



# Results of paleoecological studies in the loess region of Szeged-Öthalom (SE Hungary)



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## ABSTRACT

New results of sedimentological, Magnetic Susceptibility, geochemical, radiocarbon and malacological analysis from a typical and an infusion loess section are presented from SE Hungary. The geologic and geomorphologic value of the area is that aeolian (typical) loess accumulated on sand dunes that formed during MIS3, while in the interdune depressions on the top of lacustrine deposit series, infusion loess developed. As the two types of loess interfinger, it is the first demonstration that the two types of loess formed during the same time period (isochron) in different environments (heterotype). At the end of MIS3 and during MIS 2 between 33,000–13,000 cal BP, a temperate steppe-forest steppe environment characterized the loess surface of the SE Great Hungarian Plain. During the first interstadial phase of MIS2 a *Pinus sylvestris* charcoal rich paleosol layer developed on the loess covered surface of a wind-blown sand hummock, while in the interdune depressions a pond phase developed. After the formation of the paleosol layer on the surface of the loess covered wind-blown sand hummock during the Heinrich 2 event, *Vertigo modesta*-*Vallonia tenuilabris* indicate a cold steppe-forest steppe environment and a deeper and colder lake phase in the interdune depressions. After that, a short microinterstadial phase developed and a *Pupilla triplicata*-*Chondrula tridens* dominated temperate steppe-forest steppe environment evolved on the terrestrial surface between 23,000–21,000 cal BP. After 21,000 cal BP, in the Last Glacial Maximum (LGM) the environment completely changed. The average dust accumulation accelerated and coarse silt (0.02–0.06 mm) became dominant. As a result, the lake stage transformed to a marshy environment, while on the land area shade-loving, including closed forest environment-preferring mollusca taxa appeared, such as *Vestia turgida*, *Vitrina pellucida* and *Mastus venerabilis*. Based on the mollusca fauna composition, humidity increased during the cooling of the LGM horizon, forestation started and a boreal forest-steppe evolved at the study site. During the post LGM, the interdune depressions filled and aeolian loess layers developed. Formation of the infusion loess occurred between 24,000–17,000 cal BP. Loess formation lasted until the beginning of the Late Glacial Maximum (Last Permafrost Maximum) and ended in a forest steppe environment with boreal, Central European, holarctic, palearctic and continental mollusc fauna elements.

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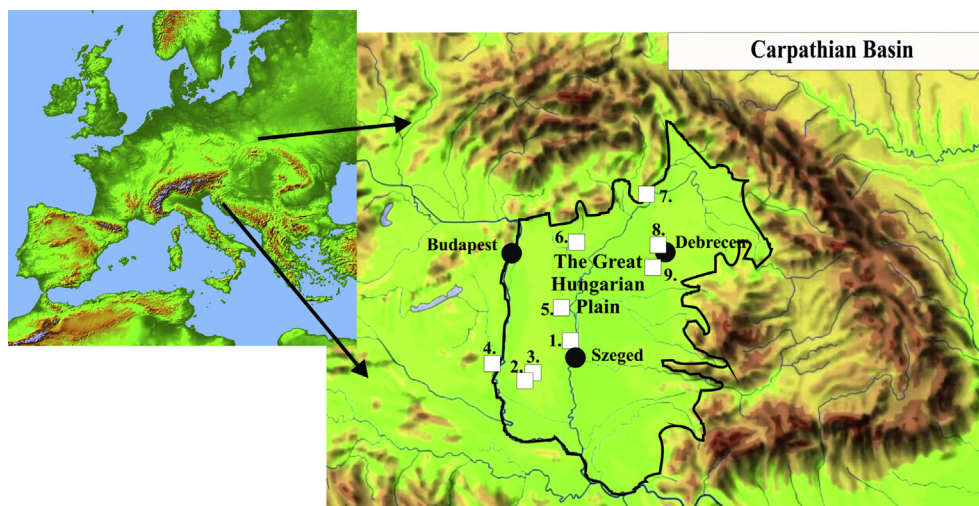
## 1. Introduction

The loess layers of Hungary are the longest-studied loess profiles in the Carpathian Basin (Wolf, 1867; Lóczy, 1886; Halaváts, 1895; Horusitzky, 1896, 1898). Due to the basin position, a significant thickness of loess layers developed in this area (Lóczy, 1886, 1910), although their crucial part can only be studied by drilling

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technology. At the same time, loess layers with the most significant thickness evolved in the near surface part, which developed during the youngest and coldest stage of the last glacial horizon (MIS2 level), during the Last Glacial Maximum (Schmittner et al., 2003; Mangerud et al., 2004; Rial, 2004; Wunsch, 2006; Clark et al., 2009; Van Meerbeek et al., 2009) or Last Permafrost Maximum (Hughes et al., 2013; Vandenberghe et al., 2014). In this youngest stage of loess formation cycle, more loess types were separated on the basis of their macroscopic development, colour and grain size composition. In the earlier studies, two main loess types were separated in the centre of the basin, in the Great Hungarian Plain



**Fig. 1.** Location of the site Szeged-Öthalom, S Hungary and mentioned sites in the Carpathian Basin and in Europe. Black circle = towns, 1 = Öthalom, 2 = Katymár brickyard, 3 = Madaras brickyard, 4 = Dunaszekcső brickyard, 5 = Lakitelek brickyard, 6 = Jászfelsőszentgyörgy Upper Palaeolithic excavation, 7 = Tokaj, Patkó-bánya, 8 = Debrecen brickyard, 9 = Látókép loess profile.

(Lóczy, 1886; Halaváts, 1895; Horusitzky, 1903). In addition to the typical, aeolian loess, a clayey loess with more significant organic content and with shells of aquatic snails, at first lacustrine (Lóczy, 1886; Halaváts, 1895; Horusitzky, 1903), marshy (Horusitzky, 1903; Miháltz, 1953), later infusion (Földvári, 1956), and then alluvial loess (Márton et al., 1979; Pécsi, 1993) or clayey loess (Smalley and Leach, 1978) were separated. In case of this latter formation, despite the fact that this type of sediment was recognized more than 120 years ago, the age of the formation, its relationship to the typical, aeolian loess, or its formation conditions have not been clarified (Márton et al., 1979; Pécsi, 1993). No previous investigations have involved such loess profiles where loess accumulated on wet surfaces (infusion loess) and typical aeolian loess layers developed together.

In 1992 in Öthalom, next to the city of Szeged, this situation changed dramatically when a profile was excavated where the two types of sediment interfinger. Samples were taken by high-resolution sampling, and radiocarbon dated. Sedimentological, geochemical, anthracological and malacological analyses were carried out in order to determine the age of the two types of sediments and the environment of sediment accumulation. Our aim was to find answers to specific questions:

What is the age of the infusion loess and what is its stratigraphic relationship to the aeolian loess layers?

What sort of environmental and geographic factors influenced the different formation of loess layers?

Are those climatic and environmental changes detectable in these formations that were demonstrated in Hungarian loess profiles?

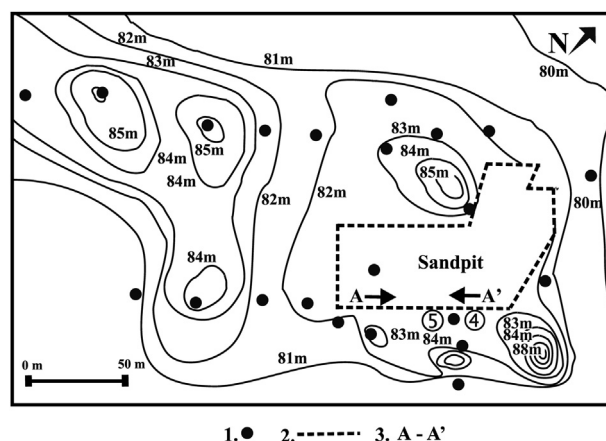
What was the impact of these changes regarding the extent and development of certain types of loess?

The second aim was to reconstruct the MIS3 and MIS2 history of Öthalom at Szeged and its environment using sedimentological, radiocarbon, charcoal and Mollusca analyses. This work presents the results of a complex palaeoecological work from the loess profile of Öthalom at Szeged and the comparative analysis with a loess profile of the Danube-Tisza Interfluve (Krolopp, 1973; Molnár and Krolopp, 1978; Krolopp and Sümeği, 1995; Molnár and Geiger, 1995; Hum and Sümeği, 2000; Sümeği and Krolopp, 2002; Markovic et al., 2006, 2008; Molnár et al., 2010; Hupucz and Sümeği, 2010; Sümeği et al., 2010; Sümeği et al., 2012).

## 2. Study area

The study area forms an interface between the alluvial fan of the Danube-Tisza Interfluve and the alluvial plain of the river Tisza. This part of the Tisza valley harbours the lowest point of the Great Hungarian Plain with an elevation of 79 m a.s.l. (Fig. 1). The island-like Pleistocene lag surface of Öthalom covered by loess emerges from this low-lying alluvial plain, having an elevation of 90 m a.s.l. (Fig. 2). The loess-covered higher background is covered by black earth soil. This area has been continuously inhabited for the past 5000–6000 years.

Scientific studies dealing with the loess sequences of the surroundings of Szeged, including the area of Öthalom, plus those dedicated to the investigation of archaeological finds recovered from the flood-free lag surfaces date to the end of the 19th century (Varázseji, 1880; Lenhossék, 1882; Rotarides, 1931; Banner, 1936; Miháltz, 1953; Szónoky, 1963; Szöör et al., 1987; Krolopp et al., 1995). Unfortunately, no scientific work has been carried out in the area of Szeged-Öthalom after World War 2 because of the presence of a Soviet military base and artillery range restricted to military persons until 1992.



**Fig. 2.** The geomorphological map of Szeged-Öthalom (Five Hills) with mapping core points.

A comprehensive morphological, sedimentological, malacological, and isotope geochemical study was initiated by the researchers of the University of Szeged and the Hungarian Geological Institute in 1992 after the withdrawal of the Soviet troops from Hungary. The extensive end Pleistocene and Holocene sequences covering an area of several hectares in the studied site are exposed in a 400 m long and 150 m wide sandpit (Fig. 2). The wall of the sandpit was cleared to a width of 200 m to a depth of 4 m in 3 m wide sections. From the floor of the sandpit a 10 m deep borehole was deepened, complemented by another 24 boreholes to determine the spatial distribution of the Quaternary sequences in the area. Four sampling sites were assigned in the cleared wall of the sandpit, sampled for sedimentological, geochemical, radiocarbon, malacological, anthracological, and vertebrate faunal analyses at 25 cm intervals. From these, only the most important profiles from a point of a comprehensive comparison are presented. Nine samples of charcoal and Mollusca shells were subjected to  $^{14}\text{C}$  analysis (Table 1).

### 3. Methods

The wall of the sand pit was cleared in full length and 4 m depth (to the subsoil water level). The excavated layers were analyzed macroscopically and a geological cross-section was drawn. Besides the cross-section, geological drillings were carried out in order to map the spatial extension of loess layers and to excavate the bottom sandy layers.

Four sampling profiles were assigned in the cleared wall of the sandpit sampled for sedimentological, geochemical, radiocarbon, malacological, anthracological, and vertebrate faunal analyses at 25 cm intervals. These samples were taken to the bottom of the loess layers, at the sandy deposit, with 20–22 samples in the 5–5.5 m-thick loessic layer. Out of the four processed profiles, the two most complete and most characteristic are presented, although the results of all processed sections were taken into account.

The lithostratigraphical description of the profiles followed the system of Troels-Smith (1955). The grain size composition of sedimentological samples was carried out using the aerometric method (Casagrande, 1934), although samples were re-analysed due to the technical development in the Department of Geology and Palaeontology, University of Szeged. The new grain-size analysis followed the laser-sedigraph method. The samples were measured for 42 intervals between 0.0001 and 0.5 mm using an Easy Laser Particle Sizer 2.0. For LOI examination sub-samples were taken at every 25 cm intervals and the loss on ignition method was applied, commonly used for the analysis of organic matter and carbonate content on calcareous sediments (Dean, 1974).

Environmental magnetic analyses were carried out on bulk samples. Samples were taken at 25 cm intervals in 1992. Prior to the start of the measurement, all samples were crushed in a glass mortar after weighing. Then samples were cased in plastic boxes and dried in air in an oven at 40 °C for 24 h. Afterwards, magnetic susceptibilities were measured at a frequency of 2 kHz using an MS2 Bartington magnetic susceptibility meter with a MS2E high-resolution sensor. All of the samples were measured six times and the average values of magnetic susceptibility were computed and reported. The recorded MS values ranged between 3 and  $159 \times 10^{-8} \text{ m}^3 \text{ kg}^{-1}$  in the studied sections. Values between 159 and  $71 \times 10^{-8} \text{ m}^3 \text{ kg}^{-1}$  characterise the recent soil horizons formed on the loess layers, in the fossil soil horizon it is  $33\text{--}48 \times 10^{-8} \text{ m}^3 \text{ kg}^{-1}$ , while in the aeolian loess layers between 17 and  $33 \times 10^{-8} \text{ m}^3 \text{ kg}^{-1}$ . In the sandy layers of the profile values of  $7 \times 10^{-8} \text{ m}^3 \text{ kg}^{-1}$  and above, on samples derive from the infusion loess layers values between 93 and  $48 \times 10^{-8} \text{ m}^3 \text{ kg}^{-1}$  occurred.

Radiocarbon dating was performed on the wood and mollusca fragments recovered from the typical and infusion loess sediment

layers.  $^{14}\text{C}$  bulk samples analyses were done at the Light Isotope Laboratory of the Nuclear Research Center of the Hungarian Academy of Sciences. The preparation of the samples and the steps of the measurement followed the work of Hertelendi et al. (1989, 1992). The raw dates were calibrated using the calib700 (Table 1) software package (Reimer et al., 2014), using the atmospheric data of Stuiver et al. (1998).

Samples for malacological analysis were dispersed in water and wet-sieved through 0.5 mm meshes. After sieving, mollusca shells were dried, sorted and identified under a stereo dissecting microscope at magnifications 6–50 $\times$ . The shells were identified using keys of Kerney et al. (1983), Liharev and Rammelmeier (1962), Ložek (1964), Welter-Schultes (2012) and Soós (1943). Shells were classified into ecological and biogeographical groups based on the system published by Krolopp and Sümegei (1995), and Sümegei and Krolopp (1995, 2002).

Relative frequencies of each taxa and the ecological groups were plotted on diagrams. Biozones were delineated via cluster analysis. Bray–Curtis similarity calculations (Southwood, 1978) were followed by Orlóci-Ward-type clustering (Podani, 1978, 1979). Numerical analyses were done with NUCOSA (Tóthmérész, 1993). Clusters on the dendograms were taken to represent a single biozone (MZ-1, MZ-2, etc.) (Molnár and Sümegei, 1990, 1992). The plotting of the sedimentological and malacological data was done using psimpoll (Bennett, 1992).

### 4. Results and discussion

#### 4.1. Radiocarbon analysis

Five samples from the aeolian (typical) loess profile subjected to radiocarbon analysis yielding the following ages: the layers between 4.25 and 4.5 m containing charcoal of *Pinus sylvestris* –  $25,200 \pm 300$  uncal BP; Mollusca shells from the depth of 2.0–2.25 m, 1.75–2.0 m and 1.5–1.75 m yielded ages of  $16,323 \pm 145$  uncal BP,  $16,080 \pm 150$  uncal BP, and  $16,000 \pm 200$  uncal BP, respectively. The dense sampling for radiocarbon analysis was necessary to determine the exact time of appearance of the species *Vestia turgida*. For this purpose, all samples containing shells of the above mentioned taxon were subjected to radiocarbon analysis. Four samples of mollusca shells deriving from the No. II. infusion loess profile were subjected to radiocarbon analysis yielding the following results:  $18,080 \pm 200$  BP between 3.0 and 3.25 m,  $15,890 \pm 100$  BP between 2.5 and 2.75 m, and  $14,179 \pm 170$  BP between the depths of 0.75–1.0 m, respectively. The mammoth (*Elephas primigenius*) bones recovered during the archaeological excavations at the Paleolithic (Gravettian) site in 1935 yielded an age of  $15,916 \pm 168$  BP. Table 1 presents  $^{14}\text{C}$  age determinations along with  $2\sigma$  ranges for calibrated ages obtained using Calib 7.0 (Reimer et al., 2014).

Based on the radiocarbon data, the sand accumulation stopped at the last phase of the MIS3 level. Then, a *P. sylvestris* charcoal rich layer with some *Abies alba* charcoals formed on the sand surface. This charcoal rich layer developed during the transition zone of MIS3 and MIS2 levels between 30,100–28,000 cal BP (Table 1). After this zone, coarse silt material accumulated in the analysed region and typical loess and loessy (infusion loess) layers formed in MIS2.

#### 4.2. Geomorphological and lithostratigraphical analysis

The bedrock of the Öthalom sequences is composed of greenish grey, calcareous floodplain deposits, exposed in the thickness of some meters, with limonite spots and recurrent intercalations of



1–3 cm thick fluvial sands, laminated clayey silts, and bands rich in silts. A few specimens of *Pisidium amnicum* retrieved from these layers clearly indicate a fluvial origin dated to the older phases of the Last Glacial, during Early Planiglacial, MIS4 level (Krolopp, 1973, 1983).

This sequences is overlain by yellowish grey, yellowish brown wind-blown sands of varying thickness forming sand dunes of 2–3 m high and 40–60 m long at an average under the overlying loessy layers, with sporadic heights around 5–6 m. According to the constructed geological cross-sections of the area (Fig. 3), these dunes form lines and clusters of 4–5 dunes with an NW–SE trend (Fig. 3). Probably this is where the name of the site Öthalom, meaning Five Hills in English, comes from. The dunes are separated by 5–30 m wide interdune areas with wind-blown sand bedrock. From this, the wind-blown sands covering the lag-surface can be related to the sedimentary sequences of the alluvial fan of the Danube-Tisza Interfluve. Consequently, aeolian activity resulting in the formation of wind-blown sands must have been rather significant in times preceding dust accumulation in the area. The movement of wind-blown sands resulted in the creation of versatile morphologies in the area of Öthalom with significant 5–6 m elevation difference between the dune tops and the bottom of the interdune areas (Fig. 4). From the analysis of charcoal fragments deriving from the layer overlying the wind-blown sands, the age of the dunes must be older than 28,600 cal BP, marking formation probably at the end of the MIS3 (Middle Würmian) phase.

The surface of the wind-blown sands is overlain by a thin layer of aeolian loess, followed by dark brown 5–25 cm thick clayey silts (paleosol) rich in humic components and embedded charcoal fragments. This paleosol is equally traceable in the side and top of the dunes. However this layer is missing in some of the interdune areas, implying the formation of minor ponds fed by groundwater during the formation of the soil layer. This soil-like sediment layer is rich in *P. sylvestris* (Scots pine) charcoal fragments with some *A. alba* (silver pine) charcoals. The pedogenesis in the area and the presence of a *P. sylvestris* rich taiga type woodland can be dated to the end of the MIS3 (Middle Würmian/Weichseilan) phase, between 28,600–30,000 (29,362 ± 745) cal BP. The mixed zone of Scots pine and silver fir developed between 1000 and 1300 m a.s.l. in the Carpathians, while in the Alps the same mixed zone evolved between 500 and 1200 m a.s.l. At the same time, the density of burned wood charcoal found in the area (Rudner and Sümeği, 2001, 2002) suggests that a forest-steppe-like, south Siberian taiga steppe (Sümeği and Hertelendi, 1998; Sümeği, 2004; Pelánková et al., 2008; Pelánková and Chytrý, 2009) evolved in this level.

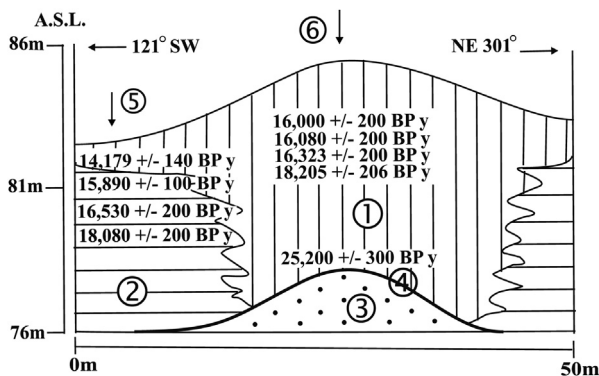


Fig. 3. The geological cross-section of the Szeged-Öthalom. The geological cross-section of sandpit at Szeged – Öthalom 1 = geological mapping core points, 2 = old sand pit area, 3 = geological cross section, 4 = aeolian loess profile position, 5 = infusion loess profile position, 6 = location of the analysed aeolian loess profile.

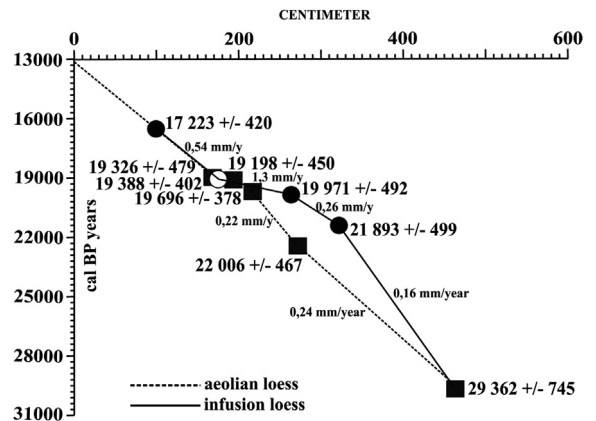


Fig. 4. The sedimentation rates of the aeolian and „infusion loess” (marshy sediment) layers of the Szeged-Öthalom site based on the radiocarbon data.

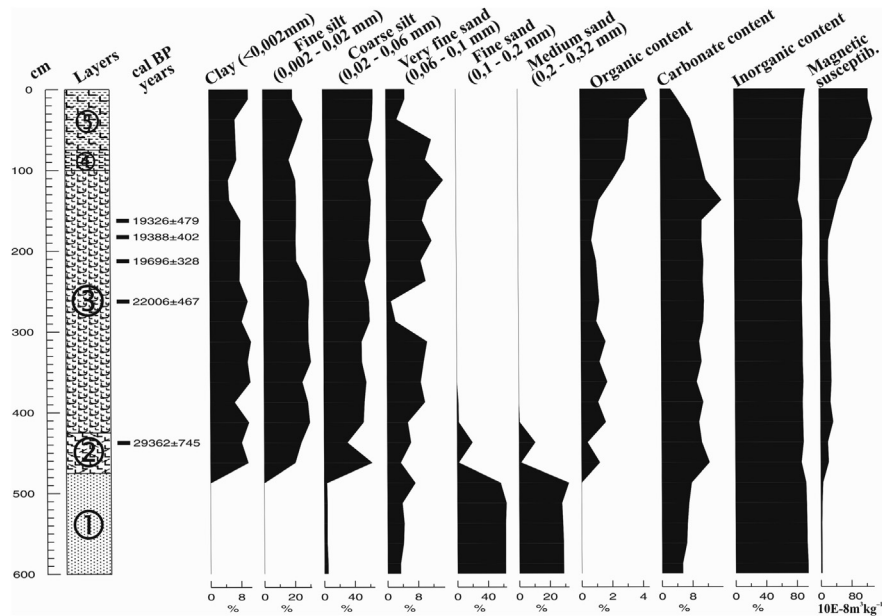
The value of Magnetic Susceptibility in the fossil soil horizon that contain burned wood material is  $33\text{--}48 \times 10^{-8} \text{ m}^3 \text{ kg}^{-1}$ . The layer was very heterogeneous, and the highest values occurred in the burnt material.

Dust accumulation started after the cessation of pedogenesis in the area in different environments, leading to the emergence of different sedimentary facies in the elevated and lower-lying areas. On top of the dunes, typical terrestrial (aeolian) loess (Pécsi, 1993) was deposited to a thickness of 2.5–4.5 m. The lower-lying wet marshlands favored the formation of infusion loess (Földvári, 1956). The spatial extent of the 2–4 m thick infusion loess is more significant than that of the aeolian loess, restricted to the top of the dunes, forming 50–60 m long and 30–40 m wide islands. The interfingering of the infusion loess and the aeolian loess observable in the side of the dunes refers to a coeval origin of the two deposits in contrast to former assumptions.

Dust accumulation must have started around 28,000 cal BP at the site and must have been continuous until 13,000–15,000 cal BP with intensive and less intensive periods. Based on the radiocarbon data the Average Sedimentation Rate (ASR) is 0.274 mm/y for the aeolian (typical) loess, although the Sedimentation Rate (SR) changed very significantly in some of the horizons (Figs. 4–6). In the transition zone of MIS3/MIS2, between 30,000–28,000 cal BP (fossil soil) the SR is 0.24–0.22 mm/y, while between 21,000–20,000 and 19,000–18,000 cal BP it is higher than 1 mm/y (Fig. 4). After 19,000–18,000 cal BP the value of SR decreased to 0.48–0.54 mm/y. Although the near-surface part of the formation was altered, originally chernozem soil formed on the aeolian loess. Based on the accumulation rate, the accumulation of the aeolian loess (later altered) ended at the beginning of the Late Glacial period, at 13,000 BP.

The Magnetic Susceptibility values of the aeolian loess layer decreased from the fossil soil horizon of the bedrock to the surface, to  $48\text{--}20 \times 10^{-8} \text{ m}^3 \text{ kg}^{-1}$ . The lowest values ( $23\text{--}20 \times 10^{-8} \text{ m}^3 \text{ kg}^{-1}$ ) were measured in the loess layers that accumulated between 17,000 and 20,000 cal BP. This is the level where the most significant Mass Accumulation Rate (MAR) was reconstructed (Figs. 4 and 5). In the recent soil horizon above the aeolian loess layer, the MS value increased sharply.

In the profile of the infusion loess (Figs. 4 and 6), sedimentation started after 28,000 cal BP in the sedimentary basin, based on the presence of burnt wood fragments. By that time, fine laminated, fine silt (0.002–0.02 mm) and clay ( $\leq 0.002$  mm) rich sediment accumulated with significant coarse silt (0.02–0.06 mm) content and with a lower SR value (0.16 mm/y). After 22,000 cal BP, the rate

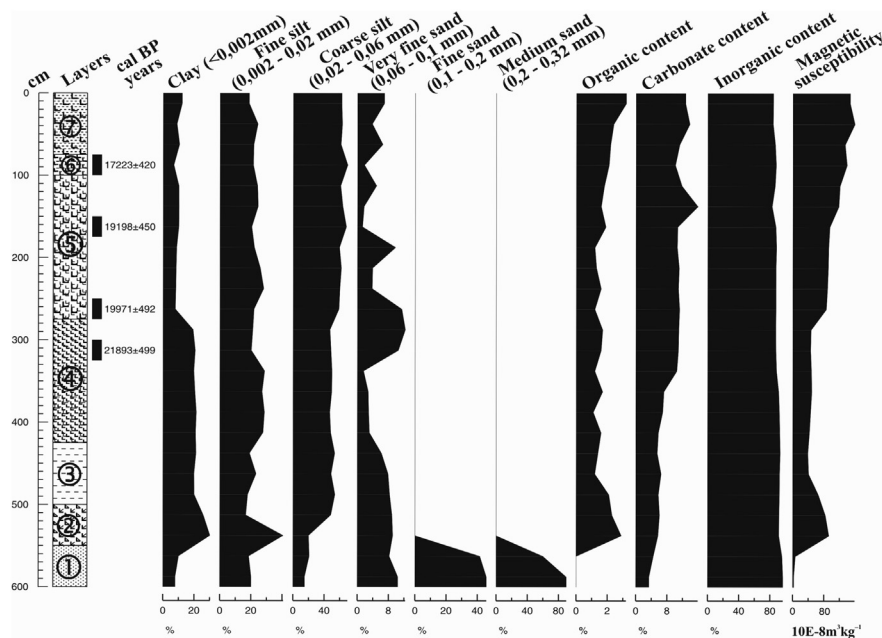


**Fig. 5.** The sedimentological results of the typical (aeolian) loess profile at Szeged-Öthalom 1 = wind-blown sand, 2 = fossil soil horizon, 3 = aeolian loess layer, 4 = carbonate rich layer, 5 = recent soil horizon.

of coarse silt increased and after 20,000 cal BP it became the dominant fraction in this profile. The structure of the sediment changed and porous, greyish-green infusion loess, similar to aeolian loess, containing shells of aquatic snails developed (Földvári, 1956). At the beginning of the formation of the infusion loess, at 22,000 cal BP, the sedimentation rate was 0.26 mm/y, and between 20,000–18,000 cal BP it exceeded 1 mm/y, similarly to the profile of the reconstructed aeolian loess (Fig. 6). After 18,000 cal BP, sedimentation rate decreased to 0.54 mm/y, and the sediment facies changed in the analysed profile. A yellowish-brown aeolian loess-like sediment accumulated with dominantly terrestrial snail shells. Originally, the major dust accumulation could have been more significant, as during loess diagenesis (Pécsi, 1991)

significant compaction could have occurred. The SR could be reconstructed only on the basis of the chronological data and sediment thickness of the aeolian loess profile. The inaccuracy arose from loess diagenesis, especially layer compaction, and the porosity of loess was specified by the Aeolian Mass Accumulation Rates (MARs = g m<sup>-2</sup> year) method after the works of Kohfeld and Harrison (2001), Tegen and Lacis (1996), Frechen et al. (2003) and Újvári et al. (2010).

The bulk density of loess carried out in the course of a gravity study (Papp, 2009) using two different techniques yielded a mean dry value of  $1.497 \pm 0.079$  g cm<sup>-3</sup>. Therefore we used a dry bulk density of 1.5 g cm<sup>-3</sup> for our MAR calculations. As the radiative effect of particles larger than 10 mm in diameter can be considered



**Fig. 6.** The sedimentological results of the „infusion loess” (marshy sediment) profile at Szeged-Öthalom 1 = wind-blown sand, 2 = organic material rich lake sediment horizon, 3 = organic material poor (oligotrophic) lake sediment, 4 = shallow lake sediment, 5 = “infusion loess” layer – marshy sediment, 6 = carbonate rich layer, 7 = recent soil horizon.

as negligible in the atmosphere (Tegen and Lacis, 1996) and for the purpose of model-paleodata comparison, different fine fractions of MAR (<10 and <2 mm) have been calculated as  $MAR_{PM10}$  and  $MAR_{PM2}$  (Tegen and Lacis, 1996; Újvári et al., 2010).

Based on the change of the sedimentation rate, the values of  $MARs$ ,  $MAR_{PM10}$  and  $MAR_{PM2}$  were analysed in the profiles of Szeged-Öthalom. The radiocarbon data indicate that the deposition rate changed several times during MIS2. As a result, our primary goal with the reconstruction of the extent of the former dust accumulation was to demonstrate if there is a connection between the local environmental change and the transformation of dust accumulation rate. Based on the results, it seems clear that the transformation of the environment led to the change of the sedimentation rate.

However, the aeolian loess and infusion loess formation was simultaneous, and in both loess types the trend of SR values was similar (Fig. 4). These results demonstrated that the development of infusion and aeolian loess layers was simultaneous and the two types of sediment interfingered (Fig. 4), with transitions between them. The development of the two types of loess depended on the former geomorphologic position. This is the first analysed site in the Great Hungarian Plain where it was demonstrated that the two loess types evolved simultaneous (isochron) in different facies (heterotype).

In the bedrock of the infusion loess layer sequence, on the surface of the sandy layer, a deposit with high organic material content developed parallel to the fossil soil that has the highest MS value of  $93\text{--}66 \times 10^{-8} \text{ m}^3 \text{ kg}^{-1}$ . Above this layer a lacustrine sediment evolved with MS values between  $39$  and  $43 \times 10^{-8} \text{ m}^3 \text{ kg}^{-1}$ , and an infusion loess layer with values between  $46$  and  $86 \times 10^{-8} \text{ m}^3 \text{ kg}^{-1}$ . The surface of the infusion loess is covered by aeolian loess. However, the effect of surface alteration occurred in this level, so MS values are significant in this horizon, between  $89$  and  $118 \times 10^{-8} \text{ m}^3 \text{ kg}^{-1}$ . Above this level, in the recent soil horizon, the highest MS values occurred ( $118\text{--}159 \times 10^{-8} \text{ m}^3 \text{ kg}^{-1}$ ).

The near-surface part of the aeolian loess as well as that of the infusion loess is covered by sandy loess, occasionally wind-blown sands. The Holocene soil layer emerged on top of these sandy loess deposits. This soil horizon was missing in several areas, being preserved in spots only because large amounts of soil were removed for the construction of flood-protection levees following the devastating great flood of 1879 (Varázseji, 1880). On the other hand, the continuous presence of humans significantly altered the surface as well through the construction of burial sites and buildings. The archaeological excavations carried out in the first half of the 20th century also resulted in disturbance of the near surface layer, preventing the accurate reconstruction of the relationship between this soil layer and the underlying near-surface deposits.

#### 4.3. Sedimentological analysis

Two out of the four constructed profiles of the sandpit exposed the Quaternary sequences at a full length. One of the remaining two exposed the infusion loess and the other the aeolian loess sequences of the site. No I. profile (Fig. 3) was dug into aeolian (typical) loess, and No II. was dug into infusion loess. The perched groundwater table marked the lower limit of our sections.

The bedrock is composed of brownish yellow (2.5 Y 5/6 – 5Y 6/4), well sorted, calcareous, fine sands (wind-blown sand) between the depths of 4.75 and 6 m (Fig. 3). According to the results of radiocarbon analysis, the accumulation of these wind-blown sands can be dated to the end of MIS3.

There is a significant drop in the sand content between the depths of 4.75–4.5 m, marking the presence of a dark brown, brownish grey (10 YR 6/2), humic-rich, non-calcareous, fine silty

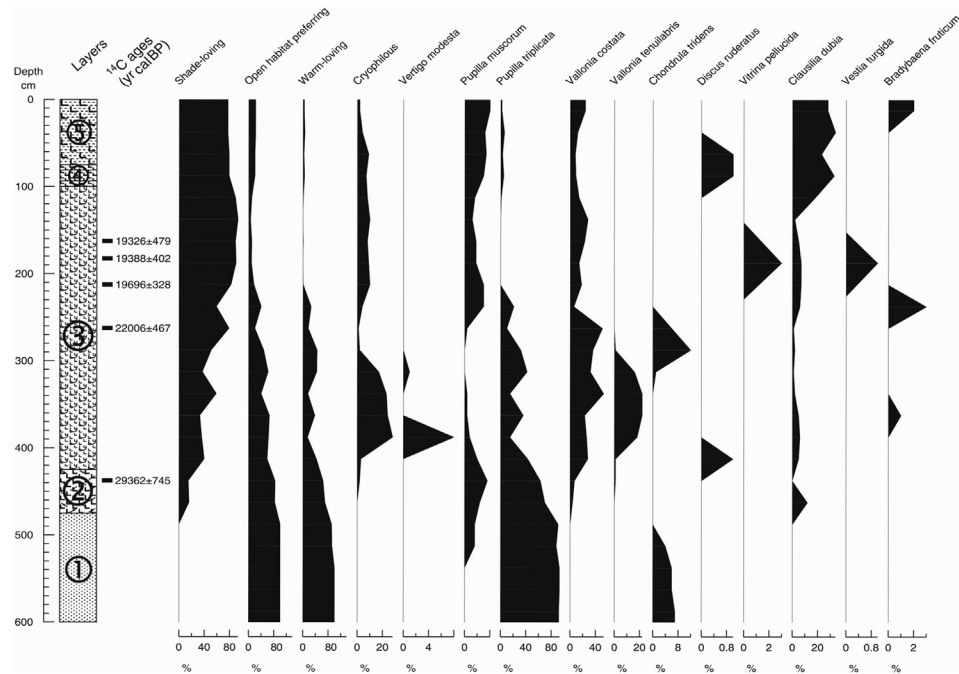
coarse silt with a relative higher clay content (paleosol). This paleosol is overlain by a layer of brownish yellow (10 YR 7/3), calcareous, sandy silt between the depths of 4.5–4.25 m, composed of coarse silty fine sands. The uppermost part of the section to the level of the modern soil from a depth of 4.25 m is composed of homogenous, yellowish brown (10 YR 6/4), calcareous, fine silty coarse silt (aeolian loess), with the proportion of the coarse silt fraction exceeding 60%.

At the beginning of the formation of the aeolian loess layers in the first half of the MIS2 stage, until 22,000–21,000 cal BP the Aeolian Mass Accumulation Rate was low, between  $359$  and  $325 \text{ gm}^{-2} \text{ y}^{-1}$ . In this level the dominant grain size was fine silt (Figs. 4 and 5). From 21,000–20,000 cal BP the value of MAR exceeded  $1000 \text{ gm}^{-2} \text{ y}^{-1}$  and this high value remained until the end of 19,000 cal BP, beginning of 18,000 cal BP. From 18,000 cal BP the value of MAR decreased to  $418 \text{ gm}^{-2} \text{ y}^{-1}$ . The grain size composition changed and coarse silt became dominant (Fig. 4). MAR values changed significantly during the formation of the aeolian loess profile and significant differences evolved compared to the  $420 \text{ gm}^{-2} \text{ y}^{-1}$  average value of MAR. Thus, the previous average sedimentation rate calculations (Újvári et al., 2010) made data significantly underestimated the values of MAR and its changes in the study area. The data demonstrate that a greater dust accumulation phase had been formed between 21,000–20,000 cal BP and 19,000–18,000 cal BP. It is possible that this change has occurred in the wake of a short-term climate change, as identified elsewhere (Porter, 2001; Rousseau et al., 2002). This intensive dust accumulation phase occurred in MIS2, in the second half of the Last Glacial Maximum Event (LGM) (Johnsen et al., 1992; Bond et al., 1993; Voelker et al., 1998; Voelker and de Abreu, 2011) in the study area, based on radiocarbon data.

The base of the infusion loess profile is well sorted, yellowish grey (2.5 Y 5/6), calcareous fine sands (wind-blown sand) located between the depths of 6.0–5.5 m (Fig. 5). These wind-blown sands are overlain by a layer of grayish green, calcareous, clayey silt with high limonite content (shallow lacustrine and marsh deposits). This sequence is composed of alternating layers or bands of poorly sorted slightly calcareous clayey silts displaying slight horizontal lamination and limonite spots and bands as well as that of clayey coarse silts marking the accumulation of dust particles in the pond besides the typical lacustrine deposits, or the inwash of aeolian loess into the ponds from the top of the dunes, respectively. There is a layer of relatively homogenous, porous, greyish green (5Y 6/2), calcareous clayey silt between the depths of 4.5–2.5 m, embedding a spectacular terrestrial and aquatic mollusc fauna (infusion loess).

There is a considerable upward decrease in the clay content, accompanied by an upward increase in the carbonate and coarse silts between the depths of 2.5–1.75 m. However the greyish green (5Y 6/2) hue of the deposits was preserved. This horizon must correspond to transitional deposits between the lower infusion loess layers and the uppermost aeolian loess layers observable in the No II. profile (Fig. 6). From a depth of 1.75 m upwards there is yellowish brown, calcareous fine silty coarse silts with minimal clay content (aeolian loess). The filling of the sedimentary basin between sand dunes, the transformation of infusion loess layers and the formation of aeolian loess layers was parallel to the acceleration of dust accumulation and the increase of the rate of coarse silt fraction during the second phase of the LGM. From 18,000 cal BP, aeolian loess layers accumulated on infusion loess layers.

The aeolian and infusion loess layers are separated on the basis of MS values. In the infusion loess, as in previous studies (Márton et al., 1979), the highest MS values (double) occurred compared to the aeolian loess. The infusion loess formed in a cyclic drying marsh environment where the *Siderobacterium* group in the alternating reduction and oxidation environment created a very



**Fig. 7.** The results of the malacological analyses from the aeolian loess profile of Szeged-Óthalom (selected taxa) 1 = wind-blown sand, 2 = fossil soil horizon, 3 = aeolian loess layer, 4 = carbonate rich layer, 5 = recent soil horizon.

significant amount of ferrous-limonite precipitates. These strongly influenced the values of MS in the infusion loess layer. MS values of the recent and fossil soil were typical of the expected values of the Carpathian Basin (Hambach and Schnepf, 2008; Hambach, 2010). Based on the NGRIP core (Andersen et al., 2006; Svensson et al., 2006; Rasmussen et al., 2006) the level of the Greenland Interstadial 3 (GIS3) correlates well to the fossil soil horizon indicating high MS values (containing burnt wood material) developed between 28,000 and 30,000 BP. The recent soil level with outstanding MS values is due to the high content of organic material (Sun and Liu, 2000) and human settling, significant human activity (hearth) (Meng et al., 1997; Hus, 2003), as demonstrated by archaeologists (Banner, 1936).

As a result of radiocarbon analysis, at the beginning of the formation of the loess layer, we achieved about 1000 years resolution/samples applying 25 cm intervals of sampling. In the LGM level, we achieved about 300 years of resolution with this sampling strategy. However, a denser sampling, at 4–5 cm intervals, might have divided this horizon into smaller parts corresponding to intensive climatic changes lasting for a shorter time of some hundred years. Unfortunately, in the study area the sand pit was filled so it is no longer suitable for sampling. However, as a result of an agreement between our team and the relevant National Park staff and management a protected surface will be designated, where a finer sampling and a finer temporal resolution will be carried out concerning the palaeoecological development of the site.

#### 4.4. Malacological investigations

The aeolian loess profile of the site contained dominantly terrestrial mollusca species with more than 10,000 specimens of 28 terrestrial gastropods. Furthermore, 10 specimens of highly eurytopic aquatic mollusca representing 7 species have also been retrieved.

Four Mollusca zones could have been distinguished in the upper 4.75 m part of the profile. The lowermost part located between the

depths of 4.75–4.25 m is poor in species and the specimen number is low, dominated by xerophilous, thermophilous, steppe dweller elements such as *Pupilla triplicata* (Fig. 7). According to the composition of the fauna, the soil formation, followed by dust accumulation and loess diagenesis, was initiated under a milder but arid climate around approximately 30,000–32 000 cal BP (Fig. 7).

There is a strong and relatively rapid change in the Mollusca fauna between 4.25 and 3.75 m dated between 28,000 and 23,000 cal BP, characterized by the appearance of cold-loving forms with the thermoxerophilous steppe dwellers, such as the Circumpolar, Boreo-Alpine *Vertigo modesta* (Liharev and Rammelmeier, 1962; Kerney et al., 1983). This is a character species of subarctic pine woodlands with a carbonate substrate (Pokryszko, 1990), and reaches 2100–2200 m, to the zone of alpine meadows in the Carpathians and the Alps (Klemm, 1974; Kerney et al., 1983; Horsák et al., 2013). A significant dominance of the cold-loving, Northern Asian, xeromontane *Vallonia tenuilabris* (Ložek, 1964; Sümegei, 2005; Meng, 2009) is also observable in this part of the section. Besides the advent of the cold-loving elements, the milder climate preferring forms also are present in considerable numbers. All these refer to the development of a transitional fauna at the boundary of a warm and cold period. This horizon embedded charcoal remains of *P. sylvestris* (Rudner in Krolopp et al., 1995) and *A. alba* (Greguss in Banner (1936)). According to the results of the malacothermometric analysis (Sümegei, 2005), there was a 3–4 °C decrease in the mean July paleotemperatures during this time compared to the previous zone (Fig. 7) from the value of 18–19 °C to 15 °C, which is 7 °C lower than the present-day values. A denser sampling, say at 4–5 cm intervals, might have divided this horizon into smaller parts corresponding to intensive climatic changes lasting for a shorter time of some hundred years.

After the cold wave, a strong warming can be observed in the area, marking the emergence of a short microinterstadial bringing about the advent of warmth-loving, xerophilous steppe dweller mollusca and a drastic drop in the proportions of the cold-loving elements. The species *V. modesta* totally disappeared from the



profile, giving way to the thermophilous, hygrophilous *Bradybaena fruticum*, preferring larger vegetation cover and numerous other shade-loving mesophilous and thermophilous Mollusca taxa among the accessory elements. These changes must have occurred between 23,000–21,000 cal BP, as shown by the radiocarbon results (Fig. 7).

After this warming, there were wave-like fluctuations in the temperature, resulting in the alternation of colder and milder climatic phases lasting for one-two thousand years, and finally the emergence of relatively temperate vegetation periods characterized by mean July paleotemperatures around 16–17°C (Fig. 8). According to the radiocarbon dates available, the accumulation of dust was relatively rapid in the area during these climatic phases. Besides the dominance of *Punctum pygmaeum*, the presence of the Carpathian forest dweller *V. turgida* in this part of the section is very important from a biostratigraphic point of view. Thanks to the extensive vegetation cover, *Vitrea crystallina*, *Clausilia dubia*, *Discus ruderatus* and *Vitrina pellucida* appear in large numbers with *V. turgida*. This fauna horizon can be dated between 18,500–20,500 cal BP in the area (Sümeği and Krolopp, 2000).

During the archaeological excavations of Banner (1936), numerous morphological, sedimentological and malacological investigations were implemented in the area of Szeged-Óthalom independently (Rotarides, 1931, 1936). A very unique mollusc fauna was retrieved from the layers embedding Palaeolithic tools during the course of these studies. In the malacological studies the ancient method of singling and other approaches no longer applied in Quaternary mollusca studies (Sparks 1961, Krolopp, 1983) leading to the discovery of the following taxa as they were described in the original publication by Károly Czöglér and Mihály Rotarides in Banner (1936): *Helicigona arbustorum* (presently nominated as *Arianta arbustorum*), *Trichia hispida*, *Perforatella bidentata* (*Perforatella bidentata*), *Fruticola fruticum* (*B. fruticum*), *Jaminia tridens* (*Chondrula tridens*), *Succinea putris*, *C. dubia*, and *Laciniaria turgida* (*V. turgida*).

In the samples collected in 1992 and 1995, these species occurred collectively in the aeolian loess profile between the depths of 1.25–1.75 m. The most important indicator form for the comparison of the findings of archaeological excavations implemented in 1935 and our profiles was that of *V. turgida*. In order to more accurately determine the temporal occurrence of this species, the shells of the species deriving from the aeolian loess profile were subjected to radiocarbon analysis, along with the mammoth bones retrieved during the 1935 archaeological excavations from the site (Sümeği and Krolopp, 2000).

According to the results, the shells of *V. turgida* taxon must have accumulated between 20,500–18,500 BP in the aeolian loess profile. The highly similar age of 19,400–18,900 cal BP (17,500–17,000 cal BC) for the hunted mammoth bones corroborated the age of the loess horizons embedding the shells of *V. turgida*.

The composition of the mollusca fauna and the dominance peak of the shade-loving species in this malacological zone suggest that forestation occurred in this time. Besides the forest habitat preferring and shade loving species, specimens of open areas appeared in high values. These data indicate that forest steppe vegetation developed in the area between 21,000–20,000 and 19,000–18,000 cal BP. Based on radiocarbon data from mammoth bones excavated in 1935 from the Upper Palaeolithic (Gravettian) site, the Upper Palaeolithic hunters appeared in this forest steppe environment in the study area.

The mollusca fauna of the infusio loess profile (Fig. 8) was rich in species yielding numerous specimens as well: more than 11,000 specimens of 22 aquatic, 34 terrestrial gastropods and 1 bivalve species, including about 6000 aquatic elements.

Five Mollusca zones could have been identified within this latter profile. Unit 1 located between the depths of 4.5–4.0 was dominated by aquatic species of *Lymnaea palustris*, *Aplexa hypnorum*, *Planorbis planorbis*, *Anisus spirorbis*, *Segmentina nitida* and *Pisidium*. In the terrestrial fauna, the littoral and marshland dweller elements

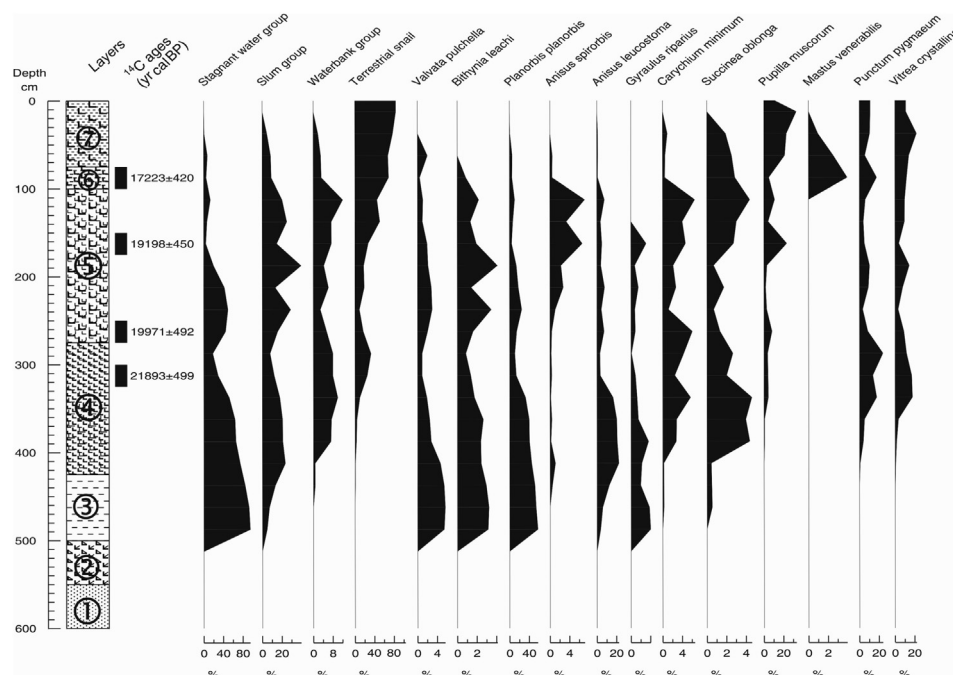


Fig. 8. The malacological results of the „infusio loess” (marshy sediment) at Szeged-Óthalom (selected taxa) 1 = wind-blown sand, 2 = organic material rich lake sediment horizon, 3 = organic material poor (oligotrophic) lake sediment, 4 = shallow lake sediment, 5 = „infusio loess” layer – marshy sediment, 6 = carbonate rich layer, 7 = recent soil horizon.



such as *Carychium minimum*, *S. putris* and *Limacidae* were present in considerable amounts (Fig. 8). The composition of the mollusc fauna suggests that a shallow pond with rich waterbank vegetation formed in the interdune depression around 28,000 cal BP.

The 2nd malacological unit located between the depths of 4.0–3.25 m is characterized by a transformation in the aquatic fauna: reduction in the proportions of *A. hypnorum*, *A. spirorbis*, the complete disappearance of *Pisidium* and *S. nitida*, plus a substantial increase in the cold-resistant elements such as *Valvata pulchella*, *Bithynia leachi*, *Anisus leucostoma*, *Anisus vortex* and *Bathymphalus contortus*. Within the terrestrial fauna, *C. minimum* and *S. putris* remained dominant. However, the calcite plates of *Limacidae* completely disappeared in this part of the section. Furthermore one of the several peak dominances of the mesophilous, partial-shade lovers *P. pygmaeum*, *V. crystallina*, and *B. fruticum* is found in this part of the profile (Fig. 8). This colder and deeper lake phase developed between 26,000–23,000 cal BP.

The third mollusca zone or Unit 3 found between 3.25 and 2.5 m can be dated between 22,400–19,700 cal BP. There is no change in the composition of the aquatic fauna compared to the previous zone. The general composition of the fauna as well as the dominance values of the individual taxa were very similar to those observable in Unit 2. There is hardly any change in the composition of the terrestrial fauna as well with the appearance of such shade-loving bioindicator elements, characteristic of woodland areas as *V. turgida*, *D. ruderratus*, *V. pellucida*, *P. bidentata* and *B. fruticum*. *P. pygmaeum*, *V. crystallina*, *C. dubia* and *A. arbustorum* are characterized by their maximum proportions within the profile in this part. Between 23,000–19,700 cal BP the mollusca fauna of the infusion loess changed. In this level, the value of stagnant water-preferring fauna elements significantly decreased compared to the previous zone. Among aquatic taxa, the fauna elements of the group remained significant and the ratio of terrestrial species preferring waterside wet environments increased. Based on the changes from 22,400 cal BP, the lacustrine environment changed and a periodically dry marshy environment evolved in the interdune depression. The development of the marshy facies can be correlated to the LGM level, and on the basis of sedimentological studies dust accumulation rose in this horizon. It is likely that the filling of the lake system and the development of a marshy phase is associated with the faster filling of the sedimentary basin and accelerated dust accumulation.

The next, 4th, unit between 2.5 and 2.0 m is characterized by a steady retreat of the woodland dweller elements of the previous unit such as *V. turgida*, *P. bidentata*, *B. fruticum*, *D. ruderratus* and *V. pellucida*. There were hardly any changes in the general composition of the aquatic or terrestrial faunas. However, the observable decrease in the above mentioned woodland dweller character species called for the separation of this part of the profile as a separate unit dated around 19,700–18,800 BP. The lower lying areas of the Szeged-Öthalom site must have formed marshlands with lush littoral vegetation harbouring cold-resistant and mesophilous Mollusca during this time.

There is a marked change in both the aquatic and the terrestrial Mollusca fauna at the depth of 2.0 m, characterized by a decrease of the formerly dominant forms (*L. palustris*, *B. contortus*, *Perforatella rubiginosa*, *P. pygmaeum*), accompanied by a gradual rise in the eurytopic *Nesovitrea hammonis*, *Vallonia costata* and *Euconulus fulvus*. This unit located between the depths of 2.0–1.0 m can be dated between 17,600 and 17,000 BP. The interdune depressions must have been covered by drier open vegetation areas during this period, characterized by the alternations of high and low ground-water levels within these interdune areas.

In Unit 5 there is a drastic drop in the proportions of the aquatic elements at 1.0 m, concomitant with the increase of species

preferring larger vegetation cover such as *P. pygmaeum*, *C. dubia* and *V. crystallina*. The closed woodland dweller *Mastus venerabilis* also appeared here, marking forestation or the expansion of woodlands dated between 17,000–16,000 cal BP (1.0–0.5 m). The fauna of the remaining layers up to the surface was not suitable for evaluation, due to the high disturbance of the deposits resulting in strongly decreased specimen numbers.

## 5. Evolution of the study site between MIS3/MIS2 and MIS2/MIS1

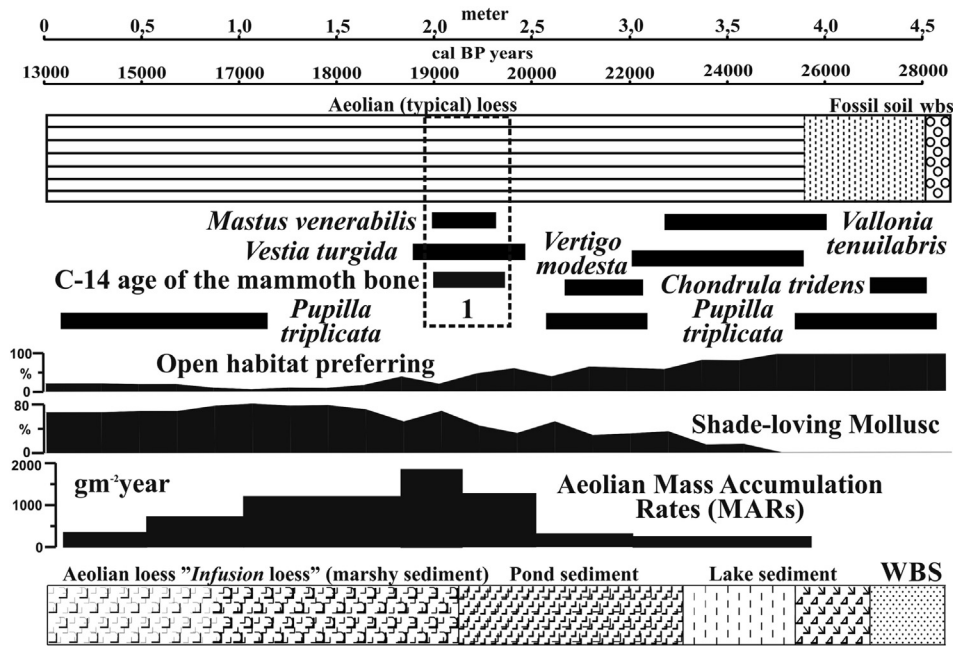
In the Szeged-Öthalom site, in the surface of the Danube alluvial fan, after the sand movement occurred during MIS3, an area with diverse geomorphology divided by sand dunes developed. After the end of sand movement, a fossil soil developed on the surface of the sand dunes with burnt *P. sylvestris* and sporadic *A. alba* charcoals approximately between 30,000–28,000 cal BP. The sand movement and the formation of the fossil soil occurred in a mild climatic phase based on Mollusca fauna elements preferring a thermophilous steppe environment. We correlated this milder phase with the level of Dansgaard-Oeschger 3 and 4 intervals.

At the same time, between 28,000–23,000 cal BP, at the end of fossil soil formation and beginning of loess formation, cold-loving mollusca species appeared (Fig. 9) that recently inhabit the Central Asian and Central European mountain zones. After 28,000 cal BP, aeolian loess formation started over sand dunes, with terrestrial gastropod dominance. In the interdune depressions, shallow ponds evolved where aquatic snails dominated at 28,000 cal BP. In the lacustrine environment, a relatively colder and deeper lake stage developed between 28,000–23,000 cal BP while on sand dunes aeolian loess formation occurred. This cooler climatic phase correlates to the Heinrich 2 level (Bond et al., 1993).

Between 23,000–21,000 cal BP, fauna elements favouring a thermophilous steppe environment appeared, and the lacustrine environment in the interdune depressions gradually developed into a periodically drying marshy environment. In these depressions a porous, carbonate rich greyish-green infusion loess formed with fine silt and clay content and with aquatic snails. This horizon corresponds to the Dansgaard-Oeschger 2 level. Although the value of the sedimentation rate and MAR (Mass Accumulation Rates) were at the Hungarian average values ( $320\text{--}360\text{ gm}^{-2}\text{ y}^{-1}$ ) between 28,000–21/20,000 cal BP, between 21/20,000–19/18,000 cal BP these values abruptly increased with MAR values of  $1000\text{ gm}^{-2}\text{ y}^{-1}$  (Fig. 9).

Reviewing the radiocarbon dated loess profiles of Tokaj, Madaras, Katymár, Dunaszekcső, Lakitelek, Jászfelsőszentgyörgy, Látókép, and Debrecen (Sümegei, 1996, 2005; Sümegei and Hertelendi, 1998; Hum and Sümegei, 2000; Sümegei et al., 2007, 2011) it is clear that in the same period the sedimentation rate and dust accumulation was higher in all of the analyzed sites in the Carpathian Basin, corresponding to the LGM (Voelker et al., 1998; Voelker and de Abreu, 2011). The formation of infusion loess continued during the LGM as well. The formation of infusion and aeolian loess was parallel in this chronological horizon.

Besides the fast and strong increase of dust accumulation, the local environment significantly changed, and surprisingly forestation started in the study area despite the recognized global cooling. As a result, closed forest habitat-preferring mollusca species, such as *V. turgida*, *D. ruderratus*, *V. pellucida* and *M. venerabilis* appeared in the profile. Based on the ratio of Mollusca taxa favouring open and closed forest habitats, a forest steppe environment developed in the LGM at the site. The spread of a very similar forest habitat loving malacofauna was demonstrated in other profiles of the southern part of the Carpathian Basin in the level of LGM (Sümegei and



**Fig. 9.** Summarized palaeoecological results from the loess profiles of Szeged-Öthalom, WBS = wind-blown sand, 1 = Upper Palaeolithic (Gravettian) archaeological level in the loess based on the radiocarbon data of the mammoth bone from archaeological excavation in 1935.

Krolopp, 1995, 2002; Hum and Sümegi, 2000; Sümegi, 2005; Sümegi et al., 2011, 2013). Forestation was not only local but regional in the southern part of the basin and presumably in the internal areas of the Carpathian Basin where a significant continental and sub-Mediterranean effect can be detected (Sümegi et al., 2011). Probably as a result of global cooling perceived in the level of LGM, in the internal and drier areas of the Carpathian Basin, the increase of humidity resulted in forestation. The fauna composition indicates that a boreal type forest steppe developed in the study area. This is supported by pollen analytical data (Sümegi et al., 2013) and anthracological analysis (Rudner and Sümegi, 2001). Based on the Mollusca fauna analysis and the radiocarbon analysis of a mammoth bone from the Upper Paleolithic (Gravettian) archaeological site (Banner, 1936) discovered in 1935, the Upper Paleolithic hunters appeared in this boreal type forest-steppe during the second half of the LGM. Results of the seasonal analysis (Sturdy, 1975; Vörös, 1982, 1987) indicate that the Upper Paleolithic hunters appeared during the winter season in the LGM level.

After the horizon of the LGM, loess formation continued, although dust accumulation greatly decreased. The interdune depressions filled up during LGM and after 18,000 cal BP aeolian loess accumulated on these areas as well. Results of radiocarbon analysis and sedimentation rates indicate that loess formation continued until 13,000 cal BP. However, the near-surface, youngest part of the loess layer was altered during the Holocene. At the end of loess formation a unique fauna composition evolved, completely unknown today. Besides the holarctic and Palearctic elements, both forest dweller species (*M. venerabilis*) of the Northern Balkan Mountains (Pfeiffer, 1853; Klimakowicz, 1883–1884, 1890; Westerlund, 1887; Grossu, 1987) and species of Central European temperate forest-steppe–steppe environment (*P. triplicata*) appeared (Welter-Schultes, 2012). Loess formation ended at the beginning of the Late Glacial Maximum when a forest-steppe environment developed with Balkan and continental elements.

## 6. Conclusions

The investigations in Szeged-Öthalom site were very important in reconstructing the age of loess formations and the environment using sedimentological, radiocarbon, charcoal, and malacological analysis. Based on our results, we were able to distinguish six environmental changes from MIS3/MIS2 to MIS2/MIS1. These alterations are supported by the dominance changes of open habitat preferring and shade-loving Mollusca groups, the alternations of sand and coarse silt fractions, and the significant change of organic material content. Climate, local vegetation and fauna changed in a wide spectrum during the time period of loess formation. Besides the three significant coolings, three milder climatic phases occurred between 28,000 and 13,000 cal BP. The change of the sedimentation rate indicates that the maximum of dust accumulation occurred between 21,000 and 17,000 cal BP.

Our results indicate that the aeolian dust started to accumulate in a shallow lake environment (infusion loess) between 20,000–21,000 cal BP and continued to accumulate in a marshy environment between 20,000–17,000 cal BP. As a result of the filling of the marsh, it transformed to an aeolian loess sequence between 17,000–16,000 cal BP. Our results indicate that the term infusion loess can no longer be used because originally loess was identified as terrestrial sediment (Pye, 1984, 1995). Cyclical drying and seasonally dry marshy environment is a part of the terrestrial environment, although only seasonally and periodically. At the same time, a shallow lake environment developed seasonally in the site of infusion loess formation, in the interdune areas of the study area. The previous opinions (Horusitzky, 1903; Földvári, 1956) about sediments called 'hydroaleurit' or 'hydrosilt' that are sediments where aeolian dust accumulated in marshy, shallow lake environments, characterized by cyclic water cover and drying out, are correct based on our data. At the same time, there are geological formations that were previously classified as infusion loess and accumulated in lake (Pécsi, 1993) or alluvial (Smalley and Leach, 1978; Márton et al., 1979) environments. These sediments should

**Table 1**

The results of radiocarbon analysis from bulk samples of the Szeged Őthalom profiles.

Profile	Meter	Uncal BP age (years)	±	Cal BP age (years)	Cal BC age (years)	Material	Code
Typical loess	1.50–1.75	16,000	200	19,805–18,847	17,856–16,898	Shell	Deb-2056
Typical loess	1.75–2.00	16,080	150	19,789–18,986	17,840–17,037	Shell	Deb-1486
Typical loess	2.00–2.25	16,323	145	20,073–19,318	18,124–17,369	Shell	Deb-3159
Typical loess	2.50–2.75	18,205	206	22,474–21,539	20,525–19,590	Shell	Deb-3184
Typical loess	4.25–4.50	25,200	300	30,108–28,617	28,159–26,668	Wood	Deb-2049
Infusion loess	0.75–1.00	14,179	140	17,643–16,803	15,694–14,854	Shell	Deb-2057
Infusion loess	1.50–1.75	15,890	200	19,649–18,748	17,700–16,799	Shell	Deb-2054
Infusion loess	2.50–2.75	16,530	200	20,463–19,479	18,514–17,530	Shell	Deb-1600
Infusion loess	3.00–3.25	18,080	200	22,392–21,395	20,443–19,446	Shell	Deb-3183
Bone from archaeological site in 1935		15,890	100	19,416–18,914	17,512–16,965	Bone	Deb-3344

be considered as lacustrine or alluvial sediments (Sümegi et al., 2013), where significant amounts of aeolian dust accumulated during Pleistocene: however, as a result of the environment of formation, they are not loesses.

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