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PEDOGENESIS AND QUATERNARY SEDIMENTOGENESIS IN NORTHERN-DOBRUDGEA (SOUTH-EASTERN PART OF ROMANIA)

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Abstract: The Northern Dobrudgea consists of Palaeozoic and Triassic formations, geologically being one of the oldest regions of Romania. In this area, in post tertiary times, pedogenesis and sedimentogenesis may be differentiated into two main periods: before and synchronous with quaternary loess deposits and soil development. During the first period, the sedimentogenesis seems to have been weak and pedogenesis strong. The soil cover developed on the account of Paleozoic and Triassic rocks. The pedogenesis would be of "denudational – compensative" type. The soil cover developed then, have been subsequently destroyed by erosion or buried beneath quaternary sediments (mainly loess deposits) either. The remnants preserved on some cretaceous surfaces (of residual relief) witness that the soils were deep, clayey and red similar to the present day Haplic Luvisols (Rhodic-Abruptic). They may belong to the end of Pliocene or to the beginning of Quaternary. The second period is characterized by the interference of pedogenesis and intense sedimentogenesis generated by wind-borne dust fall-out and formation of sequences consisting of soils, loess and loess-like deposits. The loess layers and associated fossil-soils strips formed during that period may be considered as complex entities and called "Pedolithological complexes". The pedogenesis of this period is of "sedialternating" type. This means that the periods with prevailing pedogenesis alternated with those of prevailing sedimentogenesis. The thickness of "pedolithological complexes" varies from 3-5 m on highlands up to 15-25 m in low-lying areas and inner depressions of the region. The upper part of them is of Würmian and Holocene age but some basal layers may be Rissian even Mindelian. For spatial juxtapositions of palaeosols and actual soils the term "chronopedogeographic discontinuity or contrast" has been introduced.

Key words: pedogenesis, Quaternary sedimentogenesis, loess and loess-like deposits, fossil soils, Northern Dobrudgea

1. INTRODUCTION

Although often viewed as distinct and even opposed processes, however both pedogenesis and sedimentogenesis are strongly interrelated. Erhart (1951) is credited as being the first author that, in the frame of his concept called "biorhexistasy" binds pedogenesis with sedimentogenesis, at least as concern the formation of sedimentary rocks. However, by far earlier Murgoci (1910) noticed that within areas with air-borne dust fall-out, soil development is going hand-in-hand with loess deposits formation. Subsequently, the idea of joining pedogenesis with sedimentogenesis makes way in the works of many authors, as: Lieberoth (1963); Dan and Yaalon (1968); Buol & all (1980); Gerard (1981); Arnold (1983, 1992); Protopopescu Pache & Spirescu (1963); Spirescu (1970); Conea (1967, 1968, 1970); Florea (1985, 1994, 2009); Munteanu & all (1997). Florea (2009), introduced the concept of "sedialternating pedogenesis" according to, in periglacial areas, periods of prevailing pedogenesis alternates with those of prevailing sedimentation, resulting in vertical sequences consisting of fossil soil strips separated by loess/loess-like deposits.

The main goal of this paper is to disclose the relationships between pedogenesis and quaternary sedimentogenesis in Northern Dobrudgea (Fig. 1), geologically one of the oldest regions of Romania. Both, the pre-quaternary as well as the quaternary pedogenesis and sedimentogenesis were investigated.

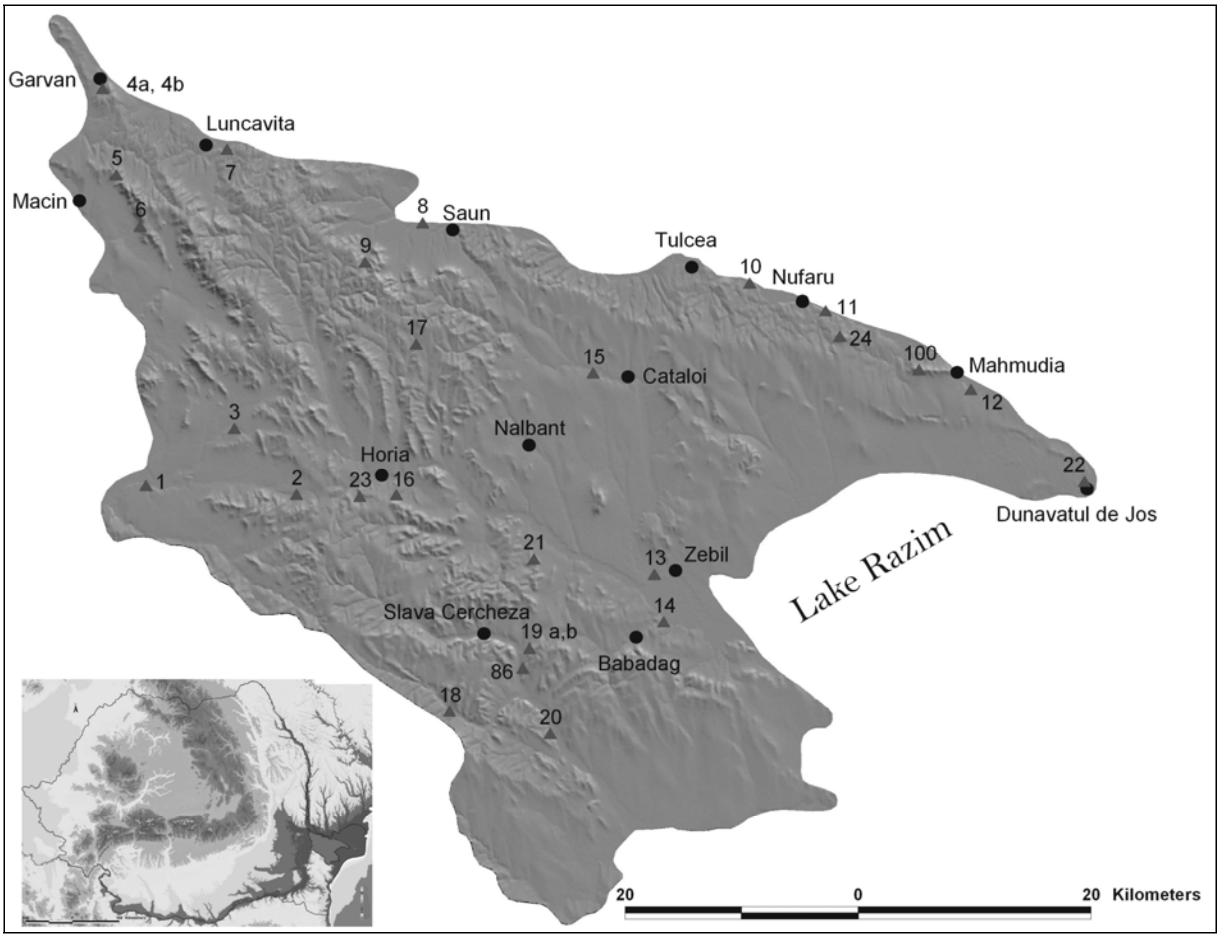

Figure 1. The map of the surveyed quaternary sections (14 section number in table 1)

In parallel, a new concept, called "pedolithological complexes" has been developed. This concept integrates in a single whole present day soils, fossil soils, sediments (e.g. loess) and regoliths as well.

2. MATERIALS AND METHODS

The present research is based on the idea that in Northern Dobrudgea two main periods of soil cover development could be identified: a) before and b) synchronous or posterior to the quaternary mantle (loess & loess-like deposits) sedimentation.

The paper is based on field descriptions and observations along with laboratory data provided by soil surveys undertaken in 1957, 1958[x], 1959[x], 1965[xx], 1966[xx], 1969 and 2009 years. About 26 sections (outcrops) provided by cliffs, gullies or open pits of 2-5 to 24 (25) m depth were examined, described, sampled and/or analyzed. Geographical position and some lithological – stratigraphic characteristics of these sections are presented in figure 1 and table 1, respectively. Figure 2 displays the overall legend of signs used for diagrams that are included in the text.

3. SOME GEOLOGICAL-GEOGRAPHICAL DATA ABOUT THE STUDY AREA

In geological and geographical Romanian literature (Murgoci, 1911; Brătescu 1912, 1936, Oncescu, 1959, Ianovici & all, 1961; Cotet, 1973; Mihăilescu, 1969) the part of Dobrudgea situated northward of the Pecineaga – Camena fault line is regarded as an important tectonic unit, being a remnant of an old Hercynico – Cimmerian catena nowadays reduced to a hilly and dissected table-land or highly peneplanized landscape. Only the North-Western part of the territory, the Măcin Mountains – 467 m absolute altitude, witnesses the old mountainous relief.

In the geological constitution of Northern Dobrudgea participates strongly folded geo-synclinal formations of Palaeozoic and Triassic age partly overlaid by upper Cretaceous deposits. About 80 percent of the Pre-Quaternary terrains are covered by loess and loess-like deposits (Munteanu, 1997).

[x] with participation of pedologist-geographer, N. Ionescu
[xx] with participation of pedologist-geographers Gh. Babos & Maria Corhea (Munteanu)

Table 1. Sections (profiles) in Quaternary deposits (loess & loess-like) surveyed in Northern Dobrudgea (SE part of Romania)

Nr. crt.	Location (see fig.1)	Thickness (m)	Nr. of fossil soils	Absolute altitude (m)	Geomorphic unit	Observations
Western sector						
1	V, Traian	25	1 (?)	30	Side stepped plain - Măcin	-
2	Praporgescu	5-15	1 (?)	120	Măcin Mountains	with siliceous gravel
3	V, Cerna	6	1 (?)	70	idem	idem
4 a,b	S Garvăn	5-10	2 (?)	60	idem	with fluviatile deposits
5,	Pricopan (summit)	2	-	250	idem	with granitic gravel
6	Pricopan (Suluc Valley)	5	-	100	idem	idem
Northern sector						
7	E Luncavița	12	1 (?)	20	Side stepped plain Luncavița	-
8	V, Saun	10	1	15	Side stepped plain Isaccea	underlain by fluviatile deposits
9	V, Niculițel (Badila)	6-7	2 (?)	130	Niculițel hills	with siliceous gravel
10	V, Malcoci	12	2	15	Tulcea hills	-
11	E, Nufărul	24	6	28	idem	-
12,	E, Mahmudia	18	4	30	idem	-
South-Eastern and Central sectors						
13 (1)	S, Zebil	6	1	7	Razelm plain	with deep gleying
14 (2)	E, Babadag	15	5	16	Babadag table-land	idem
15	V, Cataloi	11	5	65	Nalbant Depression	-
16	S, Horia	9	2	90	Babadag table-land	with siliceous gravel
17	N, Valea Teilor	2-5	1	240	Niculițel hills	idem
18	E, Baspunar	3	1-3	280	Babadag table-land	-
19 a,b	E, Slava Cercheză	3-5	1-3	200	idem	-
20	S, Slava Rusă	9	2	180	idem	-
21	S, Turda	5	1	50	Tulcea hills	with pebbles
22	N, Dunavățul de Jos	5	1	20	idem	-
23	Cloşca	12	1	95	Babadag table-land	with calcareous gravel
24	Beilia Mare	1	-	150	Tulcea hills	schists & sandstone

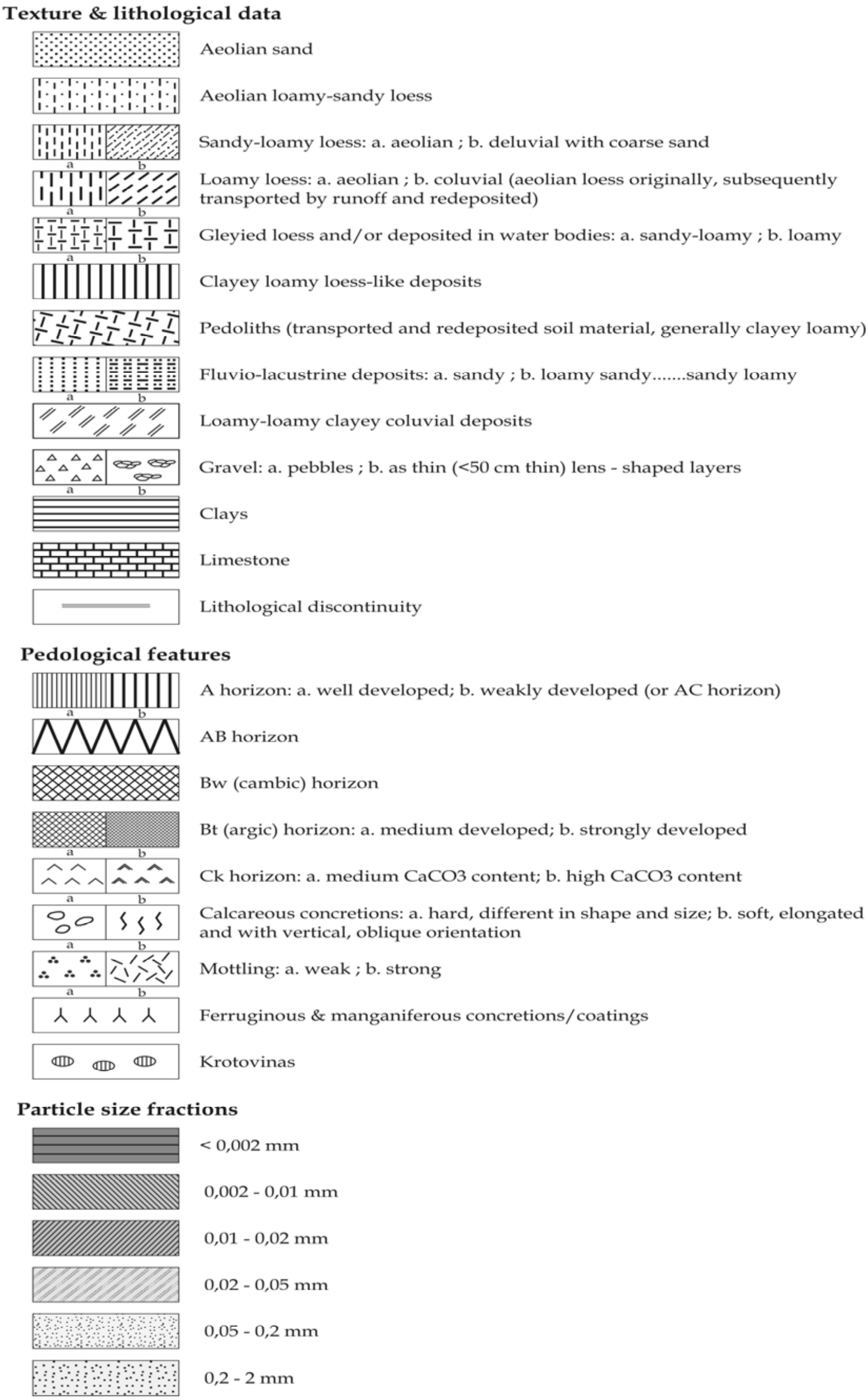

Figure 2. General legend of signs used in diagrams of soils & Quaternary sections

4. PEDOGENESIS PREVIOUS TO THE FORMATION OF LOESS/LOESS-LIKE MANTLE

The main part of the soil cover, developed before the loess/loess-like deposits have been laid down has been removed through water erosion or buried at great depths or e.g. on the low-lying areas surrounding the Razim lake, drowned as effect of Black Sea level rise (Brătescu, 1912, 1936; Panin, 1983) combined with epirogenetical sinking movements in the last part of Quaternary (Murgoci, 1911).

Nevertheless, remnants of the old soil cover are fairly frequent. They occur on Palaeozoic and Triassic/Cretaceous terrains, as clayey or clayey loamy, reddish materials, from underneath loess mantle or even at the ground surface either, in areas (on residual landforms, slopes, summits, inselbergs) where the loess could not have been formed or has been formed and subsequently removed by water/wind erosion. The frequency of these materials is higher on calcareous surfaces and lower on crystalline ones.

4.1. Pre-loessic soil cover

In figure 3 and 4, two cross-sections with contrasting soils – preloessic and actual ones (developed on loess deposits) are presented. Figure 3 shows a relatively strongly skeletic, Leptic Luvisol (p.24 Beilia Mare) developed on crystalline schists associated with a Vermic – Calcic Chernozem developed on neighbouring loess deposits (p.100 Beştepe). By contrast (in fig. 4) one can see a deep (≥ 2 m thick), Haplic Luvisol (Rhodic-Abruptic) developed on limestone (p.19a Slava Cercheză) that consist of a strongly red, clayey material with > 60%

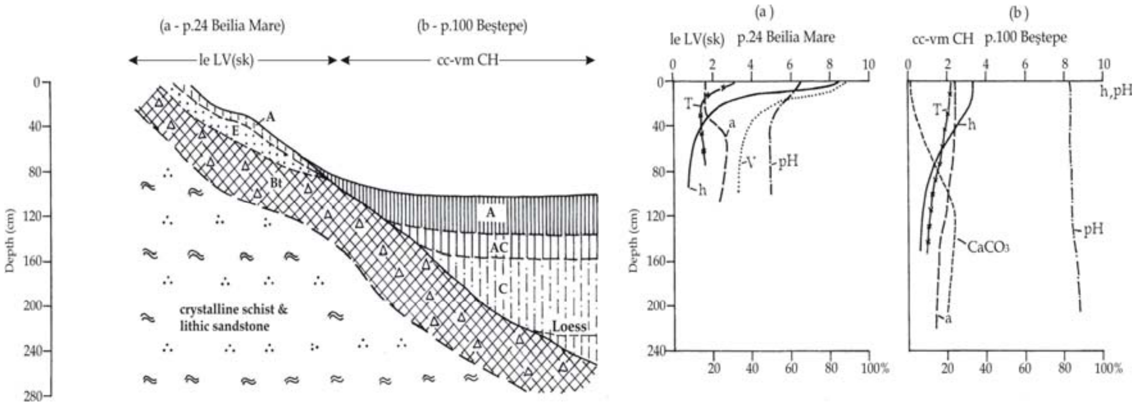

Figure 3. Cross-section and diagrams showing Leptic Luvisols (strongly skeletic) developed on crystalline schists (a) associated with Calcic-Vermic Chernozem developed on loess (b). Legend of physico-chemical characteristics: a – clay (%), h – humus (%), T – CEC (me/100 g soil), V – base saturation (%), pH – reaction (pH units), $CaCO_3$ – lime (%)

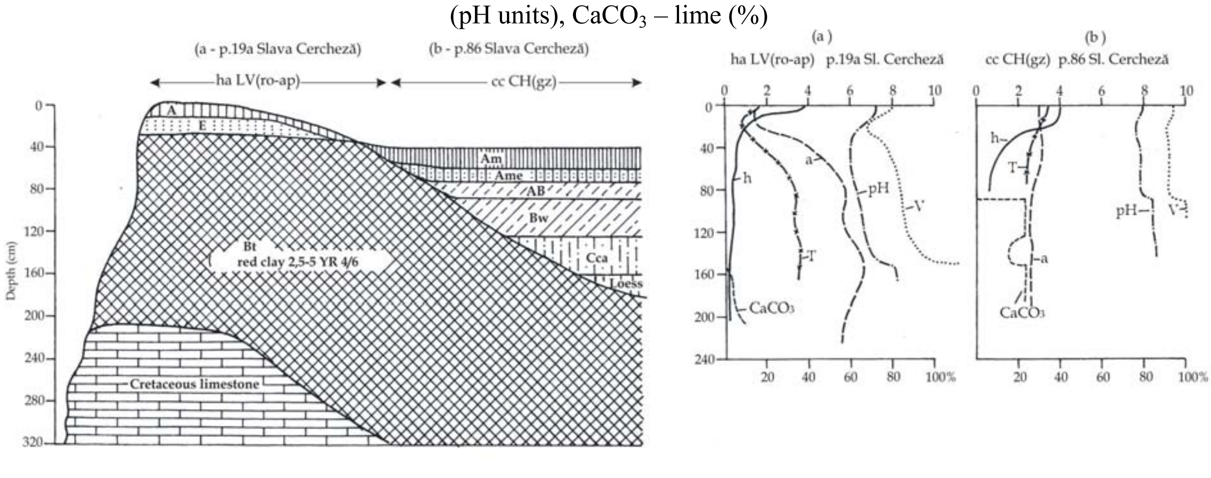

Figure 4, Cross-section and diagrams showing Haplic Luvisols (Rhodic-Abruptic) developed on Cretaceous limestrone (a) associated with Calcic Chernozems (greyic) developed on loess (b). Legend of physico-chemical characteristics: a – clay (%), h – humus (%), T – CEC (me/100 g soil), V – base saturation (%), pH – reaction (pH units), $CaCO_3$ – lime (%)

< 0,002 mm fractions; while on the immediately adjacent loess deposits, the actual soil is a Calcic Chernozem (greyic) (p.86 Slava Cercheză).

The pre-loessic soils (p.24 Beilia Mare and 19 a Slava Cercheză) appear as exhumated ones formed in wetter and perhaps warmer climatic conditions, probably prevalent in Northern Dobrudgea before the loess mantle deposition. They contrast strongly with the immediately neighbouring soil – Chernozem – developed on loess that corresponds to the present day bioclimatic conditions, forest steppe respectively. Such kind of juxtapositions could be called "chronopedogeographical discontinuities or contrasts". They are specific to areas within which present day soils are juxtaposed to vestiges from an older soil cover.

In figure 5 the stratigraphic, pedolithological and particle size columns of the profile no. 19a Slava Cercheză are presented.

Palaeopedological considerations**.** By analogy with the red clays that underlie the loess mantle from Southern Dobrudgea and from Danube Delta the red soils from Slava Cercheză could be attributed to Villafranchian (Liteanu, 1961, quoted by Popovăț & all, 1964) or to the period comprised between Villafranchian and the beginning of Mindel glacial equivalent to the Saint-Prestien-psephitic complex (Grumăzescu & Grumăzescu, 1967).

The red clay soils from Slava Cercheză could be bound with the paleogeographic history of this part of Babadag Tableland, where during Pliocene a karst relief developed (Marin, 1976). Red formations have been identified in many other places in Northern Dobrudgea e.g. Cataloi, Horia, Mahmudia; all those overlie Triassic limestone.

More difficult to be estimated is the age of pre-loessic soil from Beilia Mare developed on crystalline schist and sandstone. Being thinner, this soil seems to be younger than that of Slava Cercheză. Anyway it's mode of appearance from underneath loess mantle, is an argument that it has been formed before the loess deposition.

The strong development of the pre-loessic pedological mantle seems to be connected with a higher altitude of Dobrudgea tableland. In Lower Quaternary, according to geological literature (Oncescu, 1959) before the loess sedimentation, the Dobrudgea tableland was much raised than today and at the same time dominated by a more wet climate. The lowering of the Dobrudgea basement in the Upper Quaternary has had as effect the aging and silting of rivers valleys and installation of present day steppe climate with less clay enriched soils.

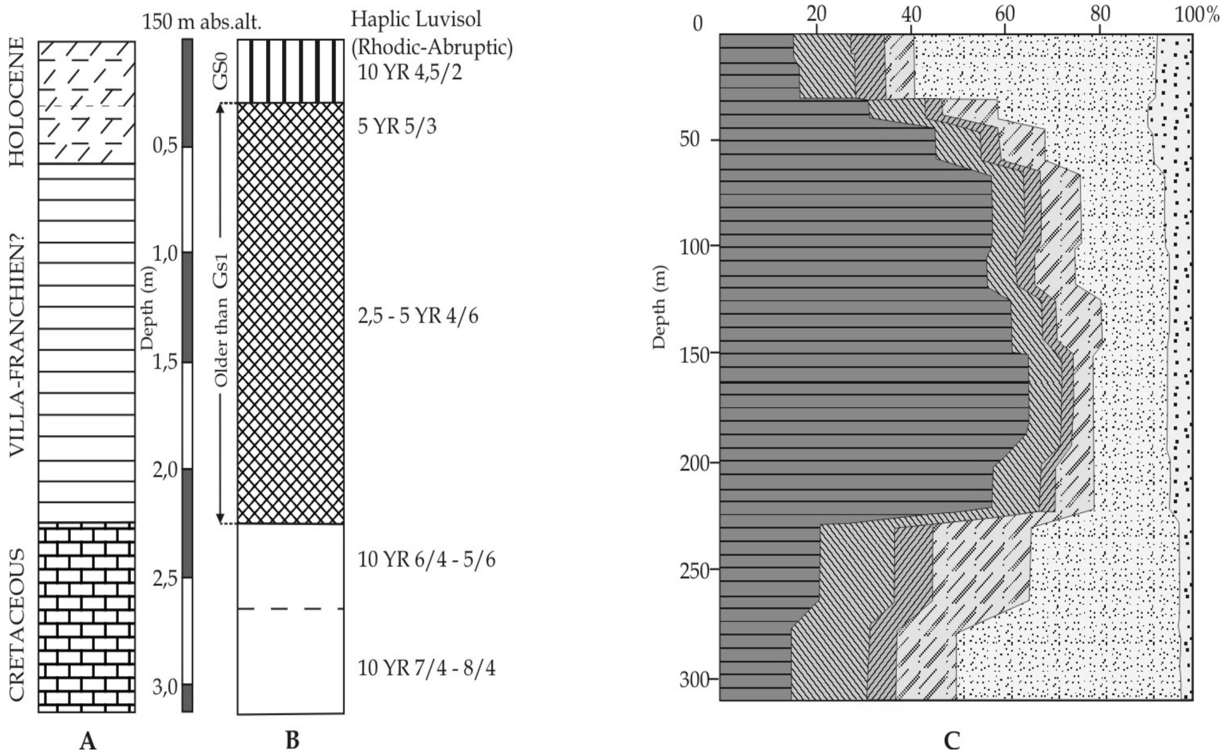

Figure 5. Pre-loessic soils from Northern Dobrudgea – profile no. 19a Slava Cercheză: stratigraphic (A), pedolithological (B) and particle size distribution columns (C)
(For legend of signs see fig. 2)

5. PEDOGENESIS SYNCHRONOUS WITH THE FORMATION OF THE LOESS MANTLE (LOESS & LOESS-LIKE DEPOSITS)

5.1. Some principial problems concerning pedological interpretation of loess deposits and the fossil soil inserted in them

In almost all contemporary approaches the development of loess deposits and of associated fossil soils are viewed as independent processes. However, based on an idea issued by Murgoci (1910) which says that "the loess is itself an old soil more or less metamorphosed", Florea (2009) developed a theory according to "during the Quaternary, in periglaciated areas, both wind borne dust fall-out that generates loess deposits and soil development have been permanent and concurrent, but with opposed intensities depending on the geographical position of the site against the ice cap". The sequences of fossil soils strips and loess layers being the result of the so called "sedialternating type" of pedogenesis in which periods of prevailing pedogenesis alternate with periods of prevailing sedimentation (Florea, 2009).

As consequence of this theory, we consider that the sequences (stacks) consisting of loess layers and fossil soils should be viewed as a single entity that may be called "pedolithological complexes". The idea to include the soil in an enlarged vision that integrates it with surface deposits, e.g. loess, transported and redeposited materials, regoliths, weathering products of hard rocks, a.o. that further may serve as soil parent material is not quite a new one. A similar approach has been used even since the beginning of modern soil science by the "agro-geological school" (Fallou, Richthofen) that viewed the study of soil as a branch of geology (quoted by Florea, 2000); moreover, Ibanez and Boixadera (2002) emphasizes that already Ramann (1928), Glinka (1931) and Cline (1961) were interested in an integrated classification of the soil –regoliths materials.

As concern the use of the term "fossil soils" for naming the darker strips found in loess deposits Murgoci (1910) considered that it is "not totally adequate". However, we believe that there are no serious reasons to drop it. The argument is given by Murgoci himself when he says that "…. all characteristics of (these) old soils are so well preserved so we can distinguish and identify the soil type…". Therefore in this paper the term "fossil soils"[x] will be further used, thus continuing the tradition of Romanian soil science literature (Brătescu, Florov, Bucur, Popovăţ, Conea, Florea, Spirescu, Asvadurov, a.o.).

The horizons of fossil soils are noted according to the provisions of SRTS-2003 and the loess layers are assimilated to C horizons. In the diagrams and tables the strips of fossil soils are designated with the letters GS (soil group) and are top down numbered. The actual (surface) soil is not counted (Popovăţ & all, 1964). For naming soils, WRB-SR-2006, terms have been used.

5.2. General features of the Quaternary mantle from Northern Dobrudgea

The first data concerning Northern Dobrudgea's Quaternary deposits are provided by Peters (1867), Murgoci (1904, 1911) and Popovăţ (1938), followed by those issued by Liteanu – Ghenea (1966) and Coteţ (1969). Grumazescu & Cornelia Grumazescu (1967) published valuable lithologic and palinologic data, while Munteanu (1972, 1982, 1997), displayed a comprehensive information that refers to all kinds of soil parent materials of this region, loess & loess-like deposits being included.

Within Northern Dobrudgea the Quaternary loess and loess-like deposits form a quasi-continuous blanket whose thickness and lithological characteristics differs depending on topography, lithological substratum and of the pre-existing relief dissection (Table 1). Thus on the low-lying, flat areas neighboring the Danube Valley and the Razim Lake, as well as on the peneplanized Tulcea hills and in the gulfs or inland depressions e.g. Niculiţel, Isaccea-Luncaviţa and Horia-Nalbant, the loess deposits may reach thickness as 20-25 m or even more. By contrast, in stepped areas e.g. Măcin mountains, Niculiţel hills, Babadag Tableland they rarely exceed 3-5 m thickness. Part of them were washed out from summits and steep slopes and redeposited as loess-like deposits often enriched in coarse fragments on the foot-slopes and valley bottoms. An important role in loess particle size and deposit thickness variation is played by the general configuration of the landforms and their orientation against the prevalent winds. Usually the wind exposed slopes are naked while the sheltered ones bear a thick loess mantle (Fig. 6).

[x] The term fossil soil has been preferred. That of "buried soil" used in taxonomies refers to a contemporary soil covered with layers of recent or subactual deposits

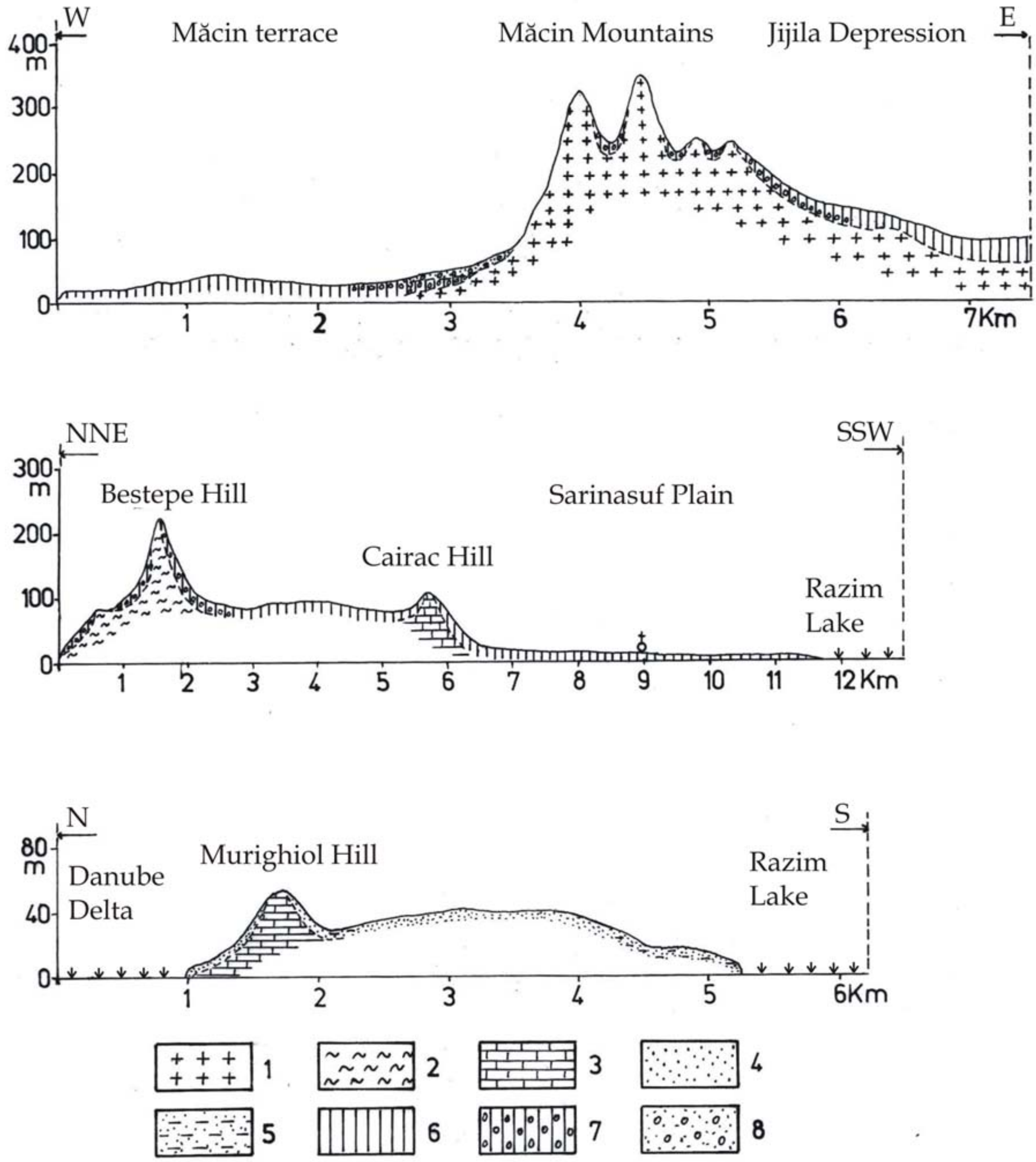

Figure 6. The relationships between the residual relief and head deposits in Northern Dobrudgea
Legend: 1. Granite; 2. Epi-metamorphic micaschists; 3. Hard limestone; 4. Sandy-loamy sandy deposits; 5. Loamy-sandy loess; 6. Loamy loess; 7. Loamy, loess-like deposits with silicatic gravel; 8. Gravelly colluvium from granite

5.3. Pedolithological complexes

The following five kinds of pedolithological complexes were distinguished in Northern Dobrudgea:

a. Aeolian loessic
b. Aeolian loessic over lacustrine loessic
c. Aeolian/Colluvial, loessic & lacustrine – riverine sandy
d. Aeolian sandy
e. Colluvial loess-like

5.3.1. Aeolian loessic pedolithological complexes

These complexes represent the main component of the Quaternary mantle in Northern Dobrudgea. They are predominant on the lower sidesteps, both on the Danubian side of the region (Măcin – Traian – Dorobanțu – Peceneaga; Luncavița – Isaccea – Tulcea – Mahmudia) and on the maritime one (northward of Razim lake) as well as within inland depressions, Horia – Nalbant, and in the peneplanized Tulcea hills.

According to the predominant texture and frequency/development of the fossil soils strips two facies have been recognized: one predominantly sandy loamy and with relatively frequent but thin fossil soil and other with loamy-clayey-loamy texture and thick, strongly developed fossil soil strips.

5.3.1.1 Aeolian-loessic, sandy loamy, pedolithological complexes

Representative for this kind of Quaternary mantle is the section no. 11 (421) Nufăru, located at 28 m absolute altitude on the Danube valley cliff (Fig. 7) close to the eastern edge of Nufăru Village (Fig. 1). From stratigraphic and pedolithological columns (Fig. 8A and 8B) respectively it results that 55% of this section consists of yellowish (2,5 Y) sandy loamy loess while the remaining 45% is occupied by soil strips. Besides present day soil from the surface (a Kastanozem) this section comprises seven soils: five of which with reddish coloured (7.5 YR) Bt horizon with clay coatings, (Luvisols ?) one with Bw horizon (a Chernozem ?) and a weakly expressed fossil soil strip, perhaps a Rhegosol. The soil from the bottom (GS_7) marks a clear lithological discontinuity. It contains a high amount of silicatic gravel announcing the nearness of the underlying Palaeozoic rocks.

Within the first 16 m depth, the thickness of both loess layers and fossil soils is remarkably constant 2.4 – 4.0 m and 1.2-1.8 m respectively. Beneath that depth the strips of fossil soils became closer each other and the loess layers thinner.

The top-down variation of the particle-size composition (fig. 8C, table 2) shows an astonishing uniformity: the clay (<0.002 mm fraction) content does not overcome 20 (11-20) % in loess layers and 32 (32.2) % in the Bt horizons of fossil soils. The difference in clay content between fossil soils and overlying loess layers is of 3% in the case the first fossil soil and reaches a maximum of 12% in the case of the fourth one. The first 8 m of this section have less clay and silt and a higher sand content than the layers beneath.

The variation with depth of humus and $CaCO_3$ content (Fig. 8D, Table 2) displays specific behaviour. The humus does not exceed 0.4 percent (except the top layers of the actual soil) but shows an extra 0.1-0.2 % in the fossil soils face to that of loess layers. This means that the organic matter content of fossil soils, although strongly diminished, through mineralization, did not reached yet the level of that from the adjacent loess layers.

The top-down variation of $CaCO_3$ content shows high amplitudes: from 7-20% corresponding to loess layers, up to 49% in some B and C horizons that appears as true petrocalcic horizons.

Palaeopedological interpretation. According to the current data from the Romanian Quaternary literature (Liteanu – Ghenea, 1966; Cotet, 1969; Grumazescu & Cornelia Grumazescu, 1967; Conea, 1970, Munteanu, 1997) the stack of loess and fossil soils from Nufăru (till 23 m depth) might belong to upper Pleistocene (Würm) and Holocene.

The net prevalence of silt and sand fractions (70-85%) pleads for an aeolian sedimentation originating from the alluvial materials of the neighbouring zone: the Danube Valley and Delta, which during the last part of Pleistocene have been dry, because the Black Sea level was 100-120 m lower than the present day one (Panin, 1974).

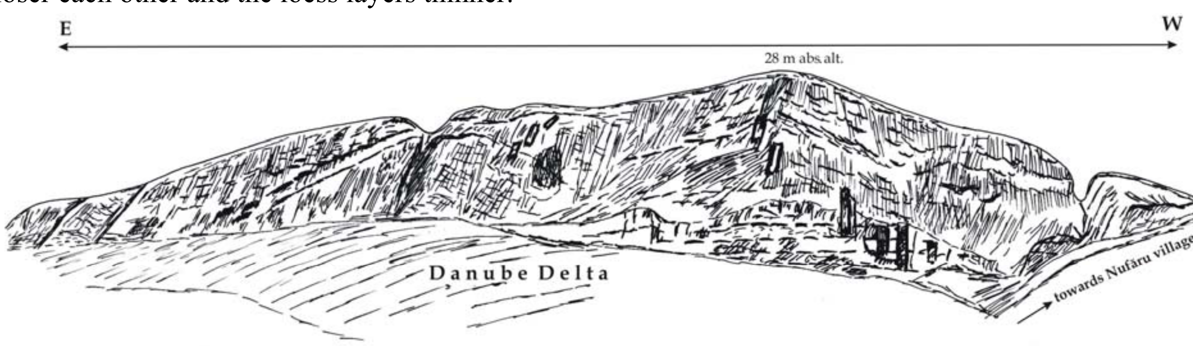

Figure. 7. Sketch of the cliff toward the Danube Delta from where the Quaternary section 11 (421) Nufăru has been sampled (cca. 15 km Eastward from Tulcea Town)
Legend: ▨ - pits for sampling; ------ fossil soil strips

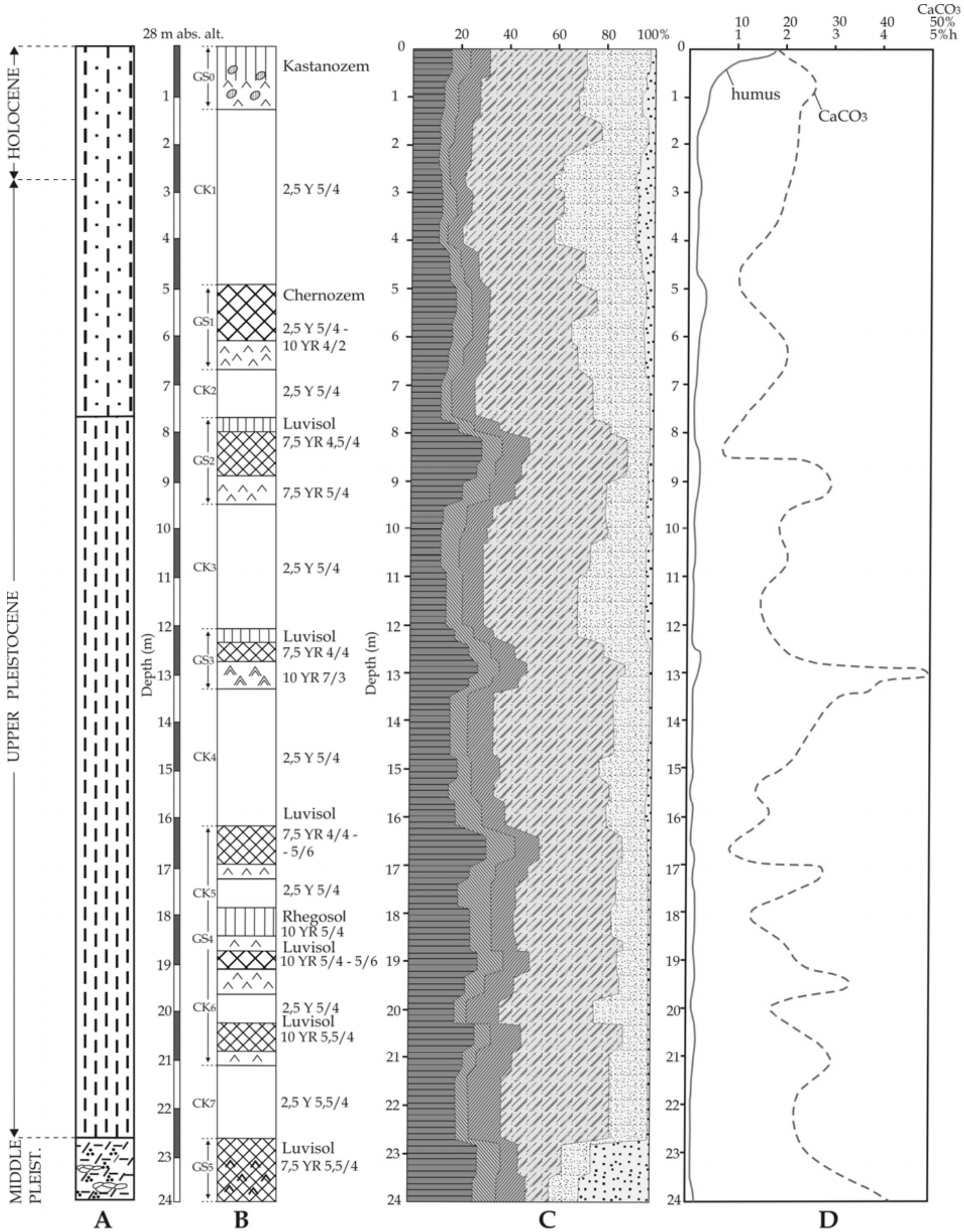

Figure 8. Quaternary section no. 11(421) Nufărul: A – stratigraphic column; B – pedolithological column; C – Particle size fractions column; D – Humus and $CaCO_3$ content (%) column, (For legend of signs see fig. 2)

According to the idea issued by Murgoci (1910) and subsequently developed by Florea, (1994, 2009) the fossil soils strips do not mark a cease of aeolian dust fall-outs, but only a mitigation of them, which joined with wetter and perhaps warmer climatic regimes favored an intensification of pedogenetic process in detriment of the sedimentogenetic one.

Table 2. Quaternary section 11 (421), 500 m Eastward Nufăru village

No.	Horizon (layer)	Depth (cm)	Particle size (mm; %)				Humus (C x 1,72) %	$CaCO_3$ %	Age ky BP
			<0,002	0,002-0,02	0,02-0,2	0,2-2,0			
1	Ap	0-20	16,4	15,1	68,4	0,1	1,2	19,2	HOLOCENE 10 -12
2	Am	20-36	15,7	16,0	68,0	0,3	0,9	21,7	
3	AC	41-58	15,7	16,2	67,8	0,3	0,7	24,6	
4	GS$_0$ Cca$_1$	60-80	13,3	15,8	70,6	0,3	0,5	26,0	
5	Cca$_2$	100-120	12,7	15,5	71,5	0,3	0,4	23,1	
6	Cca$_3$	160-180	11,3	13,1	75,2	0,4	0,2	22,5	
7	Cca$_4$	230-250	10,9	13,2	75,5	0,4	0,2	21,6	
8	bCK$_1$ (L$_1$)^x	265-285	11,9	9,8	77,7	0,6	0,3	20,6	UPPER PLEISTOCENE 128 (132) – 10 (10-12)
9		310-330	12,8	12,0	74,6	0,6	0,2	19,7	
10		370-390	11,5	10,1	77,8	0,6	0,2	17,1	
11		430-450	16,0	11,9	71,8	0,3	0,2	11,6	
12		470-490	16,6	18,2	70,6	0,6	0,3	10,6	
13	bA	500-520	19,2	14,0	66,5	0,3	0,4	11,3	
14	GS$_1$ bBv	560-580	17,6	15,2	66,8	0,4	0,3	15,9	
15	bCca	630-650	15,1	15,5	69,0	0,4	0,2	20,7	
16	bCK$_2$	700-720	12,8	13,1	74,0	0,1	0,2	16,4	
17	(L$_3$)^x	780-800	19,3	16,3	64,0	0,2	0,2	10,5	
18	bA	825-845	29,5	19,0	51,4	0,1	0,3	7,0	
19	GS$_2$ bBt	860-880	26,9	18,7	63,9	0,5	0,3	27,5	
20	bCca	900-920	21,2	22,0	56,7	0,1	0,2	29,4	
21	bCK$_3$ (L$_3$)^x	950-970	13,7	20,0	66,2	0,1	0,2	20,5	
22		1000-1020	13,3	19,2	67,4	0,1	0,2	19,5	
23		1050-1070	12,4	16,9	70,6	0,1	0,2	20,7	
24		1130-1150	14,4	15,6	69,9	0,1	0,1	15,5	
25	bA	1210-1230	18,6	15,9	65,3	0,2	0,1	16,7	
26	bBt	1240-1260	27,4	16,2	56,0	0,4	0,3	19,4	
27	GS$_3$ bCca$_1$	1280-1300	28,4	19,8	51,6	0,2	0,3	48,9	
28	bCca$_2$	1310-1330	24,3	20,7	54,8	0,2	0,1	38,2	
29	bCca$_3$	1360-1380	17,0	17,2	65,7	0,1	0,1	28,6	
30	bCK$_4$ (L$_4$)^x	1480-1500	20,0	17,7	62,2	0,1	0,2	20,8	
31		1530-1550	17,1	18,1	64,8	0,0	0,1	14,3	
32		1570-1590	18,9	20,2	60,8	0,1	0,1	16,4	
33	bA	1620-1640	20,1	19,8	58,9	0,2	0,1	12,9	
34	GS$_4$ bBt	1650-1670	32,2	21,4	46,2	0,2	0,2	9,4	
35	bCca	1700-1720	24,9	23,6	51,5	0,0	0,1	27,9	
36	bCK$_5$ (L$_5$)^x	1740-1760	20,0	24,0	56,0	0,0	0,1	23,1	
37	bA	1790-1810	24,9	18,1	56,9	0,1	0,2	13,2	
38	GS$_5$ bA	1860-1880	24,8	19,7	58,5	0,0	0,2	20,2	
39	bBt	1890-1910	28,0	21,4	50,5	0,1	0,2	22,2	
40	bCca	1930-1950	23,0	20,3	56,7	0,0	0,2	33,4	
41	bCK$_6$ (L$_6$)	1990-2010	18,5	18,4	63,0	0,1	0,2	17,5	
42	GS$_6$ bB	2040-2060	27,1	19,7	52,9	0,3	0,2	24,4	
43	bCca	2090-2110	22,1	21,1	56,7	0,1	0,1	29,9	
44	bCK$_6$ (L$_7$)	2160-2180	18,9	18,7	62,3	0,1	0,1	23,6	
45	GS$_7$ bB	2280-2300	28,0	17,5	34,5	20,0	0,1	24,1	MIDDLE PLEISTOCENE 440 (428) – 128 (132)
46	bCca	2380-2400	27,0	21,0	30,7	21,3	0,2	41,9	

^{x} L_{1-6} Loess layers were assimilated as C horizons

The higher clay content in fossil soils may be attributed to both: changes in the particle size composition of wind-borne materials (that became finer during wetter periods) and also to pedogenetic processes (clay formation) as well.

The values of 1.2-1.4 of the textural differentiation index within the fossil soil profiles are close to that of contemporary Luvisols from the forests of Niculițel and Măcin highlands. This fact shows that during the upper Pleistocene the wet phases were not too different from those of the present day ones met in the Northern Dobrudgea forests.

On the other side the occurrence of horizons with strong accumulation of $CaCO_3$ may be interpreted as being the effect of much dry phases, specific to arid climates, which are not met in present day Dobrudgea.

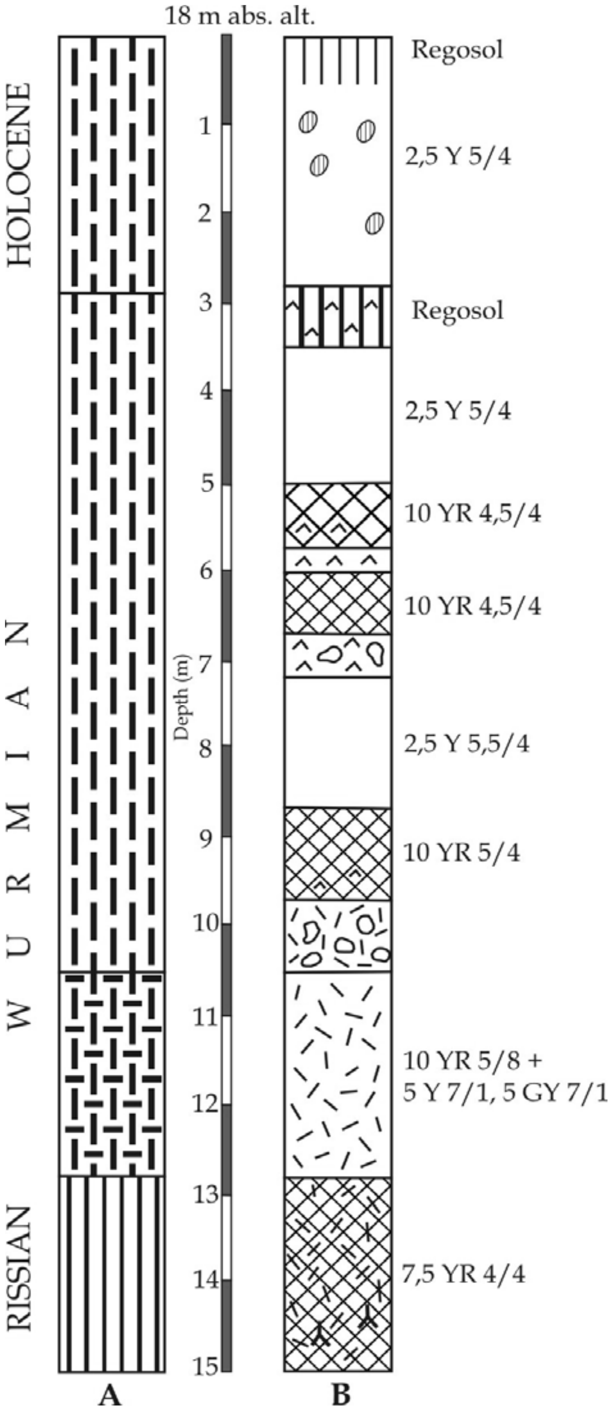

Figure 9. Quaternary section no. 14, Babadag: A – stratigraphic column; B – pedolithological column; (For legend of signs see fig. 2)

According to the average rate of loess sedimentation in upper Pleistocene (Würm) of 1.5-2.1 cm per century as it results from ^{14}C dating of loess deposits from Mărculesti – Eastern Part of the Lower Danube Plain (Munteanu, 1997) it seems that for formation of the 23 m sequence of loess layers and fossil soils from Nufăru required a period of 109 to 153 thousand years, a lag of time rather close to the age attributed to Upper Pleistocene – 128-132 thousand years (Manion, 1991). Based on the above criteria – the formation of each loess layer would necessitate 11 to 12 thousand years and each fossil soil strip between 5 to 7.5 thousand years.

As concern the development of Bt horizons of fossil soils, according to the estimation based on the data from a buried soil beneath a "Vallum Trajani" from Niculițel forests (Munteanu, 1982), the rate of clay formation in the Bt horizon is of about 0.2% per century. Because the difference in clay content of the Bt horizon against the overlying loess layer is of 8 to 12% it would result that formation of Bt horizons of fossil soils necessitated between 4000 and 6000 years.

Sections quite similar (but finner) to that described above have also been identified in the cliffs of Babadag Lake (Fig. 9) where the loess layers and fossil soils situated below 10 m are gleyied while the lowest fossil soils were sinked under the Babadag Lake waters following the last rising of the Black Sea level.

5.3.1.2. Aeolian-loessic , loamy-loamy clayey, pedolithological complexes

The main characteristic of this kind of Quaternary mantle is the loamy texture of loess layers. The number of fossil soil strips and their development is highly variable: from three and weakly developed until five and even more and with strong development as is the case in the Horia-Nalbant depression and around Babadag town.

Representative is the section no. 15 Cataloi (Fig. 10, A, B, C) located on the right side of Telița river valley (Fig. 1). Upon a thickness of 9.5 m, besides the present day surface soil (a chernozem), three complex strips of fossil soils and three loess layers occur. The first fossil soil is situated between 2 and 4.1 m depth and it consists of a strongly developed Bt horizon of reddish colour (5YR 4/6 – 3.5/4), with high clay (<0.002 mm) content – 47% in the upper part and 35% in the lower one, prismatic structure and periglacial wedges filled-up with loess at the upper boundary; large and indurated, vertically oriented $CaCo_3$ concretions are also present. The lower part of this soil is a Cca loamy, yellowish loess-like horizon (30% clay) with soft concretions and powdery $CaCO_3$ pockets.

Below 4,1 m until 7 m depth it follows a complex group of fossil soils that consists of three reddish, clayey (40-44% clay < 0,002 mm) Btk horizons, invaded by soft powdery lime, vertically oriented, oblongated pockets; between 5.0 m and 5,6 m depth occurs a Cca horizon dominated by lime, as hard concretions and oblongated soft pockets.

The lowest fossil soil, (below 8 m depth) is represented by a strong red (2.5-5 YR 4/4), clayey (52% clay < 0.002 mm) Bt horizon, in which black ferruginous and manganiferous coatings and concretions along with hard and soft lime pockets are present. By its features (colour, clay content and strong developed prismatic structure) this soil might belong to the same pre-loessic pedological mantle described previously in the section 19a from Slava Cercheză.

Paleopedological interpretation. The first two meters from the surface, in which the present day soil (a Calcaric Chernozem) is developed belongs to Holocene. The middle part of this section between 2 and 8 m depth consisting of fossil soil strips and loess layers may be attributed to Middle Pleistocene. The lowest part, below 8 m depth, may be of Villafranchian or Lower Pleistocene age, similar to red clays from Southern Dobrudgea and the red soil described in the section no. 19a from Slava Cercheză.

The Upper Pleistocene, largely represented in the section no. 11/421 Nufăru is absent. Taking into account the relative short distance (of less than 20 km) that separates the Cataloi section from the Nufăru one, this stratigraphic gap is hard to be explained. Another particular feature is the large participation of the soil material – 73%, against those of the loess layers – 27%. This means that during the formation of the Cataloi section, the pedogenesis largely prevailed against pure sedimentogenesis (if such a thing could exist).

5.3.2. Aeolian-loessic over lacustrine loessic, pedolithological complexes

Such kind of quaternary mantle consists of loamy aeolian loess deposits with one or two fossil soil strips, beneath which it follows a loess material that seems to have been deposited in water. This "lacustrine loess" has been previously described by Cotet (1969) in the Capaclia Valley southward of Isaccea town. A typical section of this kind is that of the lake Saun Cliff (Fig. 11, A, B, C) located westward from Saun Monastery (Fig. 1).

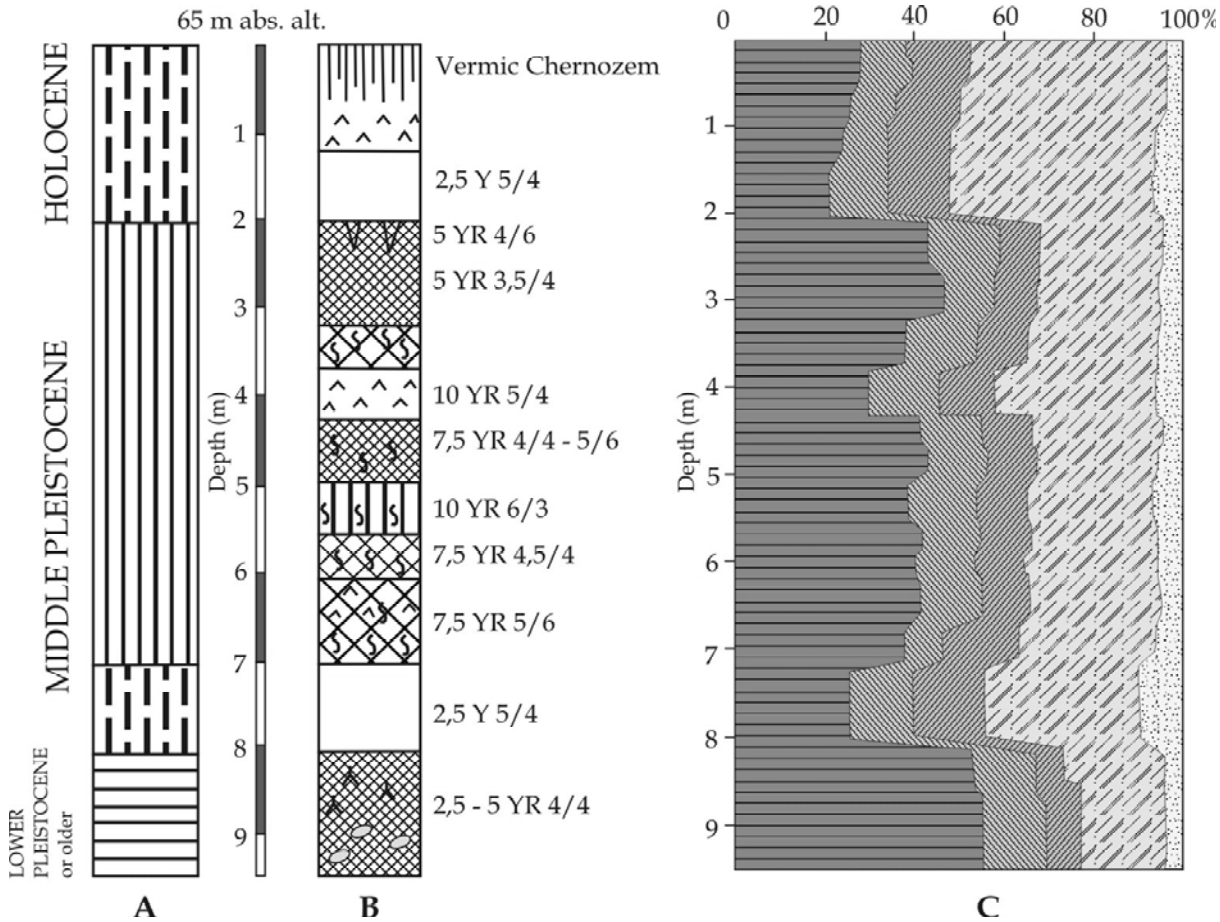

Figure 10. Quaternary section no. 15, 2 km W from Cataloi village: A – stratigraphic column; B – pedolithological column; C – Particle size fractions column
(For legend of signs see fig. 2)

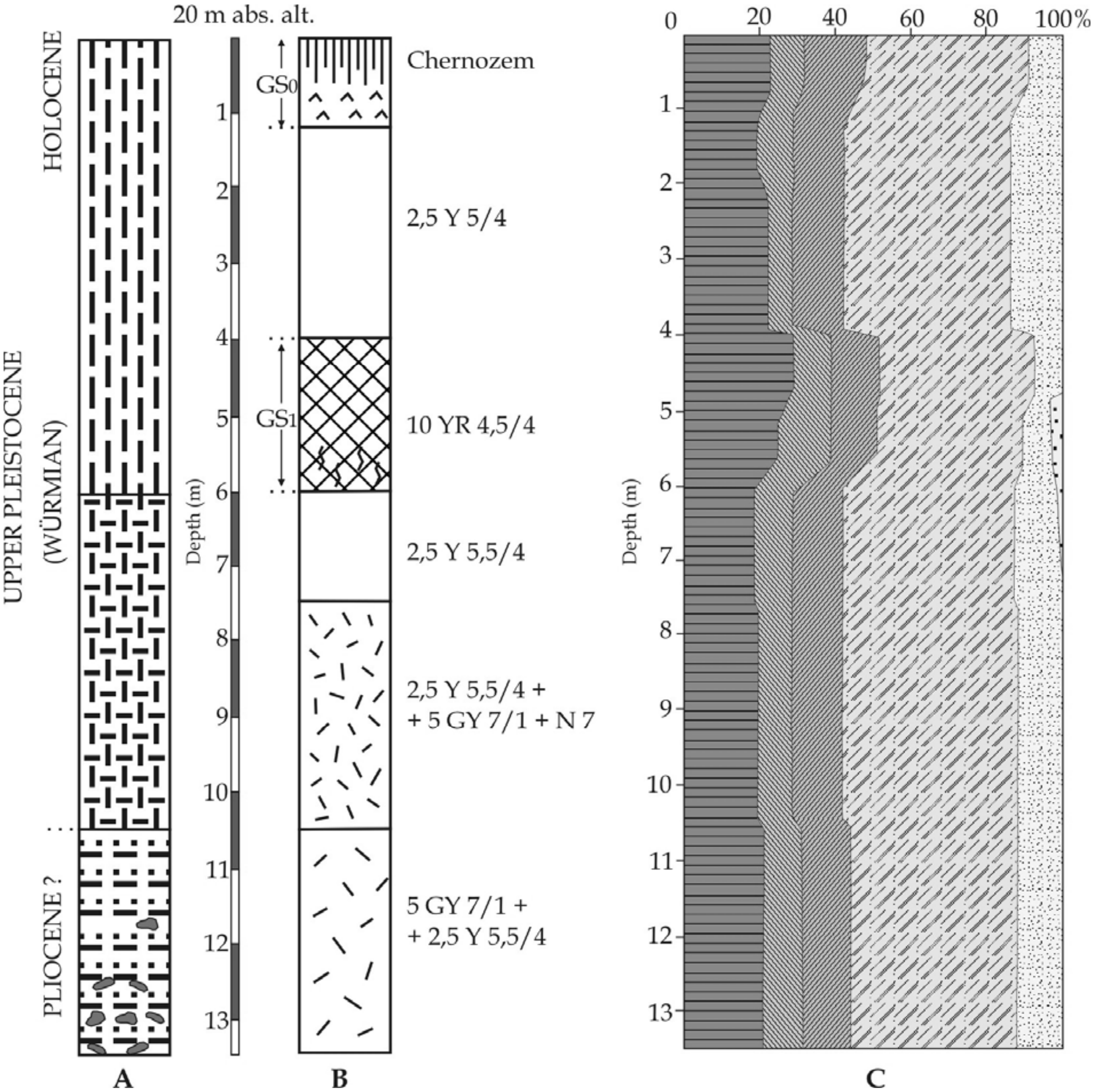

Figure 11. Quaternary section no. 8, Saun Lake cliff: A – stratigraphic column; B – pedolithological column; C – Particle size fractions column; (For legend of signs see fig. 2)

The first 6 meters of this section consists of a yellowish (2.5 Y 5/4) loamy loess deposit in whose upper 1.5 m there is a Calcaric Chernozem. Between 4 and 6 m depth occur two Cambic B horizons of yellowish reddish brown and yellowish brown colour respectively, and separated by a weakly developed Cca horizon. Between 6 and 7.5 m depth it follows a loamy, yellowish (2.5 Y 5.5/4) compact and unlayered loess-like material. Downward, between 7.5 and 10.5 m depth one continues with a very fine parallel layered loess-like deposit of olive (2.5 Y) and greenish gray (5 GY) colour. The subjacent material form 10.5 m to 13.0 m depth is represented by greenish gray (5 GY) mud with yellowish (2.5 Y) mottles and large $CaCO_3$ concretions. Below 13 m depth occurs a grayish clayey deposit which Cotet (1957, quoted by Grumăzescu & Grumăzescu, 1967; 1969) found to be fossiliferous.

The main problem of this section is if the material comprised between 6 and 10.5 m depth is loess deposited in a water body or is sub-aerial loess subsequently gleyied following the recent rise (post-wurmian) Black Sea level. The textural uniformity of this deposit pleads for the first hypothesis. However an aeolian sedimentation in a sub-aerial environment appears also plausible at least for the material comprised between 6.0 m and 7.5 m depth where the deposit does not show layering.

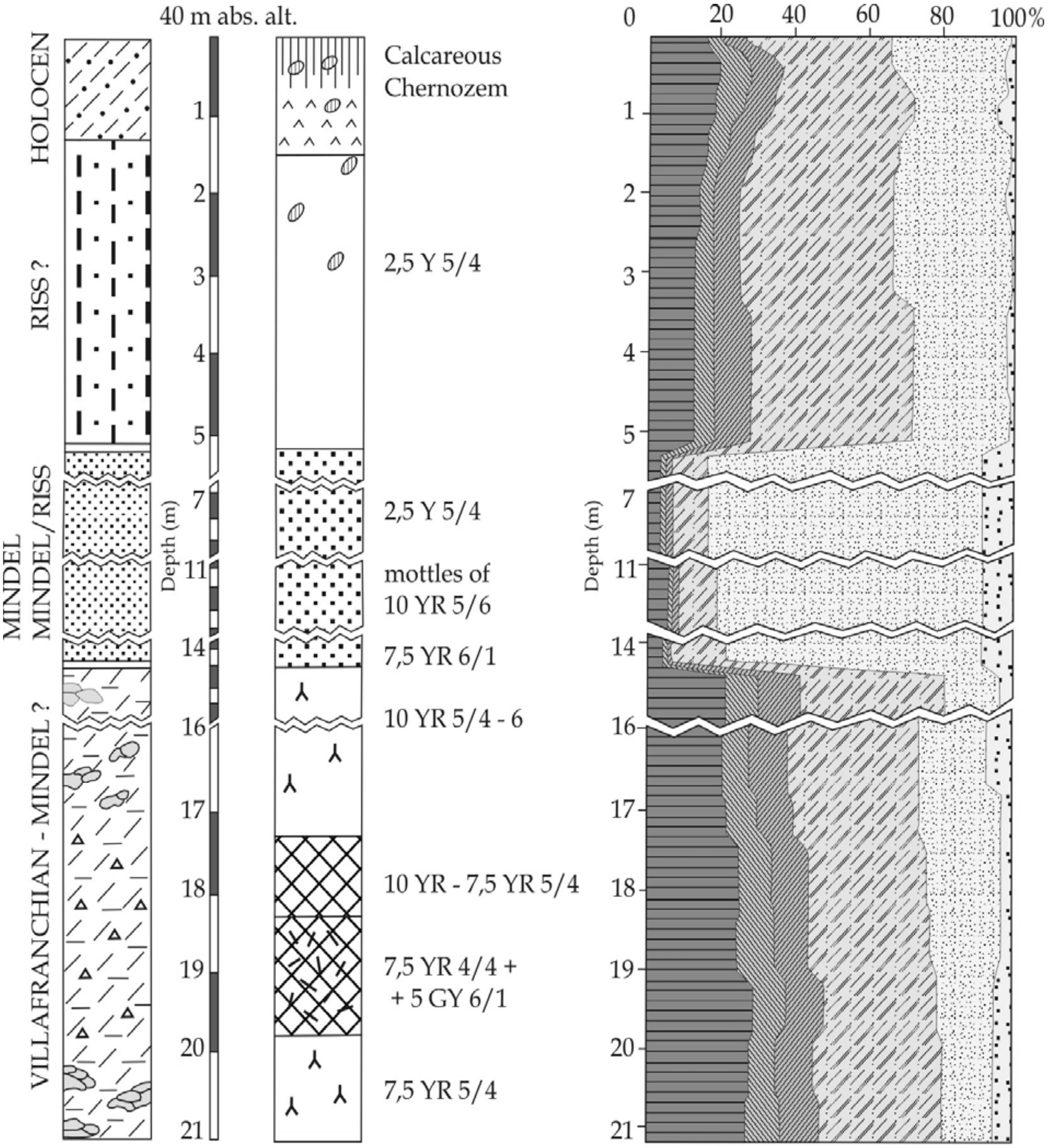

Figure 12. Quaternary section no. 4b Garvăn, 2 km Southward Garvăn village: A – stratigraphic column; B – pedolithological column; C – Particle size fractions column
(For legend of signs see fig. 2)

5.3.3. Aeolian Colluvial loessic sandy – loamy & lacustrine – riverine sandy pedolithological complexes

This kind of Quaternary mantle has been identified in a deep gully on the hills from southward of Garvăn village in the northern edge of Măcin Mountains (Fig. 1). Representative is the section 4b Garvăn (Fig. 12, A, B, C, Table 3). It comprises three segments. The first one – until 6 m depth – consists of a yellowish (2.5 Y 5/4) sandy loamy, porous, loess deposit. The upper 1 m is occupied by the present day soil – a Calcareous Chernozem. The second – middle – segment from 6 to 14.2 m depth is represented by a cross-layered fluviatile-lacustrine sandy deposit of a yellowish colour (2.5 Y) with reddish (5 YR 5/6) or yellowish-olive (7.5 YR 6/1) colours as mottles or horizontal strips. The texture is predominantly sandy (with > 80% fine sand). The third (lower) segment starts at 14.2 m and extends up to 21 m depth. Until 17.5 m depth it consists of a colluvial, loamy loess-like material with granitic gravel. Below 17.5 m depth it follows a loamy reddish (10 YR – 7.5 YR 4/4) material with greenish (5 GY) mottles in the lower part. The presence of some clay coatings as well as the colour, suggests that it may be an eroded and redeposited soil material (pedolith) originating from older soils.

Palaeopedological interpretation. The section described above shows that, in some areas, the Quaternary mantle from northern Dobrudgea is more complex than a simple alternation of loess layers and fossil soil strips. The pack of fluvio-lacustrine deposits that interrupts such an alternance or is subjacent to it has been already signaled by Peters (1867) and Coteț in 1957 (quoted by Grumăzescu & Grumăzescu, 1967). According to Grumăzescu and Cornelia Grumăzescu (1967), "the flecked loamy sandy or sandy complex appears both on higher, as 90 or even 240 m absolute altitude, as well as on the bottom of gulf-like depressions e.g. Luncavița, Niculițel and Somova. The absolute altitude at which it occurs would corresponds to erosion (abrasion) terraces of 60-70, 40-50 and 8-10m.

On palinological basis the above quoted authors believe that the age of the sandy complex would be comprised between Mindel glacial and the end of the Mindel-Riss interglacial. The overlying loess might be Rissian or post-Rissian, and the age of subjacent pedolithic material could be comprised between Villafranchian and the beginning of Mindel glacial (equivalent to the psephitic Saint Prestian complex from Danube Delta (Liteanu, 1961, quoted by Popovăț & all, 1964).

5.3.4. Aeolian-sandy, pedolithological complexes

This kind of complexes occurs in the North-Western and Eastern edges of Northern Dobrudgea, in Bugeac and Dunavăț peninsulas respectively.

Representatives is the section no. 22 Dunavățul de Jos (Fig. 13, A, B, C). The changes in sedimentation conditions are put in evidence by the higher percent of coarse sand in the first 2-3 m from the surface and the lack of this fraction in the lower tier. A slight increase toward depth is noticed in the case of silt and clay fractions that may be associated with a beginning of a soil formation although morphologicaly any marks (e.g. brownish colour) can't be noticed yet.

The origin of sandy deposits from Dunavăț is the Danube Delta (Coteț, 1973, Munteanu, 1982, 1997). As concern the age, they seem to be synchronous with the sandy deposits from western part of Caraorman dunes, estimated at 7.5-11 thousand years (Panin, 1974).

The Bugeac sands originates from Danube floodplain and they may be of the same age as the Dunavăț ones (Munteanu, 1997).

Table 3. Particle size distribution of Quaternary section no. 4b Garvăn

No.	Horizon (layer)	Depth (cm)	Particle size (mm; %)					Obs.
			<0,002	0,002-0,02	0,02-0,2	0,2-2	>2	
1	Ap	0-20	16,6	10,0	72,8	0,6	0,0	Calcaric Chernozem
2	Am	36-53	19,6	17,2	60,1	3,1	0,0	
3	AC	65-80	18,9	16,3	64,0	0,8	0,2	
4	Cca	90-110	18,2	15,9	65,2	0,7	0,2	
5	Ck_1	130-145	17,1	12,1	69,8	1,0	0,2	Aeolian loess sandy loam
6	Ck_2	200-220	14,1	11,3	74,0	0,6	0,1	
7	Ck_3	300-320	12,8	12,5	74,5	0,2	0,2	
8	Ck_4	400-420	13,5	15,5	70,6	0,4	0,2	
9	Ck_5	500-520	12,6	14,7	72,1	0,6	0,2	
10	2 Cn_1	700-720	4,8	4,9	85,2	8,1	0,0	Riverine-lacustrine sands
11	Cn_2	1100-1120	6,1	2,6	83,6	7,7	0,0	
12	Cn_3	1400-1420	5,6	0,5	84,4	9,5	0,0	
13	3 Cn_4	1440-1460	21,9	21,0	53,1	4,0	0,0	Loess-like colluvium with granitic gravel
14	Cn_5	1660-1680	21,2	18,3	54,4	6,1	0,0	
15	Cn_6	1720-1740	22,2	17,8	57,2	2,8	0,0	
16	4 bBv_1	1780-1800	22,5	18,7	52,7	3,1	0,0	Colluvial pedolith with granitic gravel
17	bBv_2	1850-1870	25,6	18,7	52,5	3,2	0,0	
18	bBtg	1930-1950	29,4	18,6	45,8	6,2	0,0	Idem, with ferruginous & manganiferous coatings/mottles
19	Cn_7	2010-2030	28,2	17,8	49,5	4,5	0,0	
20	Cn_8	2080-2100	27,2	20,2	47,6	5,0	0,0	

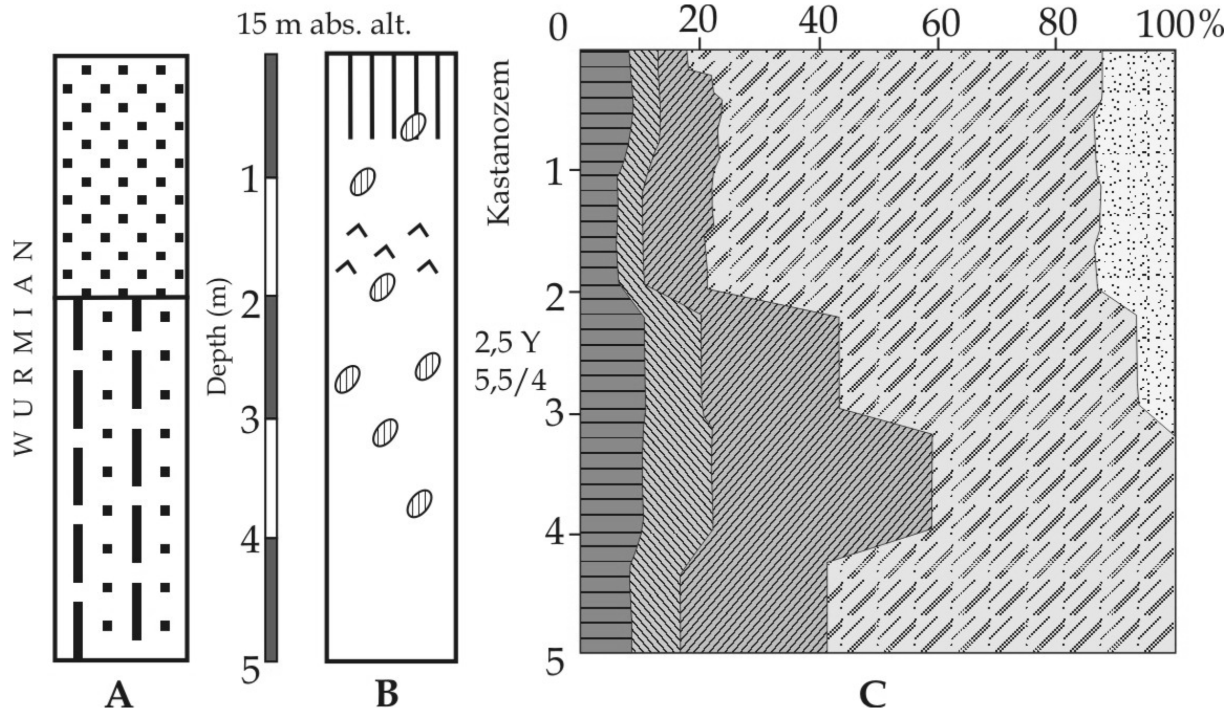

Figure 13. Quaternary section no. 22 Dunavățul de Jos: A – stratigraphic column; B – pedolithological column; C – Particle size fractions column; (For legend of signs see fig. 2)

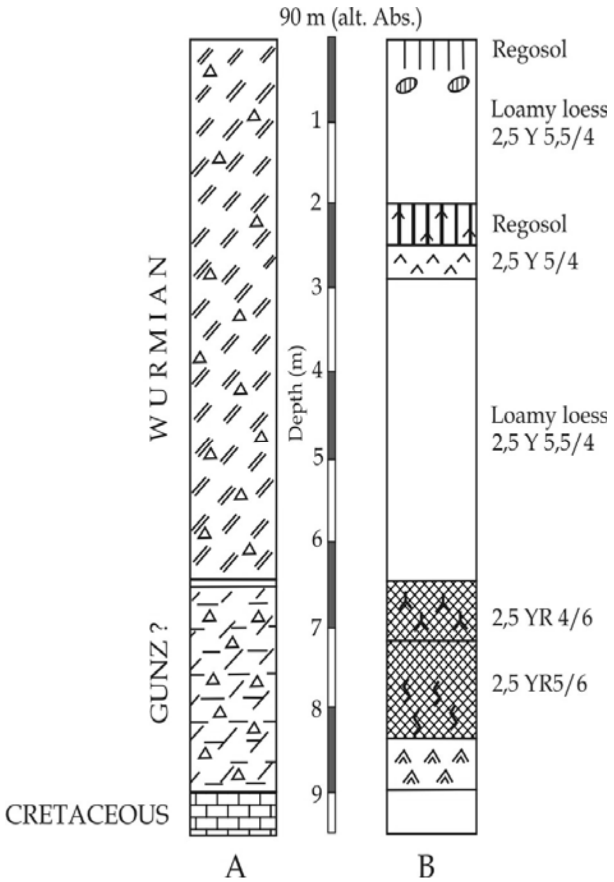

Figure 14. Quaternary section no. 16, southward Horia village: A – stratigraphic column; B – pedolithological column; (For legend of signs see fig. 2)

5.3.5. Colluvial loess-like, loamy pedolithological complexes

This kind of quaternary mantle is largely widespread in hilly and stepped areas from Măcin Mountains, Niculițel hills and Babadag Tableland. As a rule it is relatively thin – 3-5 m to 8-12 m thickness. The main component is represented by yellowish, yellow-reddish loamy loess-like materials associated with detrital, silicatic or calcareous, coarse material (gravel). Up to three fossil soil strips (Fig. 14, A, B), with Bt or Bw horizons may be present. Frequently the colluvial mantle overlies reddish clayey materials – witness of the old, pre-loessic soil cover developed upon Paleozoic, Triassic or Cretaceous surfaces. The age of the colluvial mantle seems to be Wurmian or Holocene. In some areas the colluvial mantle is covered by thick layers of aeolian loess (Fig. 15) which indicate that colluvial sedimentation has been replaced by an aeolian one.

6. CONCLUSIONS

In Northern Dobrudgea two periods of pedogenesis and quaternary sedimentogenesis can be distinguished: a. previous to the loess mantle formation and b. synchronous with the development of that mantle.

a. Before to loess mantle formation, both sedimentogenesis and pedogenesis developed on the account of Paleozoic and Triassic & Cretaceous terrains. During this period a denudational-compensative pedogenesis prevailed. The remains from that old pedological mantle, preserved on the residual landforms or buried under loess deposits, witness that upon calcareous rocks, deep, clayey and red soils were formed, while on the non-calcareous and crystalline silicatic ones the soils were thin and strongly skeletic.

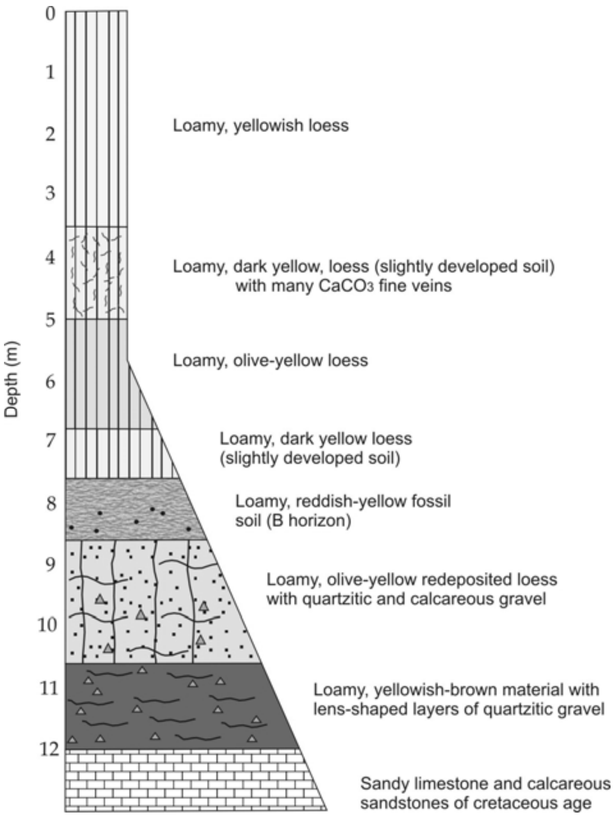

Figure 15. Quaternary section no. 23, southward Cloşca village

b. During the formation of the loessic mantle (loess & loess like deposits) generated mainly by wind-borne dust fall-out (to which weathering products of the pre-quaternary rocks has to be added), the sedimentation interfered with a sedintegrative pedogenesis. Because the loess itself is considered as being an old soil and the fossil soil strips are intimately associated with loess layers one suggests that such kinds of quaternary mantle should be considered as distinct entities and separated under the name of "pedolithological loessic complexes". By extension the term "pedolithological complex" might be applied to all sedimentary deposits that include fossil soil strips.

The pedolithological loessic complexes are the result of so-called "sedialternating pedogenesis" characterized by succession in time of period of prevalent pedogenesis with ones of prevalent sedimentation (Florea, 2009). In this sense, sequences of loess layers & fossil soil strips should be considered rather pedolitological – sedimetological formations than geological ones as they are viewed in classical Quaternary literature.

c. The study reveals that the quaternary mantle of Northern Dobrudgea is rather complex. Some anomalies e.g. the occurrence of riverine lacustrine sandy or loamy sandy/sandy loamy deposits inserted in some loess and loess-like sections do not have a complete explanation yet. It is also the case of the change, over short distance in the number and thickness of fossil soils strips.

d. The quaternary section – no. 11 Nufăru (Fig. 8) – induces an optimistic vision on climate change perspective: during the last 100-120 thousand years in Northern Dobrudgea, the amplitude of climate change was not very high: it oscillated between dry and perhaps cold climate specific to loess formation and that of temperate and moderately wet one of deciduous forests under which Luvisols from Măcin and Niculițel highlands developed.

e. The epirogenetical movement of Dobrudgea Tableland during Quaternary seems to have played an important role in both palaeopedological and palaeosedimentological history of this region.

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