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NEW RADIOCARBON DATA FROM THE PALEOSOLS OF THE NYÍRSÉG BLOWN SAND AREA, HUNGARY

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ABSTRACT. Despite many ideas about the age and processes of sand movements and paleosol formation, there are still some uncertainties in this relations in the Nyírség, eastern Hungary. The major aim of the present study was to clarify the chronology of fossil soils and blown-sand layers in the sand dunes of the Nyírség using radiocarbon (^{14}C) dating on soil and charcoal samples. Charcoal and soil samples were collected from buried paleosols from different sand quarries for ^{14}C dating. The bulk organic carbon content of the buried soil and charcoal pieces recovered from buried fossil soil layers allowed parallel ^{14}C accelerator mass spectrometry dating in several cases. The new ^{14}C results indicate paleosol development during Younger Dryas, while the preceding interstadial was assumed as a cold and dry period when only sand movement occurred in the area. Our results also confirm and support the previous assumptions, that in the Late Glacial, the first paleosol development period was during the Bølling-Allerød Interstadial. Four soil-forming periods could be determined during the Holocene (Preboreal, Boreal, Atlantic, Subatlantic). We have also indirectly identified sand movements during the Oldest Dryas, Younger Dryas, Preboreal, Boreal, and Subatlantic phase in the study area.

KEYWORDS: aeolian activity, Holocene, Late Glacial, paleosol, radiocarbon dating.

INTRODUCTION

Several scientists studied the development of the Nyírség area (Hungary) in the early 20th century. Nagy (1908) and Cholnoky (1910) were the first to discuss dune formation periods and the surface evolution of the area. The accepted theory of formation, established by Sümeghy (1944), is that the area was formed as an alluvial fan of rivers originating from the Carpathians, on the basis of stratigraphic analysis of cores from several boreholes. The alluvial fan was uplifted by tectonic forces in the Upper Pleniglacial (29–23 ka), meanwhile the surrounding regions subsided, so rivers gradually slipped down, and in dry periods, winds could blow out sand from fluvial deposits (Lóki et al. 2012).

From the middle of the 20th century, Borsy began extensive research in Nyírség over several decades. In his book *Physical Geography of Nyírség*, Borsy (1961) accepted Sümeghy's alluvial fan theory for the geomorphological development of the area. 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 (Borsy 1961). Later, the first radiocarbon (^{14}C) data from this area indicated that the first major sand movements occurred at the end of the Upper Pleniglacial (ca. 29–23 ka) (Borsy 1980; Borsy et al. 1981) and in the Late Glacial (15–10 ka) (Borsy et al. 1981; Lóki et al. 1994), when the climate was cold and dry.

Fossil soils formed on the aeolian surface in the warm and wetter periods of the Weichselian (Würm) and were covered by wind-blown sand again during the Younger Dryas (Borsy et al. 1981; Lóki et al. 1994; Buró et al. 2016).

The transformation of the sand surfaces in the Nyírség did not cease at the end of the Pleistocene but continued into the drier periods of Holocene as well (Lóki 2006; Kiss et al. 2012; Buró et al. 2016). In the first half of the Holocene, when vegetation cover decreased,

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the sand was mobilized again (Félegyházi and Lóki 2006; Kiss and Sipos 2006; Kiss et al. 2008, 2012). During the second half of the Holocene, sand started to move again during several times (primarily in the Iron Age) in the Hungarian wind-blown sand areas. This was a consequence of human impact such as deforestation, overgrazing, and ploughing (Lóki and Schweitzer 2001; Gábris 2003; Újházy et al. 2003; Nyári and Kiss 2005; Félegyházi and Lóki 2006; Sipos et al. 2006; Nyári et al. 2006a, 2006b, 2007a, 2007b; Buró et al. 2012; Kiss et al. 2012). In order to extend arable lands, deforestation was also widespread in the 18th and 19th centuries. As a result, sand was mobilized again in areas that had been deforested (Marosi 1967; Borsy 1980, 1987,1991; Lóki 2003; Buró et al. 2016).

When determining the age of sand movements and paleosols, or clarifying stratigraphic problems in sand dunes, we can use different dating methods, such as ^{14}C dating (Raghavan et al. 1989; Goble et al. 2004; Miao et al. 2016). This method has already been used in several studies to understand the surface evolution of Nyírség (Borsy et al. 1981; Kiss et al. 2012; Lóki et al. 2012).

Soil development periods in the sand dunes of the Nyírség have not been well studied. Researchers have mainly focused on periods of aeolian movement and only estimated but did not investigate soil development during wetter and warmer interstadial periods (Bølling-Allerød, Preboreal) (Gábris 2003; Buró et al. 2016). Their former estimates are based on mainly OSL and a few charcoal ^{14}C age data, but are not yet verified by parallel ^{14}C dating of soil organic carbon and charcoal remains. Thus, the major aim of our study was to determine and clarify the periods of soil formation and blown-sand movement of the Nyírség sand dunes, using new ^{14}C results.

STUDY AREA

The Nyírség is the second largest sand dune area (ca. 5100 km^2) in the Carpathian Basin, which formed on the alluvial deposits of the Tisza and Bodrog Rivers and their tributaries. Around 25 ka ago, fluvial processes ended in this area (Borsy 1991; Lóki 2006) and the alluvial fan dried out and wind again became the dominant geomorphic agent. The first significant sand movement was in the Upper Pleniglacial and the Late Glacial (Borsy et al. 1981; Borsy 1991; Lóki et al. 1994). In these periods, the main deflation (deflation depression, deflation hollows, etc.) and accumulation forms (sand hummock, parabolic dunes, asymmetric parabolic dunes, etc.) developed.

The study area is located in the temperate zone. According to the Köppen–Geiger climate classification (Kottek et al. 2006), warm summer and humid continental climate is typical on the area. The mean annual temperature is 9.6–9.8°C, January and July monthly mean temperatures are –2 and 20.4°C, respectively, and the average annual rainfall is 550–650 mm (Borsy 1961).

According to the Word Reference Base for soil classification system, the soils are classified as Lamellic Arenosols, Luvisols, Gleysols, Cambisols, and Phaeozems (Novák et al. 2014). The main texture types of the soils are sand, sandy loam, and loamy sand. The study area is situated within the forest steppe zone and potential natural vegetation could be oak forest steppes.

Planted forests, ploughed lands, and grasslands are the main land-use forms. Recently, there has been reforestation using different non-native species (*Robinia pseudo-acacia, Quercus rubra*, etc.) (Borhidi and Sánta 1999).

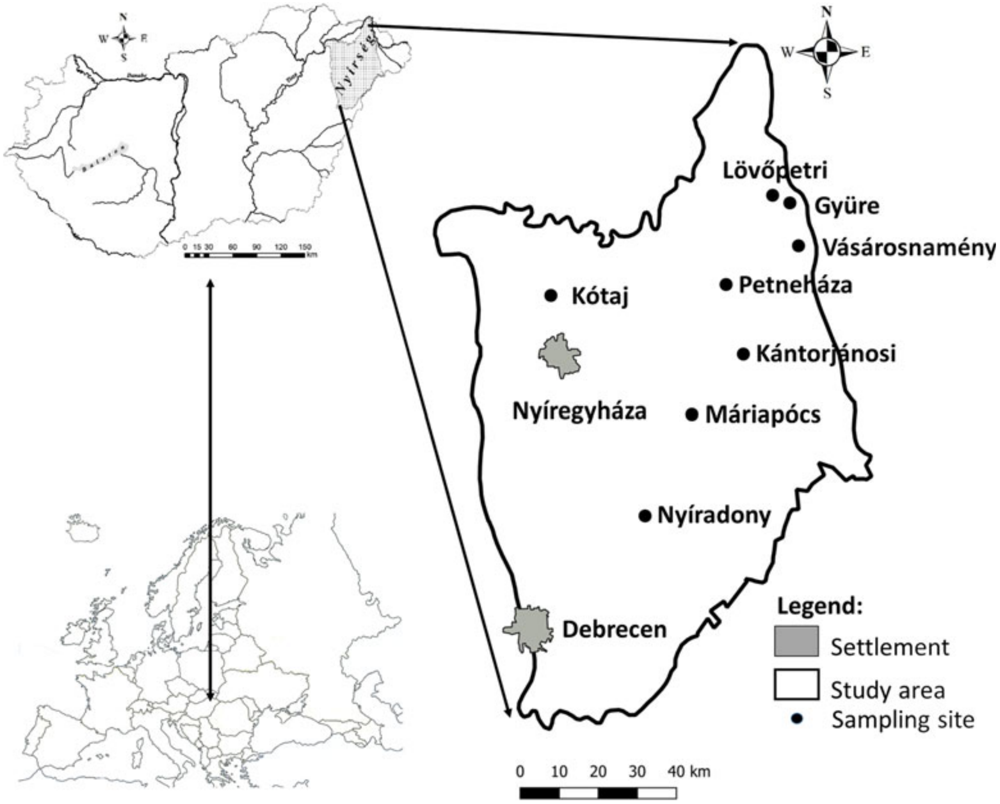

Figure 1 Locations of the sampling sites in the Nyírség.

However, the vegetation cover has changed with the climate in the past (Borsy 1961; Járainé-Komlódi 2000; Sümegi et al. 2013; Feurdean et al. 2014; Magyari et al. 2014). In the Preboreal phase, the dominant tree species were pine and birch, then the shrubs replaced these species. During the Boreal phase, peanut was the most dominant species, and in the Atlantic phase, oak was the dominant tree species. Furthermore, ash (Fraxinus), oak (Quercus), and elm (Ulmus) mixed forests covered the area. During the last 3000 years, beech and oak became the main species in the forests.

METHODS

Sampling

Outcrops were chosen for sampling where buried soil layers were clearly observable (Figure 1, Table 1). For ^{14}C accelerator mass spectrometry (AMS) determination, we collected soil samples from fossil soil layer in 8 quarries. Every sand quarry contains one fossil soil layer. From outcrops (Table 1) where the buried soil contained enough charcoal, samples for ^{14}C AMS age determination were also collected.

During the last decade, we have investigated more than 100 sand dune excavations in the Nyírség area and we found buried soil horizons only in 10 cases (Buró 2016). Even if one can find a buried paleosol, there is only a small chance of finding a macroscopic amount of

Table 1 Major properties of the sampling sites. All sites are outcrops from oval-shaped hummocks.

		Geographical coordinates				
Site nr.	Location	Φ	λ	Number of samples for ^{14}C dating (soil, charcoal)	Morphology	Vegetation
1.	Gyüre	48°10′00″	22°15′18″	1+1	Hummocky dune	Robinia forest
2.	Lövőpetri	48°10′46″	22°13′00″	1+1	Hummocky dune	Robinia forest
3.	Kántorjánosi	47°56′20″	22°08′08″	1+1	Hummocky dune	Robinia brushes
4.	Máriapócs	47°51′00″	22°00′50″	1+1	Hummocky dune	Robinia brushes
5.	Petneháza	48°02′45″	22°06′09″	1+1	Hummocky dune	Robinia brushes
6.	Kótaj	48°02′20″	21°42′15″	1+0	Hummocky dune	Grass mixed with Rubinia brushes
7.	Vásárosnamény	48°06′02″	22°16′14″	1+1	Hummocky dune	Grass
8.	Nyíradony	47°41′54″	21°53′59″	1+1	Hummocky dune	Robinia forest

charred remains. However, there is also the possibility to determine the age of paleosols not only on the basis on their charcoal content but on their organic carbon content. Therefore, we conducted exhausting measurements to clarify the applicability of this method and to compare the result of two methods to each other.

Radiocarbon Dating

For ^{14}C AMS analysis, samples from charcoal and bulk soil samples were pre-treated in the Hertelendi Laboratory of Environmental Studies (HEKAL) AMS laboratory (Molnár et al. 2013a). Inorganic carbonates in soil samples were removed by 1M HCl at 75°C, for at least 2 hr. In the case of charcoal fragments, these were treated using the standard acid-base-acid (ABA) method, i.e. a sequence of 1M HCl, distilled water, 1M NaOH, distilled water, and then 1M HCl at 75°C, for 1–2 hr each step (Molnár et al. 2013a). After the final acid wash, the sample was washed again with distilled water to neutral pH and freeze-dried. For all types of sample materials (macroscopic charcoal fragments and bulk soil), a two-step combustion method was applied: first at low temperature (400°C, "LT" fraction) and afterwards on the same sample at high temperature (800°C, "HT" fraction) in the presence of high-purity oxygen gas in a quartz tube (Jull et al. 2006; Molnar et al. 2013a). Because of the rather low organic content in the soil samples (typically: 0.1–0.6%), we had to combust 1–2 g of each bulk sample in our on-line combustion system. In every case, combustion resulted at least 0.2 mg C/sample for the both fractions, which allowed production of graphite targets and normal AMS analyses.

The CO_2 gas was then collected and purified separately to form LT- and HT-fractions using an on-line combustion system line and later converted to graphite using the sealed tube Zn-graphitization method (Rinyu et al. 2015). IAEA–C9 (fossil wood) standards were treated and measured in parallel to the samples to check the quality of the sample preparation.

All ^{14}C measurements were made on the graphitized samples using a compact ^{14}C AMS system (Environ MICADAS) (Synal et al. 2007; Wacker et al. 2010) at the HEKAL (Molnár et al. 2013b). NIST SRM 4990C standards and borehole CO_2 blanks were used for normalization of the MICADAS. The results were corrected for decay of the standard and the effect of δ^{13}C isotopic fractionation. For data reduction of the measured values, we used the BATS software (Wacker et al. 2010).

Conventional ^{14}C ages were converted to calendar ages using Calib 7.0.4 software (Stuiver and Reimer 1993) and the IntCal13 calibration curve (Reimer et al. 2013). Calibrated ages are reported as age ranges at the 2-σ confidence level (95.4%).

The HT charred fraction of the soil organic carbon (SOC) is usually older than the charcoal and LT non-charred fraction of the SOC, occasionally unrealistically older than expected. This may be due to the very low carbon content of these samples. Unfortunately, we cannot use these values. We used only the ^{14}C age of charcoal samples and the LT fraction for determining paleosol development periods.

RESULTS

Results of Radiocarbon Analyses

We present soil organic carbon and parallel charcoal ^{14}C ages from all the dunes investigated (except Kótaj). Information on the sample sites (name, landform type, number of samples) is summarized in Table 1.

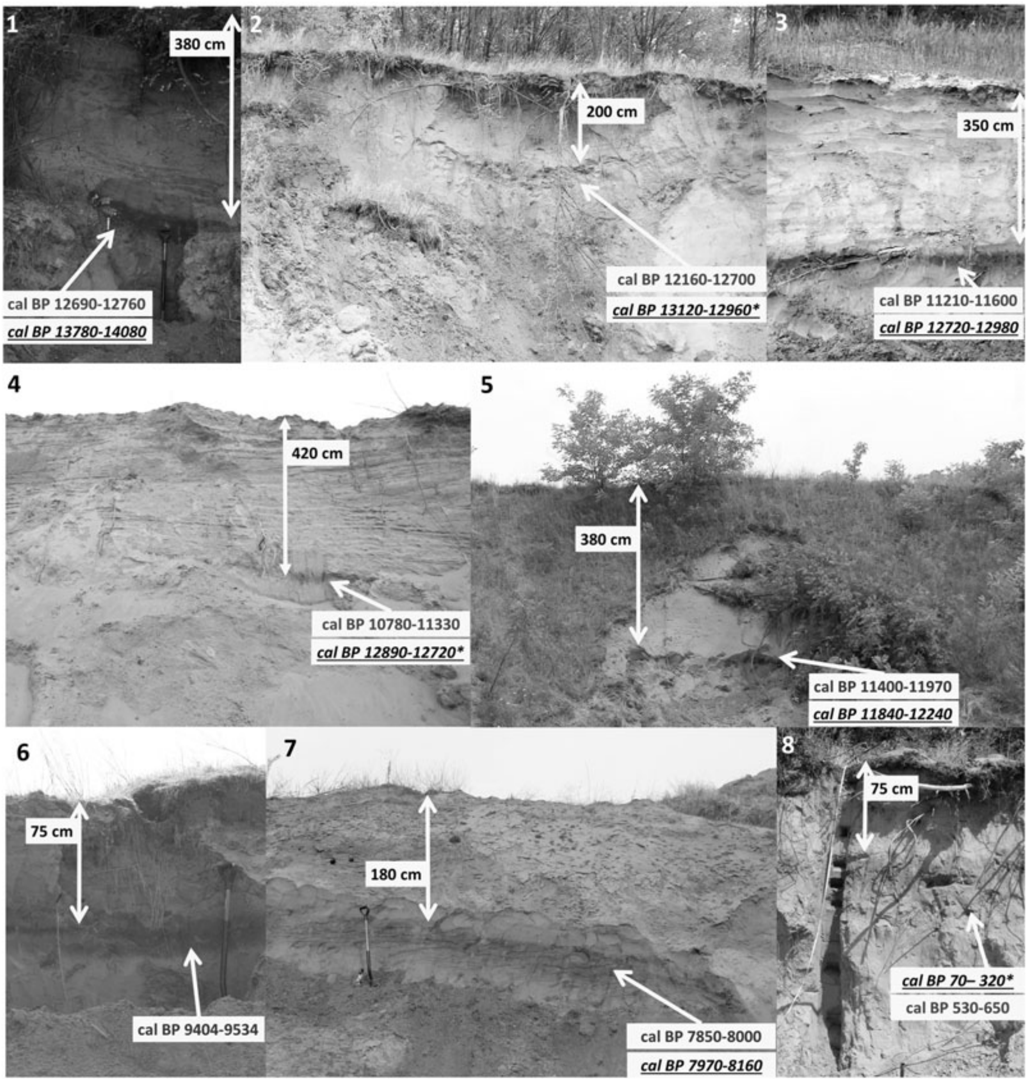

Figure 2 Sections of the sand quarries studied: 1: Gyüre, 2: Lövőpetri, 3: Kántorjánosi, 4: Máriapócs, 5: Petneháza, 6: Kótaj, 7: Vásárosnamény, 8: Nyíradony. (From Buró et al. 2016.)

Gyüre

At a depth of 380 cm, we found a 40–50-cm thick fossil soil horizon. The development of this soil layer may have started in the Bølling-Allerød phase according to the charcoal ^{14}C age (cal BP 13,780–14,080 [2σ]) and continued to the beginning of the Younger Dryas (LT-SOC: cal BP 12,690– 12,760 [2σ]) (Figure 2, panel 1; Table 2). At the beginning of the Younger Dryas, sand was not mobile in this area. This fossil soil layer was covered by blown sand, at a time when the surface vegetation cover was reduced.

Lövőpetri

In case of the Lövőpetri outcrop, there is a 25-cm-thick buried soil layer in 200-cm depth. The charcoal age (cal BP 12,890–13,110 [2σ]) from this horizon is very similar to Gyüre.

Table 2 Summary of radiocarbon ages of charcoal and fossil soil.

Site (depth)	Material	Lab. ID	Comb. temp. (°C)	C yield (m/m%)	Conventional ^{14}C age (yr BP)	Cal BP age range (2σ)	Geochronology (according to cal BP)
1. Gyüre (380–410 cm)	Soil (SOC-LT)	DeA-12994	400	0.14	10831 ± 35	12690–12760	Younger Dryas
	Charcoal (HT)	DeA-12993	800	27	12087 ± 38	13780–14080	Bølling-Allerød
2. Lövőpetri (200–225 cm)	Soil (SOC-LT)	DeA-15196	400	0.05	10552 ± 82	12160–12700	Younger Dryas
	Charcoal (HT)	DeA-3276	800	55	11153 ± 43*	12890–13110	Bølling-Allerød
3. Kántorjánosi (350–360 cm)	Soil (SOC-LT)	DeA-15194	400	0.11	9903 ± 50	11210–11600	Preboreal
	Charcoal (HT)	DeA-15192	800	20	10964 ± 53	12720–12980	Bølling-Allerød/ Younger Dryas
4. Máriapócs (420–440 cm)	Soil (SOC-LT)	DeA-15206	400	0.04	9754 ± 85	10780–11330	Preboreal/Younger Dryas
	Charcoal (HT)	DeA-1855	800	42	10947 ± 41*	12710–12930	Bølling-Allerød/ Younger Dryas
5. Petneháza (380–390 cm)	Soil (SOC-LT)	DeA-15201	400	0.09	10104 ± 49	11400–11970	Preboreal/Younger Dryas
	Charcoal (HT)	DeA-12794	800	25	10287 ± 34	11840–12240	Younger Dryas
6. Kótaj (75–110 cm)	Soil (SOC-LT)	DeA-14007	400	0.39	8447 ± 45	9400–9530	Boreal
	Charcoal (HT)	NA					
7. Vásárosnamény (180–260 cm)	Soil (SOC-LT)	DeA-14425	400	0.24	7104 ± 43	7850–8000	Atlantic
	Charcoal (HT)	DeA-17325	800	38	7227 ± 47	7970–8160	Atlantic
8. Nyíradony (75–120 cm)	Soil (SOC-LT)	DeA-15199	400	0.09	577 ± 43	530–650	Subatlantic
	Charcoal (HT)	Deb-18293	800	45	210 ± 40*	70–320	Subatlantic

*Published in Buró et al. (2016).

The non-charred fraction of soil organic carbon radiocarbon age (LT-SOC: cal BP 12,370–12,700 [2σ]) (Figure 2, panel 2; Table 2) is already in the Younger Dryas. The process of soil development for this fossil soil layer and the paleoenvironment is apparently similar to Gyüre.

Kántorjánosi

At the Kántorjánosi outcrops, the ^{14}C age of the charcoal (cal BP 12,720–12,980 [2σ]) can still be assigned to the Bølling-Allerød, while the fossil soil age (LT-SOC: cal BP 11,210– 11,600 [2σ]) is Preboreal (Figure 2, panel 3; Table 2). These ^{14}C ages are supported by OSL ages, from a previous study (Buró et al. 2016) at the same location. The age of the blown sand under and above the fossil soil layer: 12.33 ± 0.64 ka and 9.34 ± 0.52 ka (Buró et al. 2016). A 350-cm-thick blown-sand layer accumulated on the fossil soil. This accumulation indicates sand movement sometime in the Holocene.

Máriapócs

In an oval-shaped hummock near Máriapócs, we found a 20-cm-thick fossil soil at a depth of 440–420 cm. From this soil layer, the calibrated age of charcoal is cal BP 12,710–12,930 (2σ) and the age of the non-charred LT-SOC fraction is cal BP 11,060–11,330 (2σ) (Figure 2, panel 4; Table 2). The two types of radiocarbon data (charcoal and LT-SOC) indicate Younger Dryas soil development, which extended into the preboreal. However, due to environmental changes the sand started to move again and accumulated (more than 4 m thick) onto the fossil soil during the Preboreal phase. We assume that since the current surface is not the original one due to recent quarrying operations, the soil probably had a larger sand cover than currently observed.

Petneháza

In the profile at Petneháza, a 15–20-cm-thick fossil soil layer was found around 380-cm depth. Both the charcoal (cal BP 11,840–12,240 [2σ]) and the soil organic carbon (LT-SOC: cal BP 11,400–11,970 [2σ]) (Figure 2, panel 5; Table 2) ages are consistent with the Younger Dryas.

Kótaj

In the wall of the sand quarry at Kótaj, a 35-cm-thick paleosol layer was discovered, which did not contain even macroscopic amounts of charcoal. We could only date the LT-SOC fraction of the soil organic carbon, which developed in the Boreal Phase (LT-SOC: cal BP 9400–cal BP 9530 [2σ]) (Figure 2, panel 6; Table 2). On top of this horizon, there is a 75 cm thick sand deposit.

Vásárosnamény

In the huge sand quarry near Vásárosnamény, 160–180-cm-thick sand accumulated above a 70–80-cm-thick soil layer (Figure 2, panel 7), which is dated from the LT soil organic carbon to cal BP 7850–8000 (2σ) (Table 2). The charcoal age is a little bit older (cal BP 7970–8160 [2σ]) than the LT-SOC age. There was a previous surface with soil cover. Due to changes in local environmental conditions, the surface has eroded to the buried soil. Thereafter, a rapid soil development began on the eroded surface in the Atlantic phase, then the surface was covered again with sand from the same chronological phase.

Nyíradony

In the profile at Nyíradony, a 45-cm-thick fossil soil layer was found, which has a soil age for the LT fraction of cal BP 530– 650 (2σ) (Figure 2, panel 8; Table 2). This is considerably older than the charcoal age (cal BP 320–70 [2σ]) (Figure 2, panel 8; Table 2). A 75-cm-thick sand deposit accumulated above this soil layer after a fire event, so we also associate this horizon with Subatlantic soil formation and subsequent sand movement.

DISCUSSION

Observation of Upper-Pleniglacial Events

We have little information about sand movement (Borsy et al. 1987) and soil formation during the Upper Pleniglacial in the blown-sand areas of Hungary. During this period, the climate was cold and dry, and 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. The annual amount of precipitation is estimated to have been 180–250 mm (Borsy 1991). Based on previous palynological studies, pine-forest steppe vegetation covered the sandy surface and formed a taiga-like landscape at this time (Lóki et al. 2012; Buró et al. 2016). Nevertheless, the sparse vegetation could not protect the surface against high-energy winds.

Our new ^{14}C measurements from Kántorjánosi, Gyüre, and Lövőpetri indicate soil formation in Bølling-Allerød interstadial, where the sand layers under the fossil soil may have accumulated in a former cold and dry phase in the different parts of the Upper-Pleniglacial (26–20 ka BP), as described by Lóki et al. (2012). Our results also confirm previous studies including ^{14}C and OSL data about sand movements from other parts of the Nyírség (Borsy et al. 1981; Buró et al. 2016) and also in other sand dune areas of the Carpathian Basin (Sümegi and Lóki 1990; Sümegi et al. 1992; Újházy et al. 2003; Novothny et al. 2010).

Observation of Late Glacial Events

The warmer and humid climate of the Bølling-Allerød Interstadial was favorable for vegetation growth and the initiation of soil formation processes around the Carpathian Basin. With the spread of pine and birch forests, the sand surface was stabilized and soil formation began on the top of the sand dunes. This initial soil formation phase is the earliest observed not only in the Nyírség but also in the adjacent Bodrogköz (Borsy et al. 1981). The new charcoal radiocarbon ages from Kántorjánosi, Gyüre, Lövőpetri as well as previous studies (Csongor et al. 1980; Borsy et al. 1981; Buró et al. 2016) also support these soil-forming periods in the Nyírség. The features (thickness, color, carbon content) of these buried fossil soils are very variable during this period, indicating different development conditions. In the sand dunes of the Nyírség, previously and in this study, only one fossil soil layer was described. According to our radiocarbon measurements, a significant part of these soil layers developed in the Bølling-Allerød interstadial, and they are not separated by blown sand horizons. Based on these things, the existence of the two interstitial (Bølling and Allerød) and Older Dryas periods in the area can be questioned. If there was Oldest Dryas sand movement, this may have been a local event which caused strong storms. Gábris (2003) had also shared this opinion.

The Younger Dryas has been regarded as a general period of sand movement. Previous age data and publications (Gábris 2003; Újházi et al. 2003; Buró et al. 2016) show that in the Younger Dryas, sand movement was the dominant land-forming process on blown-sand areas in Hungary. However, the radiocarbon ages of soil organic carbon of fossil soils from Máriapócs, Petneháza, Gyüre, Lövőpetri suggest soil formation also took place in this period. This may be due to the lack of continuous surface coverage in the Nyírség, therefore the degree of sand movement and soil formation might vary across the landscape.

Earlier publications (Gábris 2003; Buró et al. 2016) and results from Gyüre and Lövőpetri confirm the assumption that the formation of fossil soils started in the Bølling-Allerød and this process continued in the Younger Dryas as well. Subsequently, climate and environmental conditions changed, and sand began to move again and buried these soils.

Observation of Holocene Events

The aeolian transformation of the surface did not cease with the end of the Pleistocene, as sand also started to move several times during the Holocene. Preboreal (12.1–10.2 ka) and Boreal (10.2–8.3 ka) sand movement has been described at several locations (Félegyházi and Lóki 2006; Thamó-Bozsó et al. 2007; Kiss et al. 2012; Buró et al. 2016). For the Preboreal-Boreal transition, there are good examples in the outcrops of Petneháza, Lövőpeti and Gyüre. During the early Holocene, thick aeolian sand layers were deposited during the Preboreal and Boreal onto the layers deposited in the Late Glacial.

At the same time, during this period, soil formation also took place in the Nyírség. The fossil soil age in the profile at Kántorjánosi is Preboral and the profile at Kótaj suggests soil from the Boreal phase.

In the first half of the Atlantic Phase (8.3–7.0 ka), the climate would have turned humid and temperate and was also warmer than today. A forest-steppe vegetation (mixed oak forests) was established in this area (Járainé-Komlódi 2000; Kiss et al. 2012; Buró et al. 2016). These factors provided favorable conditions for soil formation. From this period, Újházy et al. (2003) described paleosoil layers from Dunavarsány, Pócsmegyer and Kisoroszi. Earlier, no paleosol layer had been identified in the Nyírség from the Atlantic phase, but according our recent radiocarbon data the paleosol in the sand quarry of Vásárosnamény developed in this period and shows evidence of soil formation processes. In the late Atlantic Phase (7.0–5.7 ka) the climate became drier, and the sand was mobilized again (Kiss et al. 2008, 2012) and covered this weakly developed soil layer.

During the Subboreal Phase (5.7–2.6 ka), the climate was cooler, more humid and less continental in this region than today. The area was covered mainly by mixed oak-hornbeam forests and swamps (Kiss et al. 2012). There are no records in the literature showing soil forming and sand movement in the Nyírség from this period.

In the Subatlantic Phase (<2.5 ka), the climate changed again and became drier and more continental and anthropogenic disturbance had become very significant (Kiss et al. 2008, 2012; Nyári et al. 2007a, 2007b; Novothny et al. 2010; Buró et al. 2012). The sample area was inhabited from historical times until the Turkish Occupation (14th–17th century). At that time, the effect of human activities was more significant than climatic effects on the transformation of the surface.

After the Turkish Occupation, the Nyírség was repopulated. The forests were cleared in order to extend the arable lands not only in the Nyírség but also in other parts of the country, mainly later during the 18th and 19th centuries. This process and overgrazing contributed to that sand movement (Frisnyák 2002). The outcrop of Nyíradony is a good example for these effects (Buró et al. 2016). After deforestation, the area became bare and the wind remobilized the upper sand layers and transported them onto the fossil soil, which had originally developed in the Subatlantic Phase.

Based on the ^{14}C results, the first paleosols development period might have happened in the Bølling-Allerød Interstadial and continued in the Younger Dryas. During the Holocene (Preboreal, Boreal, Atlantic, Subatlantic) soil layers were formed several times in the Nyírség. Formation of these soil horizons was interrupted by several sand movement periods in this area.

The properties of the investigated fossil soils vary substantially. This indicates that the soil formation conditions had been changing significantly from the Upper Pleniglacial until today. Therefore, in contrast with earlier studies, we cannot simply connect one geological/geochronological phase to one period of sand movement or soil formation in the Nyírség. This contradicts the previous opinion that sand movement only occurred during dry cold periods (ex. Younger Dryas). We also identified sand movement and soil formation within the same periods.

CONCLUSIONS

In the study area, the investigated charred plant remains are the result of fire. After the fire event, soil formation process and organic material decomposition might have continued. Except in historical times, in every investigated case the SOC-LT ages were younger than charcoal ages. The non-charred soil organic carbon fraction (SOC-LT) gave realistic ages compared to the charcoal in the same soil horizons. SOC-LT carbon is a result of a longer period of carbon integration process in the soil, which may lead to some reservoir effect, but it does not exert a significant effect, because LT ages are somewhat younger than the charcoal fragments. In most cases the SOC-LT fraction gave ages only hundreds years younger (average difference: 700 yr ± 500 yr). On the other hand, charcoal fragments represent a short period when the plant was grown, which could happen practically any time during the soil layer development and also "old wood effect" might occur. Thus, charcoal ^{14}C age results may also suffer from larger fundamental uncertainties (above the analytical error) for geochronological purposes.

In this respect, the non-charred soil organic carbon (SOC-LT fraction) ^{14}C ages might represent rather the end soil layer formation or the burial time of the soil layer and appear to be reliable for these cases where charcoal fragments could not be found in a paleosol.

Our new soil ^{14}C results are in a good agreement with the previously-published charcoal age data from the Nyírség. We conclude that using soil SOC-LT age as the time of burial is a good option if buried soil does not contain charcoal.

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