Manuscript details

Manuscript number QUATINT_2015_415

Title Assessing Late Plesitocene and Holocene phases of aeolian activity on the Nyírség Alluvial Fan, Hungary

Article type Full Length Article

Abstract There have been several studies addressing the timing and extension of Late Pleistocene and Holocene Aeolian activity in the Nyírség, the former alluvial fan of the Tisza River. Some of these already applied numerical dating techniques, however usually focused on one dune form or one site. This paper is an attempt on the one hand to review former age data and on the other hand to add new data from various sites to the landform evolution of the second largest sand dune area of the Carpathian Basin. The paper focuses on the Late Pleistocene þÿ H o l o c e n e l a n d f o r m e v o l u t the second largest sand dune area of Hungary (Nyírség). Recent age data were obtained from investigations applying several methods (radiocarbon, OSL and palynological examinations) in order to determine the periods of sand movement and paleosoil formation in the area more accurately. According to the results, six sand movement periods can be identified during the Late Glacial and Holocen (Oldest Dryas, Younger Dryas, Preboreal Phase, Boreal Phase, Atlantic Phase, Subatlantic Phase). In between periods with intensive aeolian

activity paleosoil formation occurred in the Bølling-Allerød Interstadial and in the Preboreal and Subatlantic Phases.

Keywords Aeolian activity, OSL, Radiocarbon dating, Late Glacial, Holocene, Nyírség, Hungary

Corresponding Author Botond Buró

Corresponding Author's Institution University of Debrecen

Order of Authors Botond Buró, György Sipos, József
þÿ L ó k i ,   B e n c e   A n d r á s i ,   E n i k
Gábor Négyesi

Suggested reviewers Magdalena Ratajczak-Szczerba, Erzsébet Horváth

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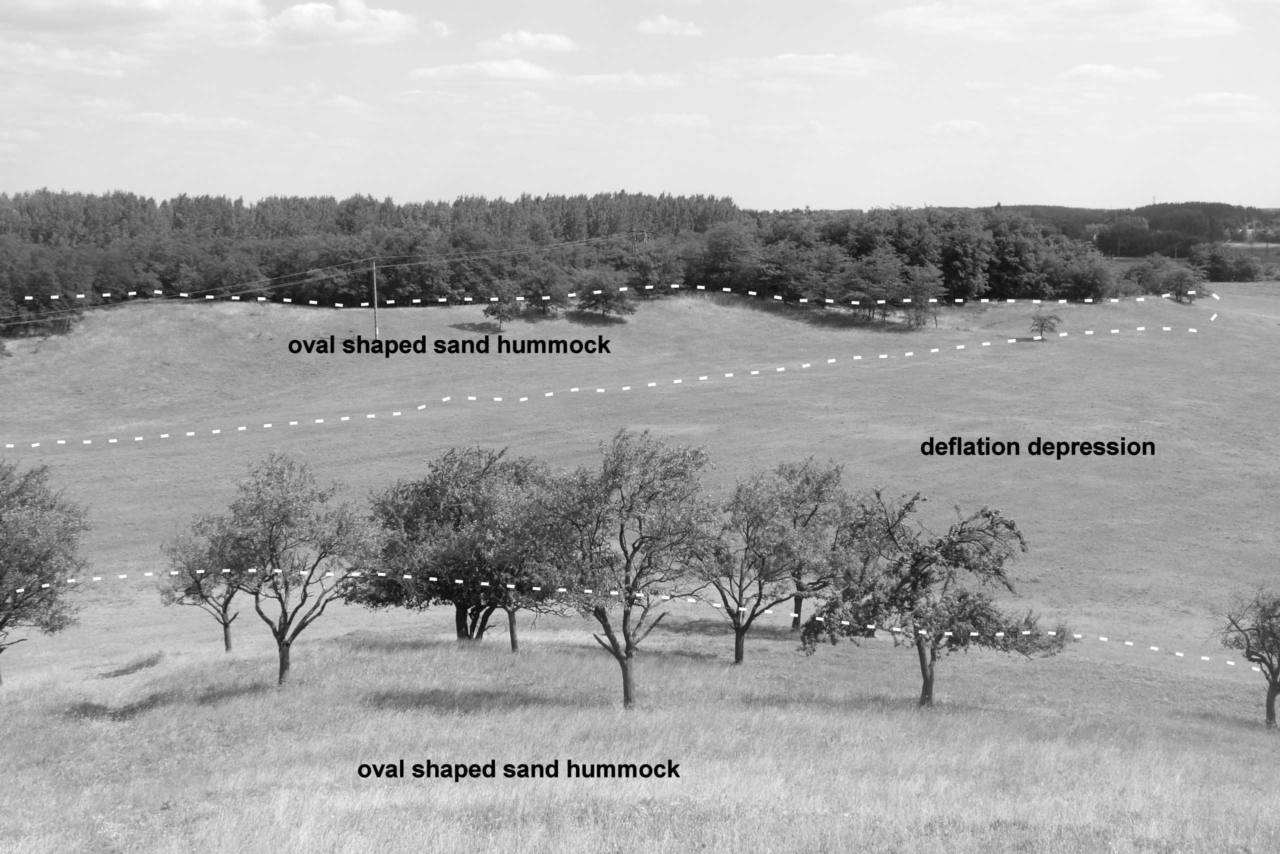
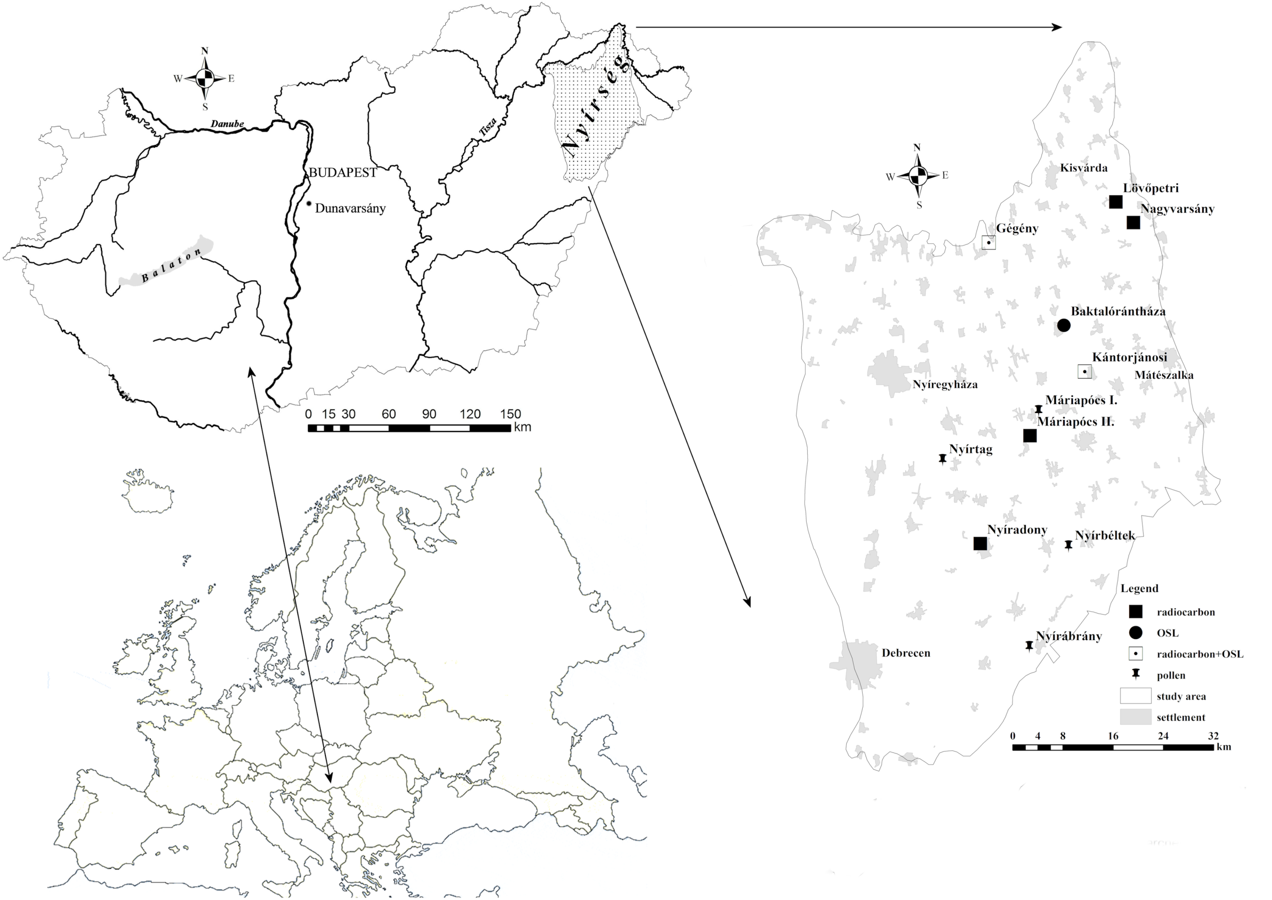
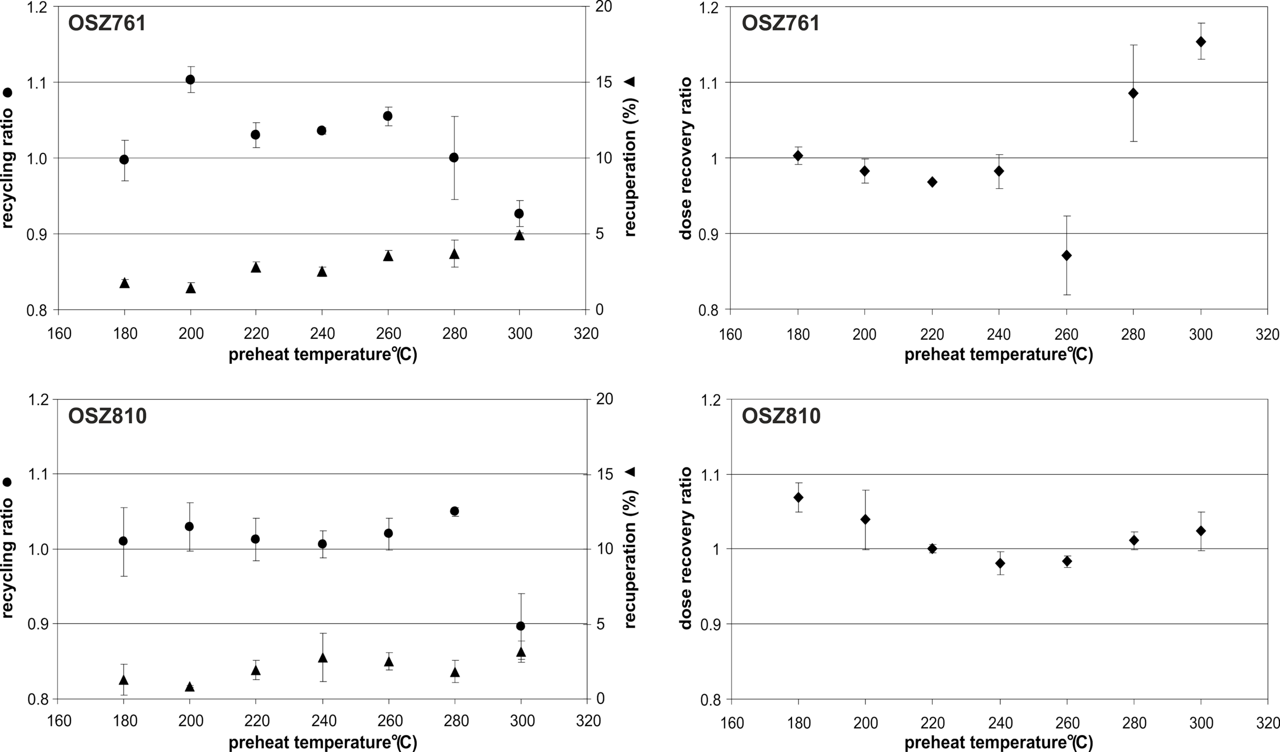
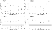
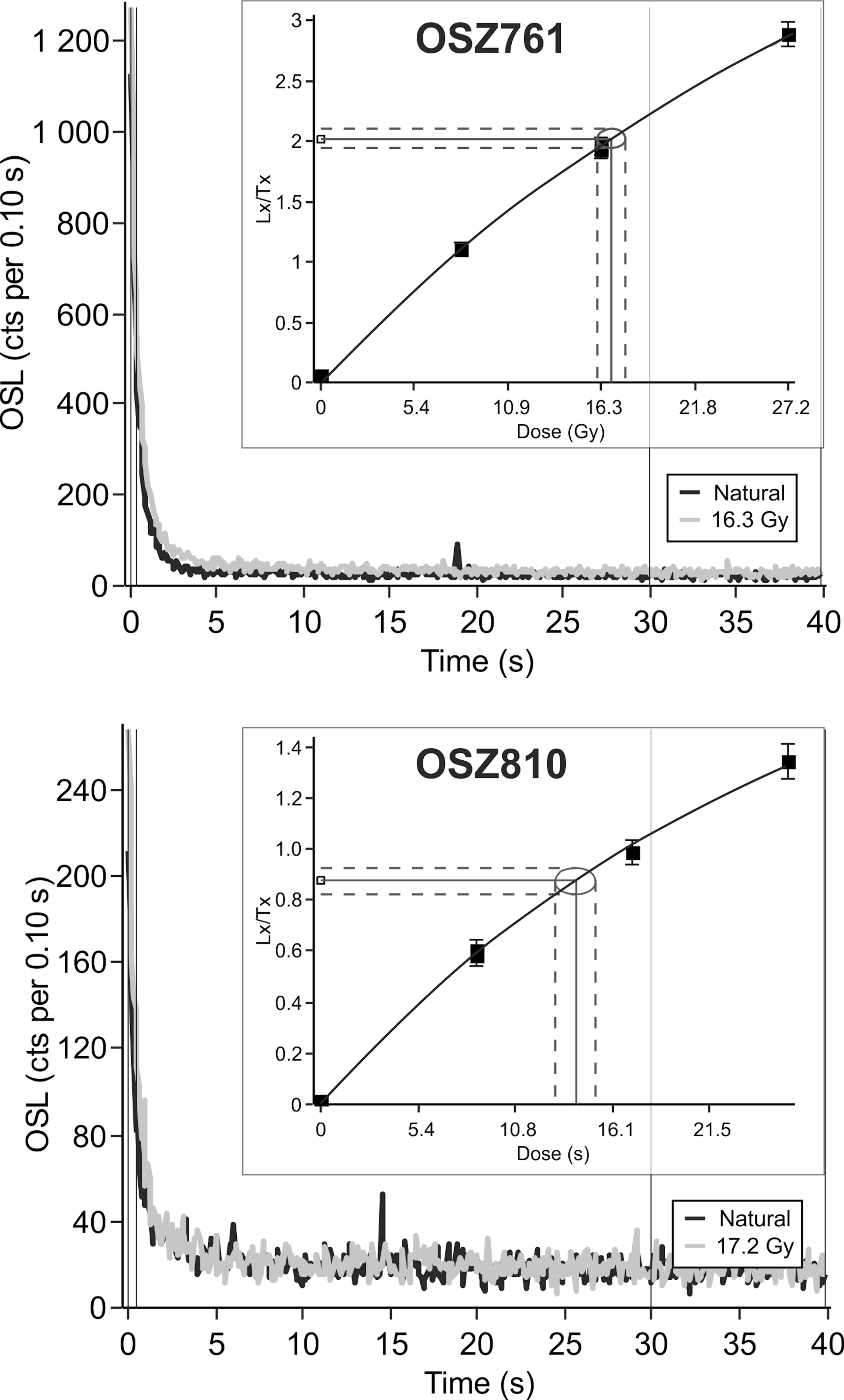

oval shaped sand hummock
deflation depression
oval shaped sand hummock


N
W
E
S
Danube
Tisza
Nyírség
BUDAPEST
Dunavarsány
Balaton
0 15 30 60 90 120 150 km
N
W
E
S
Kisvárda
Lövőpetri
Nagyvarsány
Gégény
Baktalórántháza
Kántorjánosi
Mátészalka
Nyíregyháza
Máriapócs I.
Máriapócs II.
Nyírtag
Nyíradony
Nyírbéltek
Nyírábrány
Debrecen
Legend
radiocarbon
OSL
radiocarbon+OSL
pollen
study area
settlement
0 4 8 16 24 32 km

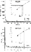


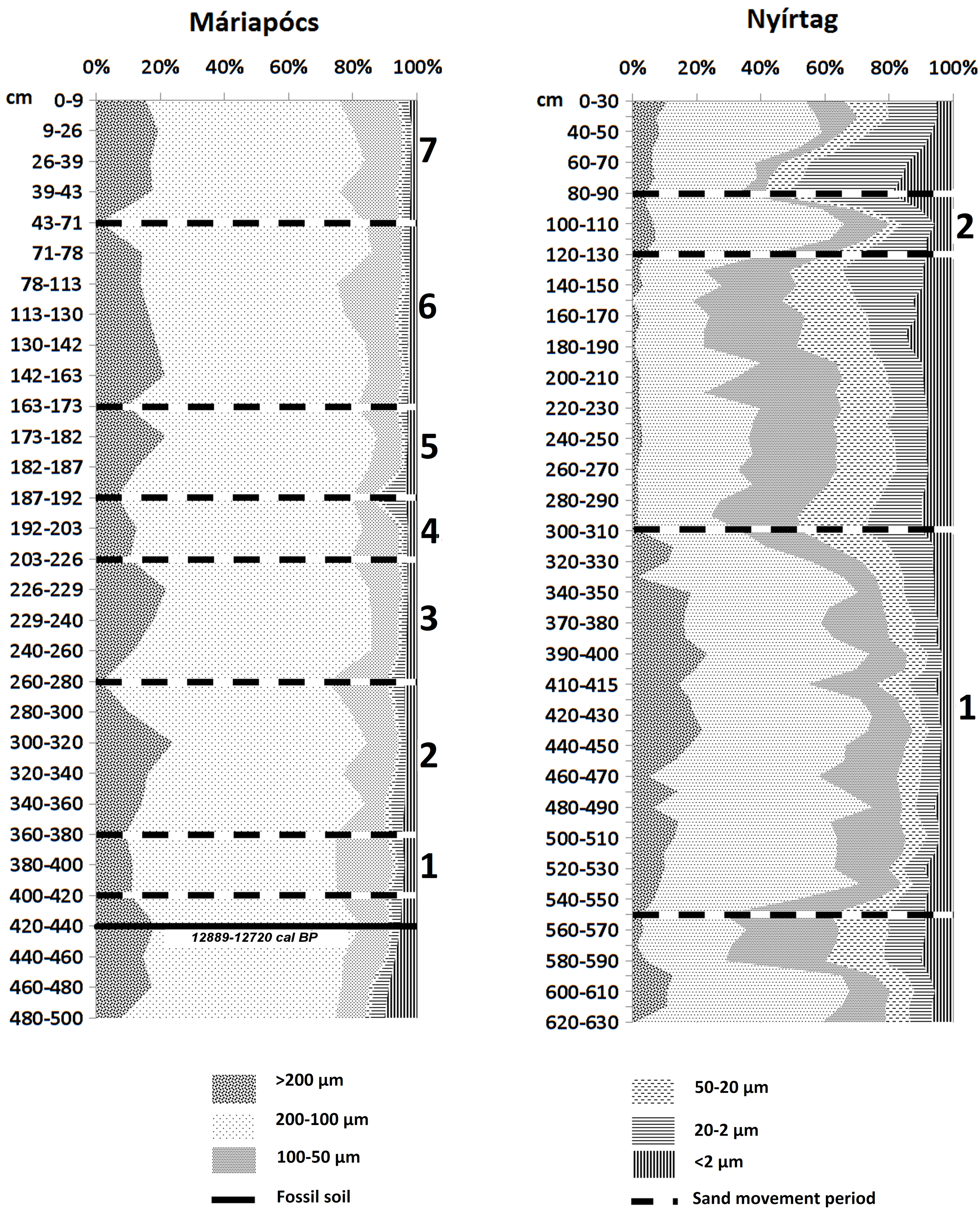
OSZ761
recycling ratio ●
recuperation (%) ◄
preheat temperature°(C)
OSZ761
dose recovery ratio
preheat temperature°(C)
OSZ810
recycling ratio ●
recuperation (%) ◄
preheat temperature°(C)
OSZ810
dose recovery ratio
preheat temperature°(C)



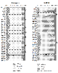


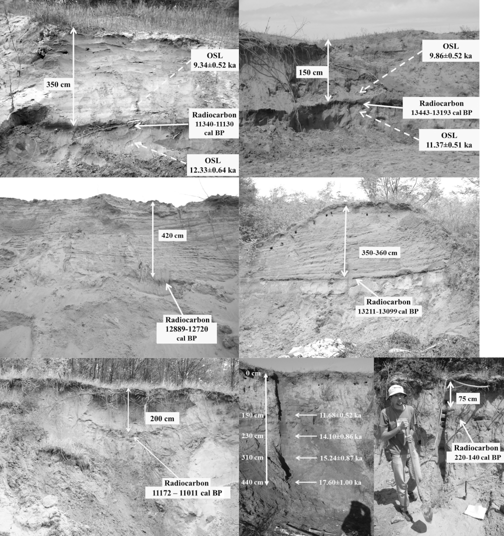
OSZ761
Lx/Tx
Dose (Gy)
0
5.4
10.9
16.3
21.8
27.2
Natural
16.3 Gy
OSL (cts per 0.10 s)
Time (s)
OSZ810
Dose (s)
0
5.4
10.8
16.1
21.5
Natural
17.2 Gy
OSL (cts per 0.10 s)
Time (s)



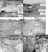


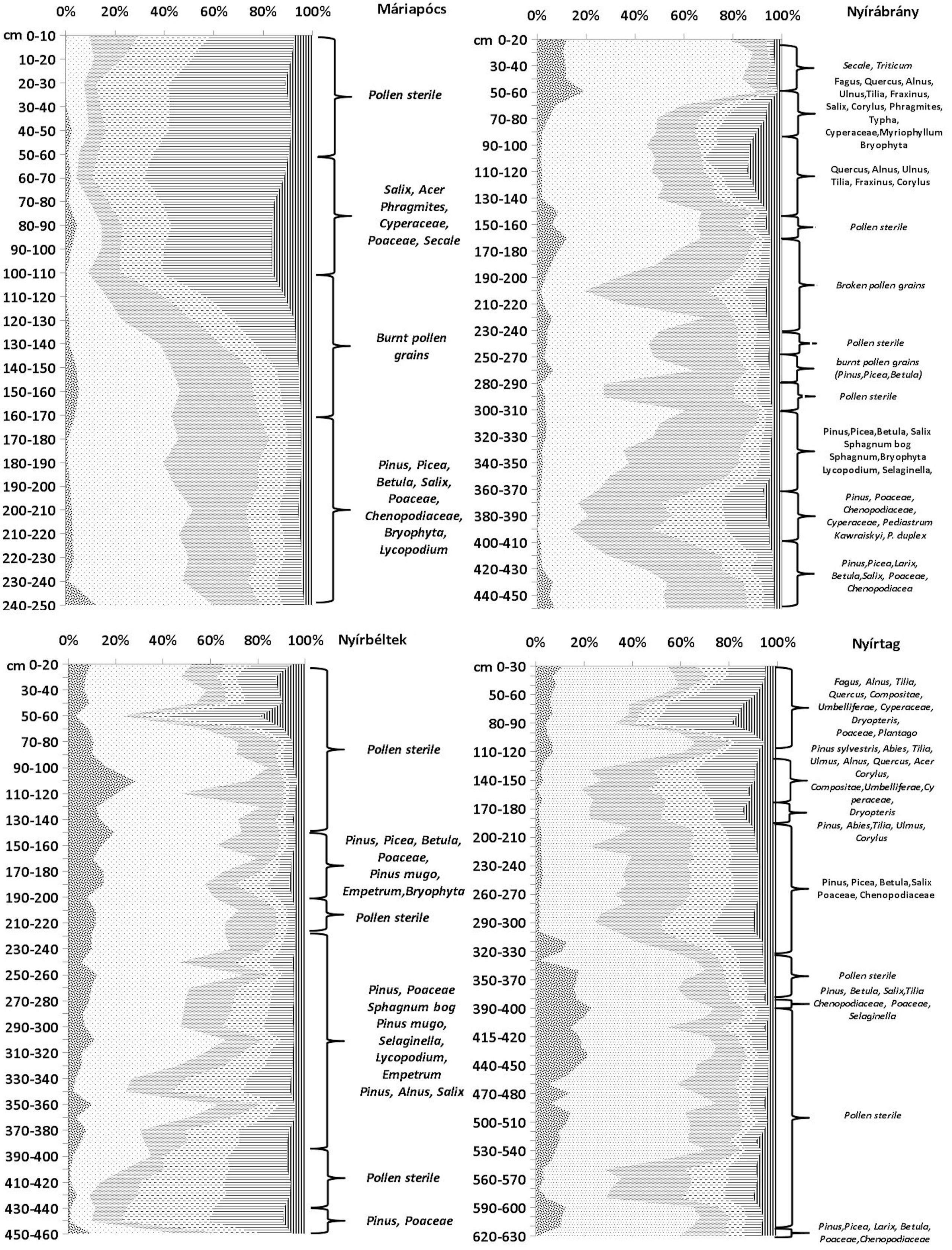
Máriapócs
Nyírtag
0%
20%
40%
60%
80%
100%
cm
0-9
9-26
26-39
39-43
43-71
71-78
78-113
113-130
130-142
142-163
163-173
173-182
182-187
187-192
192-203
203-226
226-229
229-240
240-260
260-280
280-300
300-320
320-340
340-360
360-380
380-400
400-420
420-440
440-460
460-480
480-500
7
6
5
4
3
2
1
12889-12720 cal BP
0-30
40-50
60-70
80-90
100-110
120-130
140-150
160-170
180-190
200-210
220-230
240-250
260-270
280-290
300-310
320-330
340-350
370-380
390-400
410-415
420-430
440-450
460-470
480-490
500-510
520-530
540-550
560-570
580-590
600-610
620-630
2
1
>200 µm
200-100 µm
100-50 µm
Fossil soil
50-20 µm
20-2 µm
<2 µm
Sand movement period

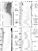




350 cm
OSL
9.34±0.52 ka
Radiocarbon
11340-11130
cal BP
OSL
12.33±0.64 ka
150 cm
OSL
9.86±0.52 ka
Radiocarbon
13443-13193 cal BP
OSL
11.37±0.51 ka
420 cm
Radiocarbon
12889-12720
cal BP
350-360 cm
Radiocarbon
13211-13099 cal BP
200 cm
Radiocarbon
11172 – 11011 cal BP
0 cm
150 cm
230 cm
310 cm
440 cm
11.68±0.52 ka
14.10±0.86 ka
15.24±0.87 ka
17.60±1.00 ka
75 cm
Radiocarbon
220-140 cal BP




Máriapócs
0% 20% 40% 60% 80% 100%
cm 0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
100-110
110-120
120-130
130-140
140-150
150-160
160-170
170-180
180-190
190-200
200-210
210-220
220-230
230-240
240-250
Pollen sterile
Salix, Acer Phragmites, Cyperaceae, Poaceae, Secale
Burnt pollen grains
Pinus, Picea, Betula, Salix, Poaceae, Chenopodiaceae, Bryophyta, Lycopodium
Nyírábrány
0% 20% 40% 60% 80% 100%
cm 0-20
30-40
50-60
70-80
90-100
110-120
130-140
150-160
170-180
190-200
210-220
230-240
250-270
280-290
300-310
320-330
340-350
360-370
380-390
400-410
420-430
440-450
Secale, Triticum
Fagus, Quercus, Alnus, Ulnus,Tilia, Fraxinus, Salix, Corylus, Phragmites, Typha, Cyperaceae,Myriophyllum Bryophyta
Quercus, Alnus, Ulnus, Tilia, Fraxinus, Corylus
Pollen sterile
Broken pollen grains
Pollen sterile
burnt pollen grains (Pinus,Picea,Betula)
Pollen sterile
Pinus,Picea,Betula, Salix Sphagnum bog Sphagnum,Bryophyta Lycopodium, Selaginella,
Pinus, Poaceae, Chenopodiaceae, Cyperaceae, Pediastrum Kawraiskyi, P. duplex
Pinus,Picea,Larix, Betula,Salix, Poaceae, Chenopodiacea
Nyírbéltek
0% 20% 40% 60% 80% 100%
cm 0-20
30-40
50-60
70-80
90-100
110-120
130-140
150-160
170-180
190-200
210-220
230-240
250-260
270-280
290-300
310-320
330-340
350-360
370-380
390-400
410-420
430-440
450-460
Pollen sterile
Pinus, Picea, Betula, Poaceae, Pinus mugo, Empetrum,Bryophyta
Pollen sterile
Pinus, Poaceae Sphagnum bog Pinus mugo, Selaginella, Lycopodium, Empetrum Pinus, Alnus, Salix
Pollen sterile
Pinus, Poaceae
Nyírtag
0% 20% 40% 60% 80% 100%
cm 0-30
50-60
80-90
110-120
140-150
170-180
200-210
230-240
260-270
290-300
320-330
350-370
390-400
415-420
440-450
470-480
500-510
530-540
560-570
590-600
620-630
Fagus, Alnus, Tilia, Quercus, Compositae, Umbelliferae, Cyperaceae, Dryopteris, Poaceae, Plantago
Pinus sylvestris, Abies, Tilia, Ulmus, Alnus, Quercus, Acer Corylus, Compositae,Umbelliferae,Cyperaceae, Dryopteris
Pinus, Abies,Tilia, Ulmus, Corylus
Pinus, Picea, Betula,Salix Poaceae, Chenopodiaceae
Pollen sterile
Pinus, Betula, Salix,Tilia Chenopodiaceae, Poaceae, Selaginella
Pollen sterile
Pinus,Picea, Larix, Betula, Poaceae,Chenopodiaceae



Place	coordinates		Type of sample site	landform type	Age determination methods	Number of samples for absolute age determination	Number of samples for sedimentological and pollen analyses[1]
	EOVY	EOVX					
Lövőpetri	885644	319885	outcrop	oval shapes hummock	^{14}C	1	0
Nagyvarsány	888446	316595	outcrop	oval shaped hummock	^{14}C	1	0
Gégény	865403	313436	outcrop	oval shaped hummock	^{14}C+OSL	1+2	25
Kántorjánosi	880688	292920	outcrop	oval shaped hummock	^{14}C+OSL	1+2	0
Baktalórántháza	877366	300265	outcrop	oval shaped hummock	OSL	3	33
Máriapócs I.	873340	286596	borehole	abandoned river bed	pollen	0	25+(25)
Máriapócs II.	871971	282715	outcrop	abandoned river bed	^{14}C	1	30
Nyírtag	858048	278806	borehole	abandoned river bed	pollen	0	62+(62)
Nyíradony	864049	265541	outcrop	oval shaped hummock	^{14}C	1	10
Nyírbéltek	878109	265060	borehole	abandoned river bed	pollen	0	45+(45)
Nyírábrány	871868	249059	borehole	abandoned river bed	pollen	0	44+(44)

[1] The number of samples for pollen analyses are in the brackets

Table 2: Summary of the calibrated and conventional radiocarbon age data

	Site	Lab. ID	Depth (cm)	Convencional ^{14}C age (ka yr BP)	Calibrated calendar age	Geochronology (according to cal BP)
1.	Máriapócs	DeA-1855.1.1	420-440	10.94±0.041	10939-10770 cal BC (12889-12720 cal BP)	Younger Dryas
2.	Kántorjánosi	Deb-15587	350-400	9.30±0.050	9390-9180 cal BC (11340-11130 cal BP)	Younger Dryas
3.	Gégény	DeA-2939	150-170	11.40±0.052	11493-11243 cal BC (13443-13193 cal BP)	Bölling – Allerɵd Interstadial
4.	Nagyvarsány-Szabadságtanya	DeA-3275	350-360	11.24±0.042	11261-11149 cal BC (13211-13099 cal BP)	Bölling – Allerɵd Interstadial
5.	Lövőpetri	DeA-3276	200-280	11.15±0.043	11172-11011 cal BC (13122-12961 cal BP)	Bölling – Allerɵd Interstadial
6.	Nyíradony	Deb-18293	75-120	0.21±0.04	1730-1810 cal AD (220-140 cal BP)	Subatlantic Phase

Table3: Equivalent dose, dose rate and age results of OSL dating.

	Site	**Type**	**Lab. ID**	**Depth (cm)**	**H_2O (%)**	**U (ppm)**	**Th (ppm)**	**K (%)**	**D^*_{cosmic} (Gy/ka)**	**D^*_{total} (Gy/ka)**	**D_e (Gy)**	**Age (ka)**	**Geochronology**
1.	Kántorjánosi	OSL	OSZ810	140	2.6±2.0	1.10±0.11	5.09±0.51	0.94±0.05	0.21±0.02	1.73±0.06	16.11±0.68	9.34±0.52	Preboreal Phase
2.	Kántorjánosi	OSL	OSZ811	420	2.0±2.0	0.98±0.10	3.31±0.33	0.82±0.04	0.17±0.02	1.43±0.06	17.61±0.61	12.33±0.64	Younger Dryas
3.	Baktalórántháza	OSL	OSZ759	420	4.2±2.0	0,99±0.10	3,89±0.39	0,78±0,04	0,12±0,01	1.34±0.05	23.58±0.98	17.60±1.00	Oldest Dryas
4.	Baktalórántháza	OSL	OSZ760	230	10.2±5.0	1,06±0.11	4,58±0.46	0,86±0,04	0,15±0,02	1.43±0.05	20.22±0.52	14.10±0.86	Bølling-Allerød Interstadial
5.	Baktalórántháza	OSL	OSZ761	150	5.4±2.0	1,03±0.05	4,16±0.21	0,77±0,04	0,17±0,02	1.39±0.05	17.20±0.64	11.68±0.52	Younger Dryas
6.	Baktalórántháza	OSL	OSZ762	310	6.5±3.0	0,99±0.10	3,96±0.40	0,89±0,05	0,13±0,01	1.44±0.06	21.88±0.82	15.24±0.87	Oldest Dryas
7.	Gégény	OSL	OSZ808	95	2.0±2.0	0.87±0.09	3.22±0.32	0.87±0.04	0.18±0.02	1.45±0.06	14.30±0.51	9.86±0.52	Preboreal Phase
8.	Gégény	OSL	OSZ809	225	2.4±2.0	1.00±0.10	4.03±0.40	0.85±0.04	0.15±0.02	1.48±0.06	16.83±0.41	11.37±0.51	Younger Dryas

Geochronology (according to Cal yr. BP)	Age of sand movement (ka)	Radiocarbon data of paleosols
Subatlantic phase	Bagamér OSL 0.23±0.05 ka (Kiss et al. 2008.)	Nyíradony (220-140 cal BP) *
	Bagamér OSL 0.43±0.14 ka (Kiss et al. 2008.)	
	Kiskunhalas OSL 0.59±0.06 (Nyáry et al. 2007)	
	Csengele OSL 0.65±0.11 (Nyáry et al. 2007)	
	Kisoroszi IRSL 0.63±0.07 ka (Újházy et al. 2003)	
	Kiskunhalas OSL 1.21±0.19 (Kiss et al. 2008.)	
	Csengele OSL 1.33±0.21 (Kiss et al. 2008)	
	Csengele and Apostag OSL 1.70±0.37 (Kiss et al. 2008.)	
	Bagamér OSL 2.48±0.30 (Kiss et al. 2008.)	
	Tura ISRL 1.54±0.16 (Novothny et al. 2010)	
BP 2900		
Subboreal Phase	Kiskunhalas, OSL 2.91±0.31 (Kiss et al. 2008)	
	Csengele OSL 3.59±0.46 (Kiss et al. 2008)	
BP 5300		
Atlantic Phase	Bagamér OSL 5.46 ± 0.63 ka (Kis et al. 2008)	
	Bagamér OSL 6.60 ± 0.79 ka (Kis et al. 2008)	
	Dunavarsány TL 6.8±2.2. (Újházy et al. 2003)	
BP 8000		
Boreal Phase		
BP 9000		
Preboreal Phase	Bagamér, OSL 9.21±1.00 (Kiss et al. 2008)	
	Vámospércs OSL 9.27±0.8287 (E. Thamó-Bozsó et al. 2007)	
	Kántorjánosi OSL 9.34±0.52*	
	Dunavarsány TL 9.6±1.1 (Újházy et al. 2003)	
	Vámospércs OSL 9.67±0.87 (E. Thamó-Bozsó et al. 2007)	
	Gégény OSL 9.86±0.52*	
	Császár OSL 9.8 ±1 ((E. Thamó-Bozsó et al. 2010)	
BP 102000		
	Gégény, OSL 11.37±0.51*	Kántorjánosi (11340-11130 cal BP)*

Younger Dryas	Baktalórántháza, OSL 11.68±0.52*	Máriapócs (12889-12720 cal BP)*
	Kántorjánosi, OSL 12.33±0.64*	
BP 13000		
Bølling-Allerød Interstadial	Baktalórántháza OSL 14.10±0.86*	Lövőpetri (13122-12961 cal BP)*****
		Nagyvarsány-Szabadságtanya (13211-13099 cal BP)*****
		Gégény (13443-13193 cal BP)
		SSE of Debrecen II. 13784 – 13677 cal BP (Borsy et al. 1981)
		Székely 13786 – 13671 cal BP (Borsy et al. 1981)
		SSE of Debrecen I. 14009 – 13940 cal BP (Borsy et al. 1981)
		Bodroghalom II.14125 – 13054 cal BP (Borsy et al. 1981)
		Kisoroszi II. 14129-14007 cal BP (Újházy et al. 2003)
		Kisoroszi I. 14938-14879 cal BP (Újházy et al. 2003)
		Vajdácska I. 15240 – 14593 cal BP (Borsy et al. 1981)
		Dunavarsány 14762-14630 cal BP (Újházy et al. 2003)
		Kenézlő 15260 – 14151 cal BP (Borsy et al. 1981)
		Kisrozvágy 15769-14228 cal BP (Borsy et al. 1981)
BP 15000		
Oldest Dryas	Tura ISRL 14.0±1.0 (Novothny et al. 2010)	Aranyosapáti 18009 – 17038 cal BP (Borsy et al. 1981)
	Tura ISRL 15.5±1.0 ka (Novothny et al. 2010)	
	Baktalórántháza OSL 15.24±0.87*	
	Baktalórántháza, OSL 17.60±1.00*	

Dr. A. Negri
Editor
Quaternary International

18 Dec 2015

Dear Mr. Negri!,

First submission of manuscript by Buró – Sípos – Lóki – Andrási – Félegyházi - Négyesi, Quaternary International

Enclosed please find a manuscript entitled "Assessing Late Plesitocene and Holocene phases of aeolian activity on the Nyírség Alluvial Fan, Hungary" by Botond Buró, György Sípos, József Lóki, Bence Andrási Enikő Félegyházi and Gábor Négyesi, that we would like to be considered for possible publication in Quaternary International.

The paper focuses on the Late Pleistocene – Holocene landform evolution of the second largest sand dune area of Hungary (Nyírség). Recent age data were obtained from investigations applying several methods (radiocarbon, OSL and palynological examinations) in order to determine the periods of sand movement and paleosoil formation in the area more accurately.

According to the results, six sand movement periods can be identified during the Late Glacial and Holocen (Oldest Dryas, Younger Dryas, Preboreal Phase, Boreal Phase, Atlantic Phase, Subatlantic Phase).

In between periods with intensive aeolian activity paleosoil formation occurred in the Bølling-Allerød Interstadial and in the Preboreal and Subatlantic Phases.

We hope that this work could be interesting for readers of the journal.

This is a first submission; it contains new, unpublished information, and is not under consideration elsewhere. My co-authors have read the manuscript and agreed on its content.

I shall be the corresponding author regarding this manuscript. We are looking forward to your reply and the reviewers’ reports in due course.

Thank you in advance for your editorial help.

Sincerely yours,

Botond Buró

Department of Physical Geography and Geoinformation Systems, University of Debrecen, Egyetem tér. 1. 4032, Debrecen, Hungary, tel.:+36 52 512900/22325 (switchboard), fax:+36 52 512945, e-mail: bbotond86@gmail.com

Assessing Late Plesitocene and Holocene phases of aeolian activity on the Nyírség Alluvial Fan, Hungary

Botond Buró[1], György Sipos[2] József Lóki[3], Bence Andrási[4], Enikő, Félegyházi[5], Gábor Négyesi[6]

[1] *University of Debrecen, Faculty of Sciences, Department of Physical Geography and Geoinformatics, Hungary, H-4010 Debrecen, Egyetem square 1. E-mail: bbotond86@gmail.com*

[2] *University of Szeged, Faculty of Sciences, Department of Physical Geography and Geoinformatics, Hungary, H- 6722 Szeged, Egyetem street. E-mail: gysipos@geo.u-szeged.hu*

[3] *University of Debrecen, Faculty of Sciences, Department of Physical Geography and Geoinformatics, Hungary, H-4010 Debrecen, Egyetem square 1. E-mail:loki.jozsef@science.unideb.hu*

[4] *University of Debrecen, Faculty of Sciences, Department of Physical Geography and Geoinformatics, Hungary, H-4010 Debrecen, Egyetem square 1.E-mail: andrasibence.geo@geomail.com*

[5] *University of Debrecen, Faculty of Sciences, Department of Physical Geography and Geoinformatics, Hungary, H-4010 Debrecen, Egyetem square 1.E-mail: patakne@gmail.com*

[6] *University of Debrecen, Faculty of Sciences, Department of Physical Geography and Geoinformatics, Hungary, H-4010 Debrecen, Egyetem square 1. E-mail*: *negyesi.gabor@science.unideb.hu*

Address for correspondence:

Botond Buró

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[1]

Department of Physical Geography and Geoinformatics, University of Debrecen, Egyetem tér. 1. 4032, Debrecen, Hungary, tel.:+36 52 512900/22325 (switchboard), fax:+36 52 512945, e-mail: bbotond86@gmail.com

Abstract

There have been several studies addressing the timing and extension of Late Pleistocene and Holocene Aeolian activity in the Nyírség, the former alluvial fan of the Tisza River. Some of these already applied numerical dating techniques, however usually focused on one dune form or one site. This paper is an attempt on the one hand to review former age data and on the other hand to add new data from various sites to the landform evolution of the second largest sand dune area of the Carpathian Basin.

The paper focuses on the Late Pleistocene – Holocene landform evolution of the second largest sand dune area of Hungary (Nyírség). Recent age data were obtained from investigations applying several methods (radiocarbon, OSL and palynological examinations) in order to determine the periods of sand movement and paleosoil formation in the area more accurately.

According to the results, six sand movement periods can be identified during the Late Glacial and Holocen (Oldest Dryas, Younger Dryas, Preboreal Phase, Boreal Phase, Atlantic Phase, Subatlantic Phase).

In between periods with intensive aeolian activity paleosoil formation occurred in the Bølling-Allerød Interstadial and in the Preboreal and Subatlantic Phases.

Key words: Aeolian activity, OSL, Radiocarbon dating, Late Glacial, Holocene, Nyírség, Hungary

Introduction

The Nyírség is a sand dune area in the northeastern part of the Carpathian Basin. Several scientists studied the development of the Nyírség in the early 20th century. Nagy (1908) and Cholnoky (1910) were the first discussing the dune formations and the evolution of the area, however, the first still acceptable theory was established by Sümeghy (1944). Based on the stratigraphic analysis of cores from boreholes, he found that the Nyírség was an alluvial fan of rivers arriving from the Carpathians. The alluvial fan was uplifted by tectonic forces (cca. 15-25 m) in the Upper Pleniglacial (29-23 ka), meanwhile the surrounding regions were sinking so rivers gradually slipped down and in dry periods wind could blow out sand from fluvial deposits.

By considering pollen analyses and sedimentological observations, at the beginning of his research Borsy regarded the Boreal phase (9-8 ka) as the primary period of sand dune formation in the Nyírség (Borsy, 1961). In the 1980s, based on radiocarbon data, the age of the first major sand movements was placed into the end of the Upper Pleniglacial (ca. 29–23 ka) and in the Late Glacial (10-15 ka; Borsy et al. 1981; Lóki et al. 1994) when the climate was cold and dry. More recent researches (Kiss et al. 2012; Lóki 2006) have indicated that the transformation of the sand surface in the Nyírség did not cease at the end of the Pleistocene but continued in the Holocene during drier periods. In areas where vegetation cover was reduced sand started to move again. First major sand movements in the Holocene were dated to the Preboreal (10.2-9 ka) and to the drier period of Atlantic Phase (8-5.3 ka) (Félegyházi and Lóki 2006; Kiss and Sipos 2006, Kiss et al. 2008, Kiss et al. 2012).

Sand movement in the Atlantic Phase (8 -5.3 ka) and Subboreal Phase (5.3-2.9 ka) was detected at Bagamér in the Nyírség (Kiss and Sipos 2006; Kiss et al. 2008; Kiss et al. 2012).

Sand started to move at several times in Hungarian wind-blown sand areas in the Subatlantic Phase (2.9 ka -), primarily in the Iron Age (Gábris 2003; Ujházi et al. 2003; Nyári and Kiss 2005; Sipos et al. 2006; Nyári et al. 2006ab; 2007ab; Félegyházi and Lóki 2006; Lóki and Schweitzer 2001; Kiss et al. 2012) as a consequence of anthropogenic activities: deforestation, pastoralism and ploughing.

In order to extend arable lands, deforestation was widespread in the 18th and 19th centuries too. As a result, sand started to move again in areas of deforestation. Soils covered by shallow sand layers reflect such sand movements (Marosi 1967; Borsy 1980, 1987, 1991; Lóki 2003).

Optically stimulated luminescence (OSL) dating has proved to be a very useful technique to determine depositional ages of aeolian sediments around the world (Clemensen and Murray, 2006) because it directly dates the time of deposition of sediments (Duller, 2004). The results of OSL measurements could support (or not) the age data given by C14 method.

This area of Hungary provide a good opportunity to similar the results of OSL method to sites where independent age control is available from radiocarbon-dated charcoal horizons within the sand dunes.

Therefore, a major aim of the present study is to refine the chronology of aeolian activity in the Nyírség and to set up a consistent framework for further research in the region. In the meantime it was also possible to attest OSL and radiocarbon dating and to provide data not only for aeolian activity, but also for paleosoil formation.

Study area

Geomorphology

In the Carpathian Basin the Nyírség is the second largest sand dune area (ca. 4600 km2), formed on the alluvial deposits of the Tisza River and its tributaries. At around 25 ka, fluvial processes terminated on the territory; and during the rest of the Pleistocene, aeolian processes prevailed (Borsy, 1991). The strong north-westerly, northerly, north-north-easterly winds formed mostly blowouts, oval shaped sand hummocks and residual ridges. Parabolic sand dunes also evolved on a larger scale in the Nyírség (Lóki 2006).

There are two major types of blowout depressions: 1) the first group consists of elongated depressions, usually running parallel to each other, frequently for hundreds of metres, with dam-like residual ridges between them. These forms are frequently cut into the original alluvial fan material. 2) The other type of blowout depressions has an oval shape. Their development is related to sand surfaces with a relatively denser vegetation, the sand blown out of the oval windrift accumulated immediately at the end of the windrift in the shape of a sickle.

#Fig. 1#.

The sand blown out from the windrifts was usually ordered into dunes, however, it was occasionally deposited as a sand blanket in the foreland of the windrifts.

The second depositional landform is the oval shaped sand hummock. It does not join the windrift in sickle-shape, but is located behind it. The oval shaped hummocks are congested into one another in many places (Borsy 1991).

Parabolic dunes also evolved on a larger scale in the Nyírség. The majority of these parabolic dunes are asymmetric and their wings show northern-northeastern directions indicating the prevailing wind direction during their formation. The parabolic dunes are mostly the type with underdeveloped western wing. The asymmetry is mainly the result of the north-north-esterly winds forming an acute angle with the predominant north-north-westerly, northerly winds. The asymmetric parabolic dunes in the Nyírség are large in size, the eastern wings sometimes reach a length of 1.5-1.6 km. Parabolic dunes reaching the edge of an abandoned river frequently got straightened as wings continued to migrate while the head of the dune became already fixed (Borsy, 1991; Kiss 2000). At several places the asymmetric parabolic dunes were congested onto one another and now form a closed field of dunes.

Another characteristic feature of the Nyírség is the larger deflation depressions and deflation flat areas evolved in the Upper Pleniglacial period. The large amount of sand blown out from the deflation flat areas accumulated into aeolian sand fields.

The area's climate is warm, temperate and wet; the average annual temperature is 9-10°C, and the rainfall averages 550-650 mm a year. However, occasionally the area is susceptible to drought; during such periods the annual rainfall is less than 400 mm. The typical land usage forms are arable lands and forests. The arable lands mainly produce autumn-sown cereal crops and corn, and because of this in the first half of the year – which is by coincidence also the period of the fastest and strongest winds – the extensive bare lands suffer substantial wind-erosion damage (Lóki, 1985).

Methods

Sample collecting

Because most of the former age data is derived from southern part of the Nyírség, we try to find exposures where the age of sand movement is definiable in other part of the area. To collect samples for C14 age determinations, such outcrops of dunes were chosen where buried soil layers were clearly observable (Fig. 2; Table 1). These outrops (totally 7) were set up in sand dunes (parabolic dunes, hummocks). After careful cleaning samples were taken for sedimentological analyses from sand walls of these outcrops (quarries) which contained buried soil layers. From outcrops (Fig. 2:1, 2, 3, 4, 5, 6, 10, 12, 14) where the buried soil contained enough charcoal, samples were collected for radiocarbon age determination. The age of the wind-blown sand under and above the buried layer was determined by OSL measurements as well. Where buried soil was not occurred only OSL age determinations were performed (Fig. 2: e.g. 7).

Abandoned beds (paleo-valleys) of the ancient rivers building the alluvial fan were partially or completely filled up with sandy material (Fig.2: 11, 13, 15, 16, 19, 20) so samples were taken for grain size analyses from borehole cores to set up the stratigraphy of the site and also for pollen analyses. Sediment samples were taken at every 10 cm. With pollen analyses our aim was to explore the accumulation rate of abandoned beds and to set up the evolutionary of vegetation in the area. The pollen grains got into these wetland environment from the surrounding area’s vegetation, giving the possibilities for the identification of the past environment. Under dry climate these abandoned river remnants dried out, but the accumulation continued, however these became unsuitable for pollen conserving. By synchronizing the pollen sterile layers with the layers with high fine sand (100-200 μm) content we can conclude the time of sand movement.

#Table 1#

#Fig 2#

Sediment analyses

Sediment samples were taken at each site and they were analysed in the sediment laboratory of the Institute of Earth Sciences, University of Debrecen. Grain size distribution was determined using Köhn's pipette (Köhn 1929) and dry sieving. Total organic carbon content was measured according to Tyurin's method (Seo et al., 2004).

Radiocarbon dating

In the Hertelendi AMS Lab (Debrecen, Hungary) charcoal fragments were separated visually under optical microscope and treated using the standard acid-base-acid (ABA) method, i.e. in a sequence of 1N HCl, distilled water, 1M NaOH, distilled water, and then 1N HCl (Molnár et al., 2013a). After the final acid wash, the sample has been washed again with distilled water to neutral pH (4–5) and dried using freeze-drying. CO_2 was extracted by combustion of the ABA pretreated samples and further purified cryogenically and then graphitized (Molnár et al., 2013a). ^{14}C measurements were done on the graphitized samples using a compact radiocarbon AMS system (EnvironMICADAS) developed by ETH Zürich (Synal et al., 2007; Wacker et al., 2010), which was installed at the Hertelendi Laboratory of Environmental Studies, Debrecen in 2011 (Molnár et al., 2013b). Conventional radiocarbon ages were converted to calendar ages using OxCal online (version 4.2; Bronk Ramsey, 2009) and the IntCal13 calibration curve (Reimer et al., 2013). Calibrated ages are reported as age ranges at the 2 sigma confidence level (95.4%).

Luminescence dating

Aeolian sediment samples from the profiles were dated by optically stimulated luminescence (OSL). Undisturbed samples were taken with PVC tubes. Sample preparation was based on the techniques proposed by Aitken (1998) and Mauz et al. (2002). The 100–150 µm quartz fraction of samples was applied to determine the absorbed dose since deposition, i.e.: the equivalent dose (D_e). OSL measurements were made following the single aliquot regenerative-dose (SAR) protocol (Murray and Wintle 2000, Wintle and Murray 2006), on a RISØ DA-15 automated TL/OSL system with a beta dose rate of 0.109±0.002 Gy s^{-1}. Based on the results of dose recovery preheat plateau tests (Fig 3), preheat and cutheat temperatures were set in most of the cases to 240°C and 160°C.

In case of two samples (OSZ810 and OSZ811), collected from site Kántorjánosi, a considerable recuperation signal was detected (mean and standard error for 24 aliquots: 5.4±0.6% and 6.5±0.9% of the natural signal), therefore a hot-bleach (40 s blue stimulation at 280°C) was inserted at the end of SAR cycles (Wintle and Murray 2006), which helped to reduce the mean recuperation value to 0.7±0.1% and 2.1±0.6%. Other samples did not require the application of a hot-bleach.

#Fig3#

Final SAR measurements were performed on 24 aliquots using a 4 mm mask in order to enhance the signal/background ratio and to decrease D_e error. The first 0.5 s of OSL curves was taken as the signal, and the last 10 s as the background of measurements. To sensitivity-corrected dose response values a saturating exponential function was fitted to determine aliquot D_e values (Fig 4). As recuperation was successfully mitigated only about 15% of aliquots had to be rejected during D_e evaluation. Exclusion was either because the recycling ratio was outside 1.00±0.05 or the D_e error was larger than 10%. The 4 mm aliquot size did not allow to fully assess the distribution of D_e values, however earlier studies on blown sands in the region did not refer to significant incomplete bleaching (Kiss et al. 2012). Consequently the central age model (Galbraith et al. 1999) was applied for the calculation of sample D_e (Table 2.).

Environmental dose rate was determined by using high resolution, low-level gamma spectrometry. Dry dose rates were calculated using the conversion factors of Adamiec and Aitken (1998). Wet dose rates were assessed on the basis of in situ water contents varying between 2-10 % (Table 3). As samples were collected from positive dune forms and the ground water table is at a deep level (8-9 m) in general (according to own visual observation). Therefore, we suggested low water content with moderate variability throughout the Holocene. The rate of cosmic radiation was determined on the basis of burial depth following the method of Prescott and Hutton (1994).

#Fig 4#

Pollen analysis

Palynological analyses was executed on the sediment core samples collected from paleo-valleys from four sites with different depths (Máriapócs:260 cm; Nyírbéltek-Nyírlugos 460cm; Nyírábrány 460 cm; Nyírtag 630 cm). Totally 181 samples were analysed. The paleo-valleys were identified and chosen on topographic maps and on the basis of field work. To obtain analysable pollen extraction from sediment cores Zólyomi-Erdtman methods was applied (Zólyomi 1952). Firstly, the calcium carbonate content was substracted with hydrochloric acid. In the next step the organic and inorganic components were separated mechanically through flotation in heavy liquid. Finally the organic portion was removed with acetolysis in sulfuric acid and acetic anhydride. Pollen and spore identification and nomenclature were performed using the keys and illustrations of Moore et al. (1991). Identification of sporomorpha was carried out on species, genus and family levels.

To fit our results into a chronological framework, we applied the Holocene chronology set up by Járainé-Komlódi (2000) for relative dating purposes.

Results

Sedimentological results

In general, sand dominates the samples from both the material of sand dunes and that of paleo-valleys. However, due to their characteristic differences, the particle size distribution of layers in the sand dunes and that of the cores was studied separately.

In dune sand, the proportion of silt and clay is small: 3.86 % and 4.06 % on average respectively, while that of the 100-50 μm sand fraction is 10.26 %. Regarding the grain size distribution of samples from sand dunes, fine sand dominate. This fraction is present in a proportion of 62.33% on average. The ratio of sand grains coarser than 200 μm is 17.03%. The paleosols in sand dunes composed of finer particles than dune sand where they occur. Grain size distribution of the material of filled depressions, and abandoned beds differs significantly from the layers of a sand dune. Average proportion of clay and silt is twice as high: 6.94 % and 11.69 % respectively. Maximum value of silt is 56.7 % (Máriapócs, Fig. 2: 9) in bed cores while the maximum proportion of clay is 19.2 % (Nyírtag, Fig. 2: 11). The 50-20 μm and 100–50 μm sand fractions are found on average in 11.66 % and 22.23 %

respectively. Amount of finer grains increases at the cost of the 200-100 µm fraction but in total, fine sand has greatest quantity in such areas as well, however, not in a proportion like in the case of sand dunes (Fig.5.).

#Fig 5#

Organic carbon content of the samples is below 1% in all of the samples. This phenomena is characteristic for the fine sand of Nyírség. Higher organic carbon content can be found in the topmost A horizon of the soil (0.25-0.93%) and in buried soils (0.38-0.9%).

Radiocarbon and OSL dating

All results of radiocarbon and OSL dating origin from samples from different kind of dunes. The data of sample sites (name, landform type) are summarized in Table 1.

Samples were taken from the outcrop at Kántorjánosi for both OSL and ^{14}C analyses. Age of the buried soil is 11340–11130 cal BP (Table 2: 2). This is supported by the OSL data (9.34±0.52 ka) of the sample taken from above the soil, from a depth of 140 cm indicating sand movement in the Preboreal Phase (Fig. 6:1). The 12.33±0.64 ka age of the another sample from the depth of 420 (under the paleosoil layer) cm suggests Younger Dryas sand movement (Table 3: 1, 2).

At Gégény outrcrops the age of the layer above the fossil soil is 9.86±0.52 ka while that of the soil is 13443–13193 cal BP while that of the layer under it is 11.37±0.51 ka (Fig6: 2; Table 2: 3; Table 3: 7, 8). This discrepancy (the paleo soil is older than the underlying sand layer) between the OSL age and C^{14} data can be the result of either the accuracy of the applied methods or that the last sand movement period of this era was detected and it took place very close to the soil forming era. The layer under the soil has accumulated in the Younger Dryas while the 150 cm thick sand accumulated on the soil is the result of sand movement in the Preboreal Phase.

Age of the fossil soil layer in the wall of the sand quarry near Máriapócs (Fig. 6:3) is 11479–12720 cal BP (Table 2: 1) on the basis of radiocarbon data. This age suggests that the sand underneath the soil accumulated in the Late Glacial or earlier while the vast amount of wind-blown sand above the soil layer (~420 cm) started to accumulate in the Preboreal Phase. Since mining cut the top of the dune, the height of the original surface is not known. At the start of mining, the sand cover was probably thicker than its current thickness of 420 cm.

In the wall of the sand quarry at Nagyvarsány-Szabadságtanya the age of paleo soil layer can be dated in the Bölling – Allerɵd Interstadial (13211–13099 cal BP; Table 2: 4). On top of it a 350 cm thick sediments were deposited in the Younger Dryas or in the Holocene. Since the current surface is not the original one due to mining, the soil probably had a sand cover larger than the current one. Directly underneath the buried soil a loess layer was found. The soil was formed on this loess layer (Fig. 6:4).

In the vicinity of Lövőpetri a soil layer with the age of 13122–12961 cal BP (Table 2: 5) was found. Here around 200 cm thick sand accumulated on the top of the soil layer also in the Holocene (Fig. 6:5).

In the profile at Baktalórántháza (Fig. 6: 6; Table 3: 3, 4, 5, 6) three sand movement period were revealed. Oldest Dryas sand movement (OSL 17.60±1.00 and OSL 15.24±0.87) was detected in the lower part of the outcrop (at depths of 420 cm and 310 cm). In the upper part of the outcrop (230 cm and 150 cm) signs of Bølling-Allerød and Younger Dryas sand movement (OSL 14.10±0.86 and OSL 11.68±0.52) were found.

In the sand quarry near Nyíradony 75 cm thick sand accumulated above a 45 cm thick soil layer (Fig.6:7) which is dated to 220–140 cal BP (Table 2: 6). This refers to a very recent sand movement.

#Table 2#

#Table 3#

#Fig 6#

Relative age data

Palynological record of boreholes

In the case of Máriapócs, a boreholes with a depth of 260 cm was set up (Fig6:1) in an abandoned bed. The pollen record can be divided into three zones. In the lower part of the profile there was well definable pollen content. In this subzone (260-170 cm) coniferous (*Pinus*, *Picea*) and deciduous (*Betula*) trees were the sources of dominant arboreal pollen indicating a cold climate (Late Glacial). The NAP (non-arbor) pollens originated from *Gramineae/Poaceae, Chenopodiaceae*. The *Bryophyta* and *Lycopodim* spores indicate bog environment. The middle zone (160-110 cm) was very poor in well definable pollen, because it contained burnt pollen, plant remnants and soot. These remnants are maybe the results of a forest or local fire which destroyed the former forest and the bog. In the upper zone there was no arboreal pollen at all (110-60 cm). The pollen of NAP originated from *Gramineae/Poaceae,* planted *Secale cereale and Aqua Phragmites* and *Cyperaceae. Secale* indicates increasing human activity (Járainé-Komlódi 1995). Based on the pollen data this subzone represents the Subboreal Phase (5.3-2.9 ka).

Accumulation of sandy material of the abandoned river bed happened in the Late Glacial. In that time, a bog vegetate in it and a boreal pine-wood steppe vegetation existed in the surroundings area which was destroyed by a local fire event.

Any deciduous trees typical for Holocene is completely missing from this pollen spectrum at all. It may be explained by the fact that the wind transport the pollen-rich sediment from the dried-out river bed, so there no was pollen remnants from the early- and mid-Holocene phases. However, the Late Glacial sediments (and pollen grains) were conserved by ground-water. The depression filled up with water again only in the Late Holocene.

In the case of boreholes at Nyírábrány a boreholes with a depth of 460 cm was set up (Fig6:2). The pollen record can be divided into eleven zones. In the lowest part of the profile (460-410 cm) *Pinus, Picea* and *Larix* are the dominant species indicating cold climate and a taiga forest vegetation which was typical in the Upper Pleniglacial (29-23ka). *Betula* and *Salix* are represented in low ratio. In the NAP *Poaceae* are the dominant. In 410-370 cm *Cyperaceae, Pediastrum Kawraiskyi, P. duplex* indicate to wetland environment and in 370-310 cm *Lycopodium, Selaginella, Sphagnum* reflect bog environment indicating that the initial lake stage of the abandoned river bed ceased by the effect of accumulation. *Selaginella* and *Sphagnum* also indicate cold climate. This vegetation was typical in the Bölling-Alleröd interstadial (16-13 ka) (Járainé-Komlódi 1995). Above these zones, layers containing burnt pollens are situated (420-310 and 290-270 cm), conserving a high number of soot grains, which refers to nearby fire. According to the sedimentary and pollen data, the fire event may happened in the Preboreal Phase (10.2-9.0 ka). Between 310-290 and 270-150 cm broken pollen grains were found indicating the relocation of the sediment.. These pollen-sterile layers are the results of sand movement in the Boreal Phase (9.0-8.0 ka) which clearly supported by the accumulation of fine sand in this zone. In 150-90 cm the proportion of deciduous trees increases, reflecting warming climate. The coniferous trees were replaced by *Tilia*, *Fagus, Fraxinus, Corylus, Quercus*, *Alnus, Ulnus.* This vegetation was typical in the Atlantic Phase (8.0-5.3 ka.). In 90-60 cm beside *Fagus, Quercus, Alnus, Ulnus, Tilia, Fraxinus*, *Salix*, *Corylus* pollen garains *Phragmites, Typha, Myriophyllum* also appear indicating a mixed beech forest and a high water level and swamp. *Bryophyta* indicate to the accumulation of wetland and the starting of bog formation. In the zones above 60 cm, the proportion of NAP increased (up to 90%) meanwhile the proportion of trees decreased to a very low level. The occurrence of *Secale* and *Triticum* reveal human disturbance (Járainé-Komlódi 1995).

In the Nyírbéltek boreholes with a depth of 460 cm was set up (Fig6:3). The pollen record can be divided into six zones. In the lowest zone (460-410 cm) only *Pinus* and *Poaceae* occured, indicating a cold climate and a taiga forest steppe vegetation. We can assign it in the Upper Pleniglacial (29-23 ka). Above this zone, between 410 and 390 cm there was a pollen sterile zone. In 390-230 cm *Pinus mugo, Selaginella, Lycopodium* and *Empetrum* also indicate cold climate and suggest bog environment. This zone can be assigned as the end of the Pleistocene because there is no *Selaginella* in the upper zones (Járai-Komlódi 2000). In 280-230 cm appearance of *Salix, Alnus* indicate a warmer climate and increasing precipitation. Above 230 cm the sediment did not any contain any pollen grains, because the climate changed cold and dry, so the bog dried out and was not able to store pollen grains. It can probably be related to the Younger Dryas (13.0-11.5 ka).

In Nyírtag borehole with a depth of 630 cm was set up (Fig6:4). The pollen record can be divided into nine zones. In the lowest zone of the borehole (630-620 cm) *Pinus, Picea, Larix* and *Betula* pollen were conserved indicating the end of the interstadial of the Upper Pleniglacial. We can assigned the age of this layer is cc. 22700-21 400 cal BP according to other pollen results (Járainé-Komlódi, 2000; Nilsson 1983). In 620-400 cm there was a pollensteril zone, in which the proportion of fine sand is 60-70%. This zone of a 220 cm thick was the result of a sand movement under a cold, dry climate, when the vegetation of the surrounding area was very poor and not covered the surface of the dunes. According to the stratigraphy and pollen analyses it may happened at 19500-23000 cal BP, in the last glacial maximum. In 400-390 cm zone, the accumulation of *Pinus, Betula* and *Cyperaceae* indicate that the swamp environment reestablished again in a short time. Maybe this happened in the Bølling-Allerød interstadial (15-13 ka). This period was followed by sand movement in the Dryas when the winds of high energy dry out the surface of the area (390-330 cm). The percentage of fine sand decrease above 330 cm. In 330-200 cm, *Pinus*, *Picea*, *Betula* and *Salix* indicate the Preboreal Phase (10.2-9.0 ka). Between 200 and 180 cm, the occurrence of coniferuous tress, *Pinus, Abies, Tilia, Ulmus Corylus* indicate a warm and dry climate, which can probably be related to the Boreal Phase (9.0-8.0 ka). Between 180 and 130 cm *Pinus sylvestris, Abies, Tilia, Ulmus, Alnus, Quercus, Acer, Corylus* indicate a warm and humid clmate which can be related to the Atlantic Phase (8.0-5.3 ka). *Fagus, Alnus, Tilia, Quercus* only appear in a thin zone between 150 and 130 cm indicating an even and wet climate. It was typical in the Subboreal Phase (5.3-2.9 ka). The occurance of *Plantago* in the NAP indicates disturbance and trapping on the area. Between 120 and 90 cm, the percentage of the sand in the sediment is about 70-80% and these zones was pollen-sterile, which indicate a sand movement in the Subatlantic Phase (2.9-0 ka). It may happened in the consequence of anthropogenic activities (forest clearing, ploughing) and not climate change.

#Fig7#

Discussion

Chronology and paleoenvironments

The blown sand of the Nyírség area evolved on Pleistocene alluvial fans. After the Stillfried interstadial (34-30 ka) the climate turned first rather arid then cold and arid. According to paleontological and palynological data, at the time of maximum cooling the annual mean temperature in Hungary was -1 to -3°C, -1 to -13°C in January and 11 to 13.5°C in July (Borsy, 1991). The annual amount of precipitation may have been 180-250 mm. On the basis of pollen record near Nyírtag, Nyírlugoa and Nyírábrány, a pine forest steppe vegetation was typical in the closest surroundings of paleovalleys and form a taiga-like landscape at this time, but due to the cold, arid climate the surface of the dunes was not properly protected by vegetation from the high energy winds, thus, on the unprotected surface blown sand movement and the evolution of sand forms started. According to our stratigraphical, climathological and palynological knowledge the first great wave of blown sand movement took place between 27 and 22 ka. The radiocarbon dating of our own measurements and other scientist from another part of Nyírség (Borsy et al. 1981) and from another sand dune areas from the Great Hungarian Plain (Újházy et al. 2003), however an indirect way, but also support the idea of sand movement in the Upper Pleniglacial or in the Late Glacial (Table 4.). In the Late Glacial under more arid conditions, with a mean temperature 6-7 °C lower than the present-day one (Andreánszky 1954), the steppe vegetation became poorer again and, at many places, a new period of sand movement began which reshaped the dune forms.The OSL age of the lowermost part of outcrop near Baktalórántháza (15.24±0.87) support an Oldest Dryas (15-13 ka) event, which is thought to be the second significant period of sand movement besides the Upper Pleniglacial. Novotny et al. (2012) also revealed sand movement in Oldest Dryas near Tura in Hungary. The pollen record of Nyírtag and Nyírbéltek also support an Oldest Dryas event. In the depressions between dunes, a different thick of sand layers were accumulated, where the former pollen rich layers were covered by pollen sterile sand layers.On the basis of the thin of sand layers we can give accumulation rate: it is about 0,3 mm/year at Nyírtag and 0,5 mm/year at Nyírbéltek. But the problem is, that the area was affected by wind erosion, so deflation as well as accumulation occurred in the area (obviously in different time). So this accumulation rate is only an approximate value.

In the Nyírség, sand movement in the Younger Dryas (13-11 ka) Phase aslo can be supported by absolute and relative age determination methods as well. We could demonstrate this sand movement in the surrounding of Kántorjánosi (12.33±0.64), Baktalórántháza (11.68±0.52) and Gégény (11.37±0.51) where about 2-3 meter thick sand was accumulated. Near Kántorjánosi and Máriapócs a paleosoil layer formed out (11340-11130 and 12889-12720 cal BP) covered the sand layers indicating, that the beginning and ending of sand movement was different. The pollen record of Nyírtag, Nyírábrány and Nyírbéltek also support a Youngest Dryas event, with an accumulation rate of 0.5-0.7 mm/year, 0.2-0.16 mm/year. In the case of Nyírbéltek we could not calculate rate, because this record did not content pollen at all in the samples from 1.5 meter to the surface.

On the basis of our pollen records, the climate during the Bölling – Allerød Interstadial was warmer and humid. Pine forests and bich trees stabilised the surface. In this Phase paleosoil formed on the top of the dunes. The thin of this layers are very different, because the soil forming factors (precipitation, time, environment etc.) was also very different. In the dunes, only one paleosoil layers is observable between sand strata. From this fact, we can conclude that there was just one period in Late Glacial in Nyírség, when this paleosoil layers formed out. These palosoils are very widespread in the Carpathian basin (Table 4.) suggesting that it was a usual soil forming period.

The first half of Preboreal Phase is claimed to be dry, while the second was more humid. As the climate became warmer and more humid in the Preboreal Phase (10.2-9 ka), an increasing number of deciduous trees mixed into the pine forest. The area was covered by pine tree forest – steppe vegetation. But, in the first half, the steppe vegetation could not preserve the surface from the winds so the sand could move again. According to the present data, there are a lot of clear evidence of sand movement, not only in the Nyírség, but other part of Carpathian Basin as well (Table 4.).

At the beginning of the Boreal Phase (9-8 ka) the climate turned drier and warmer and more continental, so coniferous trees were repressed by steppe vegetation (Stipa-Festuca-Chrysophon steppe meadows). As a consequence of desiccation, the ancient swamps dried out. The remnant of sand movement is only observable in the Nyírábrány coring where sand movements was the consequence of forest fires which destroyed the vegetation and let the surface uncovered.

In the Atlantic Phase the climate turned humid and temperate was also warmer than in nowadays. A forest-steppe vegetation (mixed oak forests) established in the Nyírség, and the swamps formed out again in the abandoned river beds. According to the palynological analyses, the late Atlantic Phase was drier. Sand movement was revealed in three places in the Carpathian Basin (Table 4.). Some archeological evidences indicate anthropogenic effects (human-induced fires and sand mobilization due to slash and burn agriculture and overgrazing in the Neolithic and the Copper Age), as a cause for sand movement (Kis et al. 2012).

In the Subboreal Phase the climate was cooler, more humid and less continental than in nowadays. Large areas in the Nyírség were covered by mixed oak forests – some scattered swamps were situated between them. The extent of the swamps was the largest in this period. Up until now, there is no evidence for sand movement in the Nyírség – due to the humid climate and vegetation covering.

In the Subatlantic Phase the climate changed dryer and more continental. The disturbance of humanity becomes abundant. The Nyírség was continuously inhabited in the Medieval Ages from the 11th century until the Turkish Occuoation (XVI-XVII. century). The youngest period of sand mobilisation which was determined near Nyíradony took place during a cooler and drier period of the Little Ice Age. Furthermore it gives evidence of human activity after the Turkis Occupation, when the area was repopulated again. Large forest areas were cleared because of extension of arable lands during and after in the Nyírség. This process was accelerated in other sand territories of the country, mainly in the 18th and 19th centuries. Sand movement was further promoted by overgrazing (Frisnyák 2002). Taking into consideration the climatic conditions, we state that sand movements was mainly the consequence of human activity (Kiss et al. 2012). There are a lot of evidence of sand movement of this period in the different part of Carpathian Basin (Table 4.). Sand depositions were dated from places in NE Hungary by Kiss et al. (2008) with OSL ages. Four hundred years older sand accumulation was determined by IRSL dating from the Kisoroszi profile from the Szentendrei Island (Ujházy et al., 2003) and by OSL dating from Kiskunhalas and Csengele from the Danube–Tisza Interfluve (0.596±0.068 ka and 0.658±0.114 ka (Nyári et al., 2007).

The recently developed forms are, however, much smaller than those that have been formed by the end of the Late Glacial. Based on our results the thickness of the relocated material is very different on the surface of the dunes. This difference could be explained by the vegetation cover of the area, the sand supply, the power of the wind, the level of underground water and the length of dry periods. Since wind erosion had become increasingly intense, it caused more and more loss to agriculture. The strong spring winds can cause, in spite of the advanced agricultural techniques, heavy wind erosion losses to agriculture even today.

On the basis of the results it seems as if aeolian activity in the Holocene was more widespread in the basin than it was previously suspected, however, in areal extension it was much smaller than those in the Upper Pleniglacial (Table 4).

#Table4#

Conclusions

Wind played an important role in the development of the Nyírség alluvial fan. Land was formed primarily by wind following the drying of the alluvial fan. Different age determination methods completed each other rather well. The results of this study indicate that after the first major sand movements (Upper Pleniglacial) further sand movements followed this in the dry periods of the Late Glacial. However, aeolian transformation of the surface did not cease at the end of the Pleistocene as sand started to move several times in the Holocene as well. Sand movement in the first half of the Holocene, in the Boreal and in the Subatlantic Phase took place due to climatic and also anthropogenic reasons. The paleosols developed in the Preboreal and Boreal phases in the early Holocene.

Data obtained using absolute age determination methods (radiocarbon and OSL) support each other and determine similar sand movement periods.

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Figure captions

Fig.1. A typical landscape in Nyírség

Fig.2. Location of the studied samples in the Nyírség

Fig.3. Dose recovery preheat plateau tests of OSZ761 and OSZ810 samples

Fig.4. Shine down curves and dose response curves of selected aliquots representing a younger and an older sample

Fig.5. Grain size distribution diagram of the material of the outcrop at Máriapócs and the borehole at Nyírtag

Fig.6. The sections of the studied sand mines: 1: Kántorjánosi, 2: Gégény, 3:Máriapócs, 4: Nagyvarsány-Szabadságtanya, 5: Lövőpetri, 6: Baktalórántháza, 7: Nyíradony

Fig.7. The sections of boreholes and detailed palynological data: 1: Máriapócs, 2:Nyírábrány, 3:Nyírbéltek, 4: Nyírtag

Table1: The major data of sampling sites

Table2: Summary of the calibrated and conventional radiocarbon age data

Table3: Equivalent dose, dose rate and age results of OSL dating.

Table4: Summary of the sand movements in Hungary

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Signed by all authors as follows:

Lóki József

Andrási Bence

BURÓ BOTOND

SIPOS GYÖRGY

FÉLEGYHÁZI ENIKŐ

[illegible] Gábor

[illegible]

[illegible]

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