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

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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 Călmăţui 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.

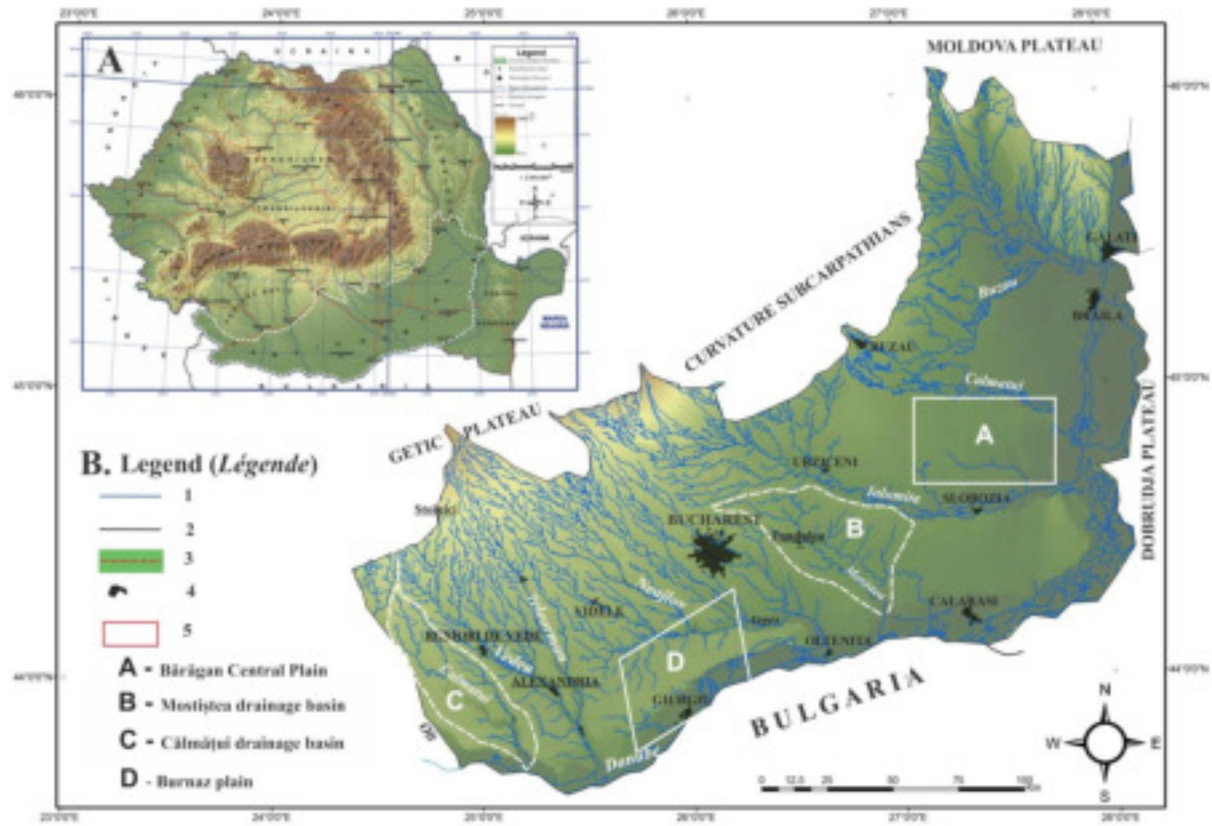

Fig. 1. **Geographical location of the studied areas:** 1 – Hydrographical network; 2 – Plain limit; 3 – Watershed; 4 – Localities; 5 – Studied areas; **A** and **B** – transversal profiles

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).

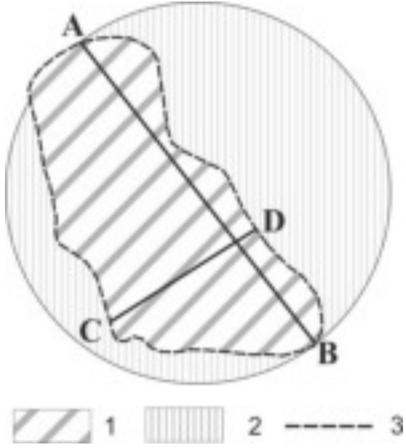

Fig. 2. **The parameters computed for micro-depressions** (AB – major axis (*L*), CD – minor axis (*W*), 1 – micro-depression area (*Ad*), 2 – area of the circle having the same diameter as the depression's major axis (*Ac*), 3 – perimeter of the micro-depression (*Pd*).

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.

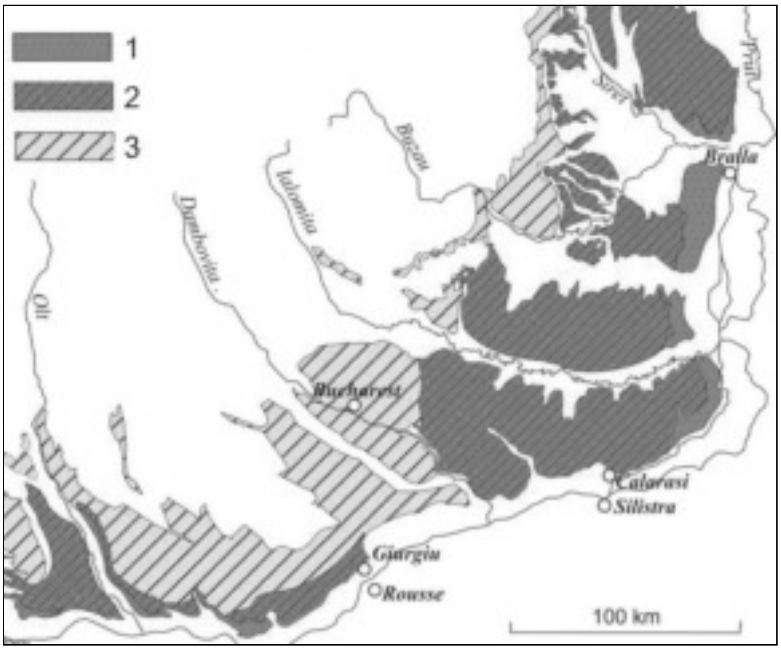

Fig. 3. **Texture of loess and loess-like deposits in Romanian Plain** (redrawn from Conea *et al.*, 1963) 1 – loess with loam and sandy loam texture, 2 – loess with silty loam texture; 3 – loess-like deposits, with silty clay loam texture

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.

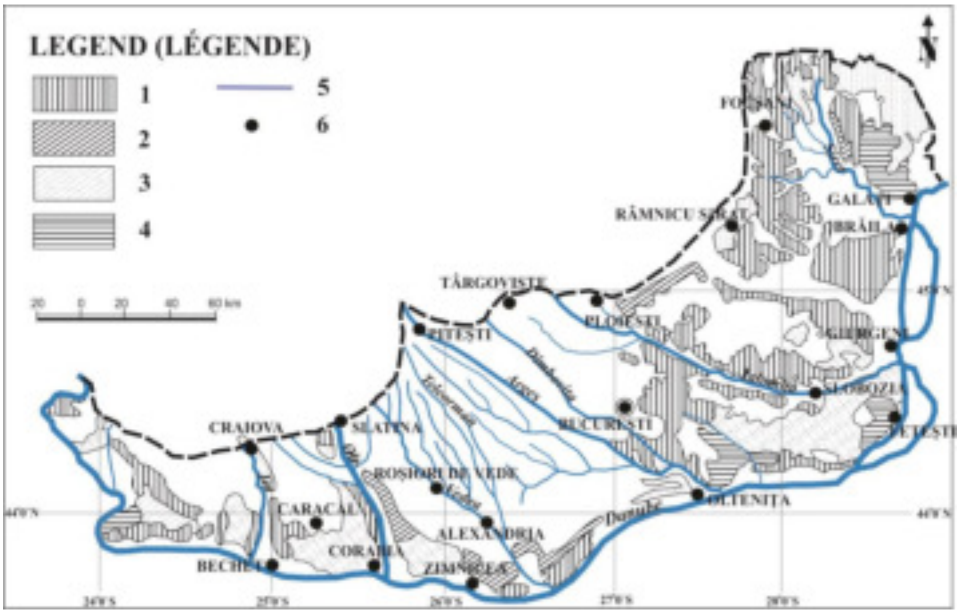

Fig. 4 – **Groups of loess and loess-like deposits sensibility in Romanian Plain** (according to the Norms regarding constructions founding, 2008); 1 – collapse loess – A1 (with continuous spread); 2 – collapse loess – A2 (with discontinuous spread) (group A – loess and loess-like deposits that experience 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}≥5 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).

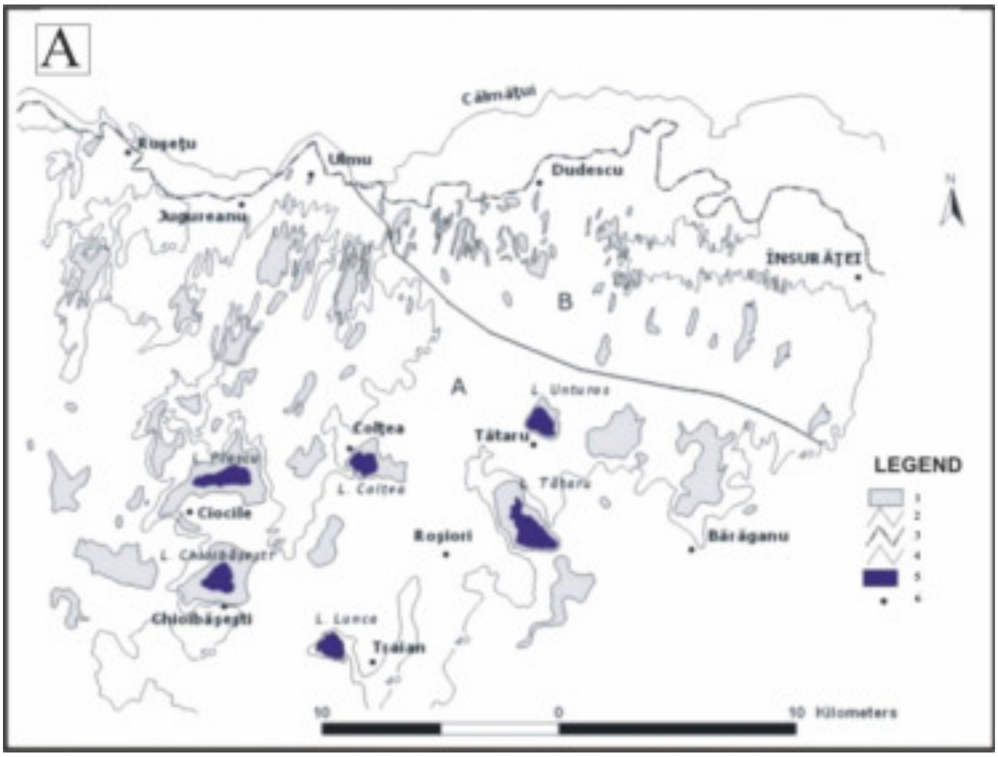

Fig. 5 a. **Central Bărăgan Plain – loess micro-depressions**
(1 – depressions; 2 – elevation; 3 – limit of the plain; 4 – rivers; 5 – lakes; 6 – localities)

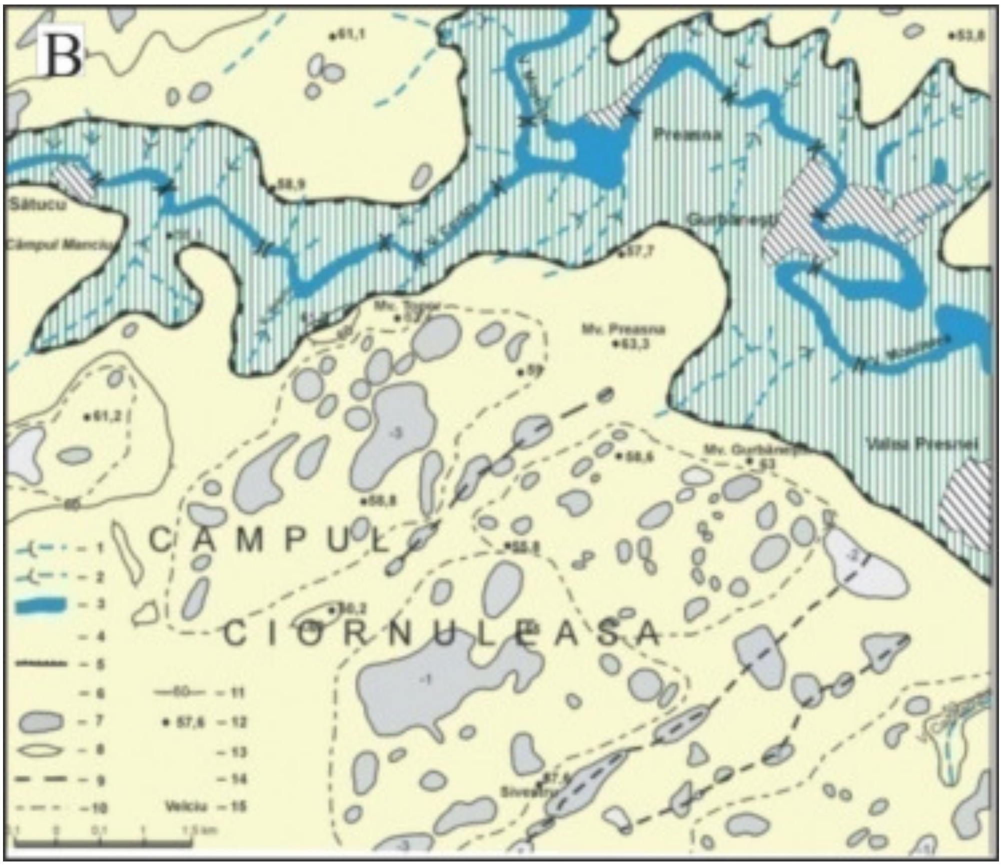

Fig. 5 b. **Ciornuleasa area (the Mostiştea basin)** (1 – overdeveloped small valleys with flat floor; 2 – small valleys, U-shaped in cross-section; 3 – artificial lakes; 4 – Mostiştei and Corâta valleys; 5 – the morphologic contact between the valley and the field relief; 6 – the morphological surface 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).

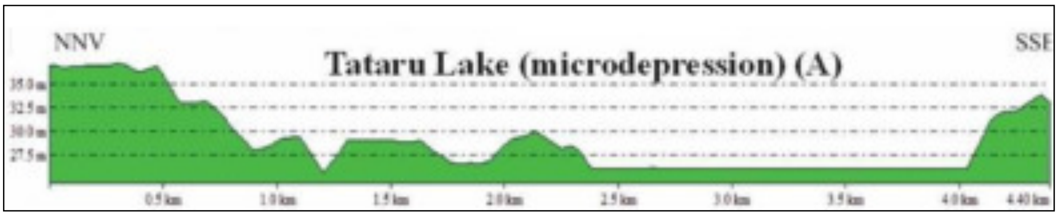

Fig. 6 a. **Transversal profiles in Central Baragan Plain**
(Tătaru Lake) in Burnaz Plain (Stoeneşti and Şerpăteasca micro-depressions)

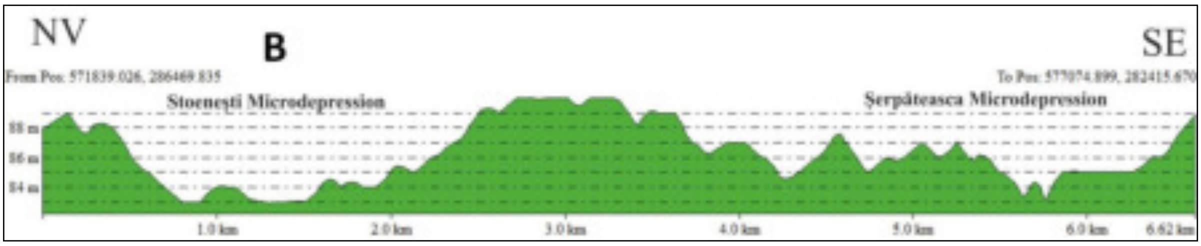

Fig. 6 b. **Transversal profiles in Burnaz Plain** (Stoeneşti and Şerpăteasca micro-depressions)

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 Călmățui 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 Călmățui 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 Călmățui 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 Călmățui 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).

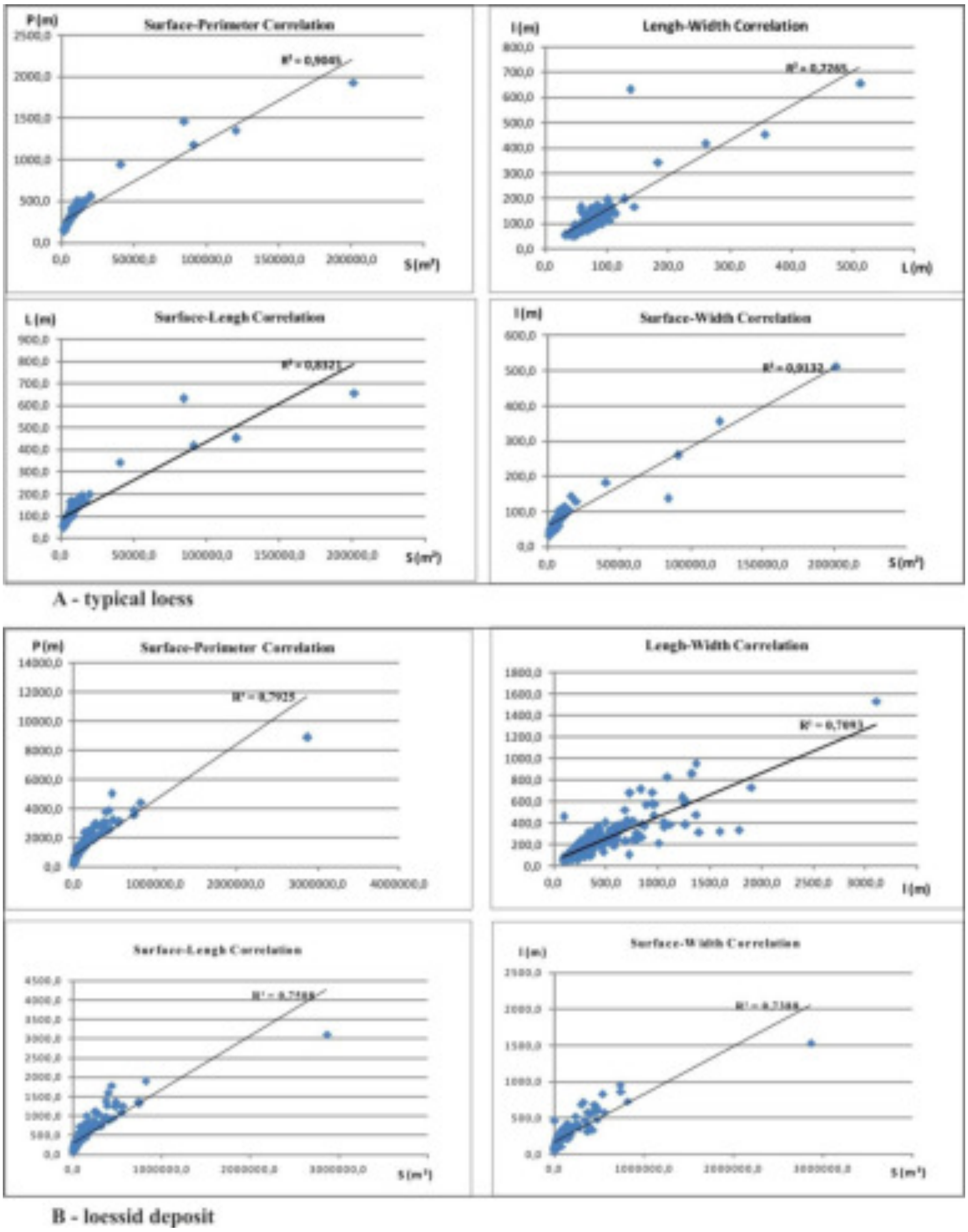

Fig. 7 . **Correlation of parameters of the micro-depressions developed on loess (A) and on loess-like deposits (B) in Călmățui basin.**

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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