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RESULTS OF RADIOCARBON ANALYSIS OF UPPER WEICHSELIAN LOESS SEQUENCES FROM HUNGARY

Pál Sümegi[1,2] • Mihály Molnár[3] • Éva Svingor[3] • Zsuzsanna Szántó[3] • László Hum[1] • Sándor Gulyás[1]

ABSTRACT. Approximately 10% of Hungary is covered by dust sequences of the Quaternary period. Samples have been taken from more than 50 outcrops and boreholes during fieldwork in the past 20 yr. Some 81 bulk samples taken from 27 profiles of the Hungarian loess regions have been analyzed for radiocarbon. Based on the ^{14}C results, loess layers that accumulated between 33,000 and 12,000 BP were selected for further investigation. The sedimentation rates of the 27 loess profiles suggest periods of slow and quick dust accumulation in the Carpathian Basin during the Upper Weichselian period. It seems to us that some soil development and intense weathering periods interrupted the loess development during the Upper Weichselian in Hungary. According to the ^{14}C dates, the estimated average rate of sedimentation was 0.31 mm/yr in both the northern and southern parts of the Carpathian Basin between 33,000 and 12,000 BP.

INTRODUCTION

Loess deposits cover a region of about 13 million km^2 on Earth, about 10% of the total area of the continents (Pécsi 1993). Approximately 10% of Hungary is covered by these dust sequences (Pécsi 1967). This sediment type is one of the most characteristic and extensive for the Quaternary, the formation of which is exclusively restricted to the Pleistocene, mainly its younger periods. According to the available information, the occurrence and formation of loess is also related to certain geographical belts or areas (North American, Eurasian, and South American loess areas) and to environmental factors.

The most remarkable fossils embedded in the loess sequences are mollusk shells, quite often accumulated in large masses. The geochemical conditions prevailing during the formation and diagenesis of these dust deposits were ideal for preserving calcareous shells (Krolopp 1961, 1966, 1967; Ložek 1964; Rousseau et al. 1990). The study of mollusk remains, the so-called "loess fauna," was of primary importance in the extensive Quaternary investigations at the beginning of the 20th century in Hungary (Horusitzky 1903; Rotarides 1931, 1942; Horváth 1954; Krolopp 1961, 1966). The representatives of the mollusk fauna retrieved from the loess deposits are important not only because of their large mass, but also because they are made up of predominantly modern forms in addition to the extinct ones, with known ecological characters, requirements, distribution, and tolerance to particular environmental factors such as temperature, humidity, vegetation cover, etc. Thus, acting as indicators of the ancient paleoecological conditions, the environmental components of loess formation can be relatively well assessed.

The Quaternary mollusk faunas are dominantly represented by recent elements (Krolopp 1967, 1984); thus, the ecological requirements of the modern taxa (Boycott 1934; Soós 1943; Ant 1963; Kerney et al. 1983) as well as their use in Pleistocene environmental interpretations (Rotarides 1931; Ložek 1964; Krolopp 1967; Rousseau et al. 1990) are relatively well established. As a consequence, the study of loess fauna has become one of the most important and fundamental assets in investigations of dust sequences. This is especially true for studies of Paleolithic (mainly Upper Paleolithic)

[1]University of Szeged, Department of Geology and Paleontology, 6722 Szeged, Egyetem u. 2-6, Hungary.
[2]Corresponding author. Email: sumegi@geo.u-szeged.hu.
[3]Institute of Nuclear Research of Hungarian Academy of Sciences, Laboratory of Environmental Studies, 4026 Debrecen Bem tér 18/C, Hungary.

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sites discovered from the loess sequences. In contrast to the vertebrate remains recovered from these sequences, the representatives of the tiny mollusk fauna, predominantly of mm size, were not subjected to selection attributed to human gathering and hunting. The investigation of the mollusk fauna enables the reconstruction of the prevailing conditions of areas surrounding settlement sites. Furthermore, one may also determine the various climatic and environmental changes—which occurred during, preceding, and following the construction of the settlement—by studying underlying and overlying sediments. Finally, a comparative analysis of several distinct profiles contributes to the reconstruction of the larger, more distant areas of ancient Paleolithic hunter communities.

Investigations on the loess malacofauna, as well as the evaluation of its paleoecological and paleoclimatological importance in Hungary, started almost coevally with international studies of similar scope in the 1890s. These studies, using different methodological and conceptual approaches, yielded an extensive database on the loess-covered areas, with information mostly related to the youngest, near-surface layers, thus enabling and requiring a comparative synthesis (Krolopp and Sümegi 1992; Sümegi and Krolopp 1996). Not only were fauna subjected to detailed analysis during these investigations, but relying on the financial support of the various National Scientific Research Funds (OTKA), the embedded deposits of the studied profiles also underwent sedimentological, geochemical, and isotope-geochemical analyses from about 1986 onwards, opening up the possibility for a complex paleoecological reconstruction. The most challenging and outstanding part of our work was the investigation of those Hungarian loess profiles, which were also the sites of human settlements and yielded Upper Paleolithic artifacts (Figure 1). The new information forced us to rethink and modify the formerly assigned paleoecological and paleoclimatological indicator roles of the terrestrial mollusk fauna. Furthermore, the intensive Hungarian studies of Quaternary mollusks over the last 20 yr has led to the re-evaluation of the former paleobiogeographical view of the Carpathian Basin for the end of the Quaternary, as well as that of the Upper Würmian vegetation and faunal history, and the final development of a complex climate and ecostratigraphic system based on the synthesis of paleontological data of the Quaternary mollusk fauna with measured radiocarbon dates (Krolopp and Sümegi 1990, 1991, 1992; Sümegi 1996, 1998, 1999, 2004, 2005; Sümegi and Krolopp 1996; Willis et al. 2000; Rudner and Sümegi 2001; Sümegi and Rudner 2001).

MATERIALS AND METHODS

Samples have been taken from more than 50 outcrops and boreholes during fieldwork over the past 20 yr. Some 81 bulk samples taken from 27 profiles of the Hungarian loess regions have been analyzed for ^{14}C (Figure 1). In our work, charcoal remains and mollusk shells retrieved from the profiles have been analyzed using 20–25 g of mollusk shell fragments and 6–10 g of the charcoal. The methods presented in Hertelendi et al. (1996) have been utilized for the preparation of the mollusk samples. Approximately 200 kg of sediment was wet-sieved to gain the required quantities of mollusk shells, which were then cleaned by boiling in distilled water and dilute H_2O_2. The steps and physical parameters of ^{14}C measurements are discussed at length in the work of Hertelendi et al. (1989).

In order to minimize or eliminate the bias deriving from the presence of inactive carbonates, only herbivorous gastropod shells (Frömming 1954; Grime and Blythe 1969), primarily those of *Arianta arbustorum*, have been used in our measurements, following the proposal of Preece (1991).

The surficial precipitates were removed by treatment with diluted H_2O_2 (Hertelendi et al. 1992). It is important to emphasize that none of the ^{14}C measurements implemented on mollusks and charcoal deriving from Hungarian profiles dated to the end of the Quaternary yielded controversial dates, i.e. younger ages within the deeper parts of the sections. Furthermore, the multiple measurements of

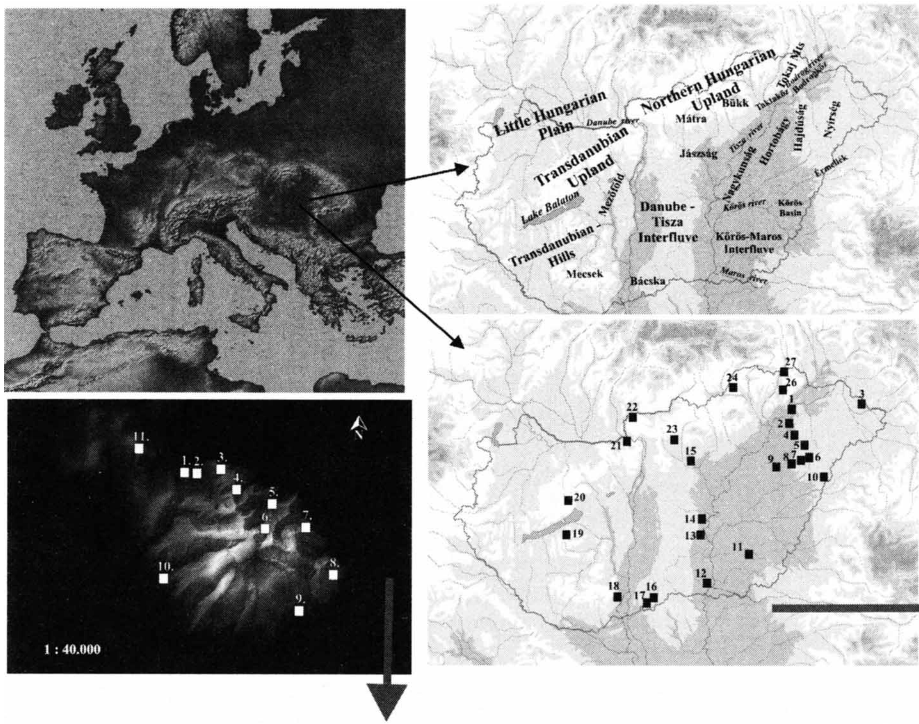

Figure 1 Geographical distribution of the studied loess profiles in Hungary

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samples deriving from several horizons of individual profiles yielded reliable, acceptable dates after comparison with each other (Sümegi 1989; Hertelendi et al. 1992; Sümegi et al. 1992; Szöőr et al. 1992; Krolopp et al. 1995). Consequently, mollusk shells seem to be suitable for ^{14}C measurements and dating horizons within embedded geological profiles or sediments. The resulting dates were calibrated using OxCal v 3.10 (Bronk Ramsey 1995, 2001) and the IntCal04 calibration curve (Reimer et al. 2004).

RESULTS OF RADIOCARBON ANALYSIS

The ^{14}C results are given in Table 1. Based on these dates, loess layers that accumulated between 33,000 and 12,000 BP were selected for further investigation. The sedimentation rates of the 27 loess profiles suggest that slow and quick dust accumulation periods must have developed in the Carpathian Basin during the Upper Weichselian. It seems to us that some soil development and intense weathering periods interrupted the loess development time during the Upper Weichselian in Hungary. According to the resulting dates, the estimated average rate of sedimentation was 0.31 mm/yr in both the northern and southern parts of the Carpathian Basin between 33,000 and 12,000 BP. The determined sedimentation rates were used to give a time frame of the inferred paleoecological changes in the profiles and in the analyzed region, because the sedimentation rate was higher in the southern part of the Carpathian Basin during the Upper Pleniglacial than in its northern counterpart. These sedimentation rate differences suggest that there were 2 sediment accumulation areas in the analyzed regions. The Quarternary malacological data show clearly that different paleoclimatic, vegetation, and soil surface conditions developed in the southern and northern parts of the Carpathian Basin.

All of these data seem to indicate that the inferred changes in the paleotemperatures reflect not only warmings or coolings in general, but changes in the intensity of the different climatic influences in the different parts of the basin as well. Thus, not only the absolute values of the temperature should be taken into account in a paleoenvironmental reconstruction, but also the trend and location of the temperature changes with regard to the position of the different overlapping climate zones. As expected, moving towards the NE in Hungary there is a gradual increase in the continental influences, while the intensity of Mediterranean influences increase towards the southern parts. The expansion of these climate zones is marked by the advent and retreat of different mollusk species and contrasting dust accumulation rates, as well as weathering processes varying regionally during the stadials and interstadials (Sümegi 2005). However, there were considerable spatial and temporal differences in dust accumulation rates in the Carpathian Basin, compared to the average value. Dust accumulation was characterized by a succession of slow and fast sedimentation cycles during the period under study. A highly characteristic soil horizon developed in the sequences between 33,000 and 25,000 yr. As a result of the significant diagenetic transformations, a reddish-brown soil horizon of considerable thickness developed in the northern montane and foothill area of the Carpathian Basin, stretching to the northern parts of the Great Hungarian Plains and northern Transdanubia as well to the west. Conversely, the center of the lowlands of the Great Hungarian Plains witnessed the evolution of immature humic horizons intercalated with wind-blown sands during this time. As shown in previous paleobotanical studies (Rudner and Sümegi 2001; Sümegi and Rudner 2001), a highly complex system of vegetation mosaics developed in the northern parts of the basin at this time, dominated by spruce woodlands containing mixed deciduous and coniferous elements as well as some open areas. Conversely, the vegetation of the southern parts was less compact, composed of Scotch pine and birch woodlands. Significant environmental differences can be observed even during this soil formation period. These differences were preserved in later periods of the Upper Würmian as well as in the Late Glacial. The estimated sedimentation rates were around 0.05–0.1

mm/yr in the north, while this value was around 0.1–0.2 mm/yr in the south due to the presence of sandy intercalations in the sequences.

Table 1 ^{14}C dates for the studied loess sites.

Sites	Depth (m)	Age (yr BP)	Lab code (Deb-)	Sample type
Basaharc, brickyard	4.25–4.5	24,030 ± 317	3353	Charcoal
Megyaszó, Szeles Hill	—	27,070 ± 680	5372	Charcoal
Hont III/Parassa, Orgonás	—	27,350 ± 610	5027	Charcoal
Püspökhatvan-Diós, Paleolithic site	1.5–1.6	27,700 ± 300	1901	Charcoal
Jászfelsőszentgyörgy, Szúnyogos	1.3–1.4	18,500 ± 400	1674	Bone
Jászfelsőszentgyörgy, Székes	0.7–0.8	11,600 ± 138	4390	Shell
Jászfelsőszentgyörgy, Székes	0.5–0.6	7750 ± 120	4391	Shell
Bodrogkeresztúr, Henye Peaks	0.5–0.6	26,318 ± 365	3051	Charcoal
Bodrogkeresztúr brickyard I	5.0–5.25	26,851 ± 398	3049	Charcoal
Bodrogkeresztúr brickyard I	3.25–3.5	19,813 ± 170	4335	Shell
Bodrogkeresztúri brickyard I	1.25–1.5	15,388 ± 147	4358	Shell
Bodrogkeresztúri brickyard II	3.0–3.25	17,680 ± 300	1614	Shell
Bodrogkeresztúri brickyard II	1.5–1.75	14,858 ± 101	4340	Shell
Bodrogkeresztúri brickyard II	0.75–1.0	4700 ± 170	1065	Shell
Tokaj Kereszt Hill II	4.5–4.75	27,323 ± 644	2657	Charcoal
Tokaj Kereszt Hill I	4.75–5.0	26,962 ± 657	5052	Charcoal
Tokaj Kereszt Hill I	0.5–0.75	17,619 ± 170	4918	Shell
Tokaj Kereszt Hill I	0.25–0.5	783 ± 35	4874	Shell
Csorgókút I	4.75–5.0	26,618 ± 532	3042	Charcoal
Csorgókút I	0.5–0.75	17,213 ± 162	2656	Shell
Csorgókút I	0.5–0.75	16,940 ± 250	2722	Shell
Csorgókút II	5.75–6.0	28,225 ± 360	3035	Charcoal
Csorgókút II	5.0–5.1	23,571 ± 486	4350	Charcoal
Csorgókút II	1.25–1.5	18,730 ± 180	4330	Shell
Csorgókút II	0.75–1.0	17,504 ± 106	4330	Shell
Patkó-quarry	5.0–5.25	27,491 ± 362	3043	Charcoal
Patkó-quarry	4.0–4.25	23,519 ± 494	4350	Charcoal
Patkó-quarry	3.0–3.25	18,506 ± 277	2661	Shell
Patkó-quarry	2.5–2.75	17,739 ± 127	4332	Shell
Patkó-quarry	2.0–2.25	16,322 ± 162	4364	Shell
Vasúti geological profile	4.75–5.25	30,174 ± 1101	4347	Charcoal
Tarcal brickyard	6.75–7.0	27,251 ± 288	4345	Charcoal
Tarcal brickyard	0.25–0.5	5350 ± 150	1063	Shell
Debrecen Alföldi brickyard	3.25–3.5	22,800 ± 300	1561	Shell
Debrecen Alföldi brickyard	2.5–2.75	18,090 ± 200	1537	Shell
Debrecen Alföldi brickyard	2.0–2.25	15,740 ± 200	1565	Shell
Debrecen Alföldi brickyard	1.25–1.5	13,380 ± 200	1547	Shell
Debrecen Alföldi brickyard	0.75–1.0	10,010 ± 200	1277	Shell
Debrecen Alföldi brickyard	0.5–0.75	8750 ± 200	1091	Shell
Debrecen Alföldi brickyard	0.25–0.5	7130 ± 200	1276	Shell
Látóképi geological profile	3.25–3.5	25,020 ± 500	1077	Shell
Nagyhegyesi geological profile	3.75–4.0	25,520 ± 500	1066	Shell
Nagyhegyesi geological profile	5.5–6.0	29,810 ± 300	1596	Shell
Derecskei brickyard	1.0–1.25	9500 ± 200	1302	Shell
Pocsaj sandpit	2.25–2.5	19,600 ± 200	1582	Shell
Pocsaj sandpit	5.0–5.25	42,500 ± 2500	1583	Shell
Lakiteleki brickyard I	5.8–6.0	29,980 ± 550	1095	Charcoal
Lakiteleki brickyard I	3.0–3.2	22,110 ± 300	1562	Shell
Lakiteleki brickyard I	2.2–2.4	16,820 ± 200	1536	Shell
Lakiteleki brickyard I	1.4–1.6	14,840 ± 300	1075	Shell
Lakiteleki brickyard I	0.6–0.8	11,700 ± 250	1092	Shell
Lakiteleki brickyard II	2.8–3.2	26,736 ± 629	4346	Charcoal

Table 1 ^{14}C dates for the studied loess sites. *(Continued)*

Sites	Depth (m)	Age (yr BP)	Lab code (Deb-)	Sample type
Szeged-Öthalom I	4.25–4.5	25,200 ± 300	2049	Charcoal
Szeged-Öthalom I	2.5–2.75	18,205 ± 206	3184	Shell
Szeged-Öthalom I	2.0–2.25	16,323 ± 145	3159	Shell
Szeged-Öthalom I	1.75–2.0	16,080 ± 150	1486	Shell
Szeged-Öthalom I	1.5–1.75	16,000 ± 200	2056	Shell
Szeged-Öthalom II	3.0–3.25	18,080 ± 200	1600	Shell
Szeged-Öthalom II	2.5–2.75	16,530 ± 200	2054	Shell
Szeged-Öthalom II	1.5–1.75	15,890 ± 200	2057	Shell
Szeged-Öthalom II	0.75–1.0	14,179 ± 140	3183	Shell
Szeged-Öthalom hunted mammoth	1.5–1.6	15,916 ± 168	3344	Bone
Katymár brickyard	9.0–9.25	29,828 ± 554	3058	Charcoal
Katymár brickyard	6.0–6.25	23,749 ± 360	3064	Charcoal
Katymár brickyard	1.25–1.5	13,944 ± 93	3253	Shell
Madaras brickyard	10.0–10.5	21,937 ± 252	3104	Charcoal
Kardoskút, Fehér-lake	6.2–6.3	23,303 ± 280	4572	Charcoal
Kardoskút, Fehér-lake	4.9–5.1	20,323 ± 300	7695	Shell
Kardoskút, Fehér-lake	3.9–4.1	17,715 ± 250	7694	Shell
Kardoskút, Fehér-lake	2.1–2.2	10,498 ± 90	4883	Shell
Kardoskút, Fehér-lake	1.5–1.6	8239 ± 70	4910	Shell
Hortobágy, Szálkahalom	1.9–2.0	19,260 ± 200	1654	Shell
Hortobágy, Szálkahalom	1.7–1.8	18,770 ± 200	1570	Shell
Hortobágy, Szálkahalom	1.5–1.6	15,800 ± 200	1546	Shell
Hortobágy, Szálkahalom	1.2–1.3	13,380 ± 200	1547	Shell
Hortobágy, Szálkahalom	0.8–0.9	10,030 ± 200	1653	Shell
Budapest, Csillaghegy, Paleolithic site	1.75–2.0	15,935 ± 142	3160	Shell
Császártöltés, brickyard	5.0–6.5	31,300 ± 300	3161	Shell
Susak, loess section	7.0–7.25	31,830 ± 720	6679	Charcoal
Tiszaalpári high-bluff	3.75–4.0	17,860 ± 350	1078	Shell
Tiszaalpári high-bluff	2.5–2.75	15,310 ± 350	1080	Shell
Tiszaalpári high-bluff	5.25–5.5	27,810 ± 210	POZ-8622	Charcoal

There was an acceleration of dust accumulation from 25,000 yr onwards in both parts of the basin, yielding values of 0.2–0.4 mm/yr in the north and 0.5–0.8 mm/yr in the south. It is no wonder that one of the most remarkable European Upper Würmian loess sequences developed in the southern parts of the basin in the Telecska Hills (Molnár and Krolopp 1978; Molnár and Geiger 1995). The observed differences in the dust accumulation rates must be attributed to both differences in the geological setting and the other environmental components. The Telecska Hills area is located at the southern margin of a dry alluvial fan of 10,000 km^2 at that time. As a result, markedly thick dust sequences evolved in this area. Conversely, while the northern areas were characterized by a discontinuous permafrost and more scant vegetation, the southern areas of the basin experienced a sporadic permafrost and were covered by more lush vegetation. The rate of sedimentation experienced several drops during the Upper Würmian to 0.05–0.1 mm/yr in the north and 0.1–0.2 mm/yr in the south. Humus accumulation zones and immature paleosol horizons of several hundred years are observable only around 23,000 and 21,000 yr and around 18,000 and 16,000 yr. The composition of the mollusk fauna implies the emergence of milder climatic periods with more precipitation, resulting in the expansion of mixed taiga woodland mosaics during these periods in the basin (Sümegi and Krolopp 1996).

There is another increase in the rate of sedimentation from 16,000 yr onwards, leading to the accumulation of dust sequences of considerable thickness up to 14,000–13,000 yr. The rate of dust accumulation was around 0.2–0.4 mm/yr in the north and 0.3–0.5 mm/yr in the south, with a gradually decreasing tendency. Finally, at around 11,000–12,000 yr, loess formation came to an end as the environmental prerequisites for loess formation disappeared.

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