFERENCES** and the actual list). The title **REFERENCES** should be centered.

Here should only be included works that are cited in the text. Do not use foot notes or endnotes as a substitute of a reference list. The entries should be ordered alphabetically by the last names of the first author of each work.

Use Times New Roman, 9.

- Journal article

All names of the authors should be provided.

Example:

COSTA, M.H., BOTTA, A., CARDILLE, J.A., (2003), "Effects of large-scale changes in land cover on the discharge of the Tocantins River, Southeastern Amazonia", *Journal of Hydrology*, **283**, 206–217.

- Book

Example :

VELCEA-MICALEVICH, V., (1961), *Masivul Bucegi: Studiu geomorfologic*, Edit. Academiei R. P. R., 152 p.

- Book chapter

Example:

CHURCH, M. A., (1992), "Channel Morphology and Typology", in: CALLOW, P., PETTS, G.E. (Eds.), *The Rivers Handbook*, Oxford, Blackwell, 126-143.

- Online document

Example:

RĂDOANE, M., CRISTEA, I, RĂDOANE, N., (2011), *Cartografierea geomorfologică. Evoluţie şi tendinţe, I*, http://geo-spatial.org. Accessed 26 June 2012

- Dissertation

Examples:

KARRAY, M.R., (1977), *L'extrémité nord-est de la Dorsale tunisienne : recherches géomorphologiques*, Thèse de doctorat, Université de Tunis, 166 p.

IOANA-TOROIMAC, G., (2009), *La dynamique hydrogeomorphologique de la riviere Prahova (Roumanie): fonctionnement actuel, evolution recente et consequences geographiques*, PhD thesis, Université Lille 1, 341 p.

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Use Times New Roman, 11, Bold for the Institution name and address, Bold italic for the Department, right alignment.

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University of Bucharest, Faculty of Geography,
Department of Geomorphology-Pedology and Geomatics,
1 Nicolae Bălcescu Blvd, 010074, Sect 1, Bucharest, Romania.
florinagrecu@yahoo.com

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