

Aeolian sedimentation in the Rhine and Main area from the Late Glacial until the Mid-Holocene

New evidence from the Magdalenien site of Götzenhain [Hesse, Germany]

Johann Friedrich Tolksdorf, Knut Kaiser, Thomas Terberger, Nicole Klasen, Birgit Schneider, Peter Masberg

Abstract:

Aeolian sediments (sandy loess, aeolian sand) were studied by pedological and geochronological (OSL) methods to reconstruct their stratigraphy and age, and to relate these results to archaeological evidence. The results prove loess accumulation on an older ventifact horizon during the Late Glacial period followed by layers of aeolian sand also dating to the Late Glacial period. Holocene aeolian sedimentation (6.9 ka) was recorded within the excavation site, which probably indicates Neolithic human impact that locally disturbed parts of the Magdalenien artefact scatter. The results are discussed by means of similar dated aeolian and archaeological stratigraphies in the Rhine-Main area.

[Äolische Sedimentation im Rhein-Main-Gebiet vom Spätglazial bis in das Mittlere Holozän: Neue Nachweise von der Magdalenien Fundstelle in Götzenhain [Hessen, Deutschland]]

Kurzfassung:

Äolische Sedimente (sandiger Löss, Flugsand) wurden durch pedologische und geochronologische Methoden (OSL) mit dem Ziel untersucht, hieraus Aussagen zur stratigraphischen Abfolge und zum Ablagerungsalter zu gewinnen und diese Ergebnisse auf die Ergebnisse der archäologischen Ausgrabung zu beziehen. Die Ergebnisse zeigen, dass die Ablagerung des Lösses im Spätglazial auf einer älteren Lage von Windkantern erfolgte und dieser am Ende des Pleistozäns von äolischem Sand überdeckt wurde. Untersuchungen der fundführenden Schichten ergaben eine mittelholozäne Datierung (6.9 ka), die mit einer lokalen Störung durch äolische Sedimentumlagerungen in Folge anthropogener Landschaftsveränderungen während des Neolithikums erklärt werden. Diese Untersuchungsergebnisse werden vor dem Hintergrund vergleichbarer äolischer Stratigraphien und Fundplätze im Rhein-Main-Gebiet diskutiert.

Keywords:

Loess, Aeolian sand, OSL, Late Glacial, Magdalenien, Germany, Rhineland

Addresses of authors: J.F. Tolksdorf, University of Marburg, Institute of Prehistoric Archaeology, Biegenstraße 11, D-35032 Marburg. E-Mail: Johann.Friedrich.Tolksdorf@gmx.de; K. Kaiser, German Research Centre for Geosciences Potsdam; T. Terberger, University of Greifswald, Department of Prehistoric Archaeology; N. Klasen, University of Cologne, Faculty of Geography; B. Schneider, University of Leipzig, Department of Geography; P. Masberg, University of Marburg, Department of Geography

1 Introduction

Few sites provide information about human settlement in the Rhine-Main area after the LGM by the cultural complex of the Magdalenian (STREET, BAALES & WENINGER 1994; BOSINSKI 2008). New contributions on this topic are presented by the Götzenhain site where artefacts dating to the Magdalenian have been excavated from sandy aeolian sediments (SERANGELI & TERBERGER 2006; TERBERGER, SERANGELI & WOERTZ 2008). To support the assumed dating and to reconstruct the processes of site formation closely connected to questions concerning the coherence and plausibility of the archaeological results, pedological and geochronological (OSL) investigations were performed. Furthermore we compared our local results with other luminescence dated aeolian stratigraphies in the Rhine-Main area.

2 Study site and archaeological record

The Götzenhain site (8°44'37''E / 50°00'07''N) is located in northern zone of the exposed foothills of the Odenwald mountains at the transition of the Main River basin (Fig. 1).

It is situated in an agricultural area on the exposed southern slope above a small stream between the villages of Götzenhain and Dietzenbach. The bedrock mainly consists of Rotliegendes of Permian age and covered by layers of loess and aeolian sands.

Based on several surface finds, since 1991 the site in general has been part of the discussion about the sparsely known Magdalenian in this area (using former classification Dreieich-Götzenhain I: JÖRIS, SCHMITZ & THISSEN 1993; Fig.1; ROSENSTEIN 1998; BOSINSKI 2008: 365f). Using the opportunity to investigate one of the rare sites of this period, excavations started in 2006 (SERANGELI & TERBERGER 2006) and continued until 2009 by a joint project between the Universities of Greifswald and Tübingen. During these field campaigns a layer of flint artefacts embedded in sandy sediment was recorded. The small assemblage (c. 650 artefacts without chips) reflects a short term occupation by a small group. The artefact distribution has a diameter of about 5 m. Some charcoal remains indicate a fire place in the centre of the find concentration. The stone artefact inventory demonstrates core preparation and blank production at the site. The limited number of about 70 tools underscores

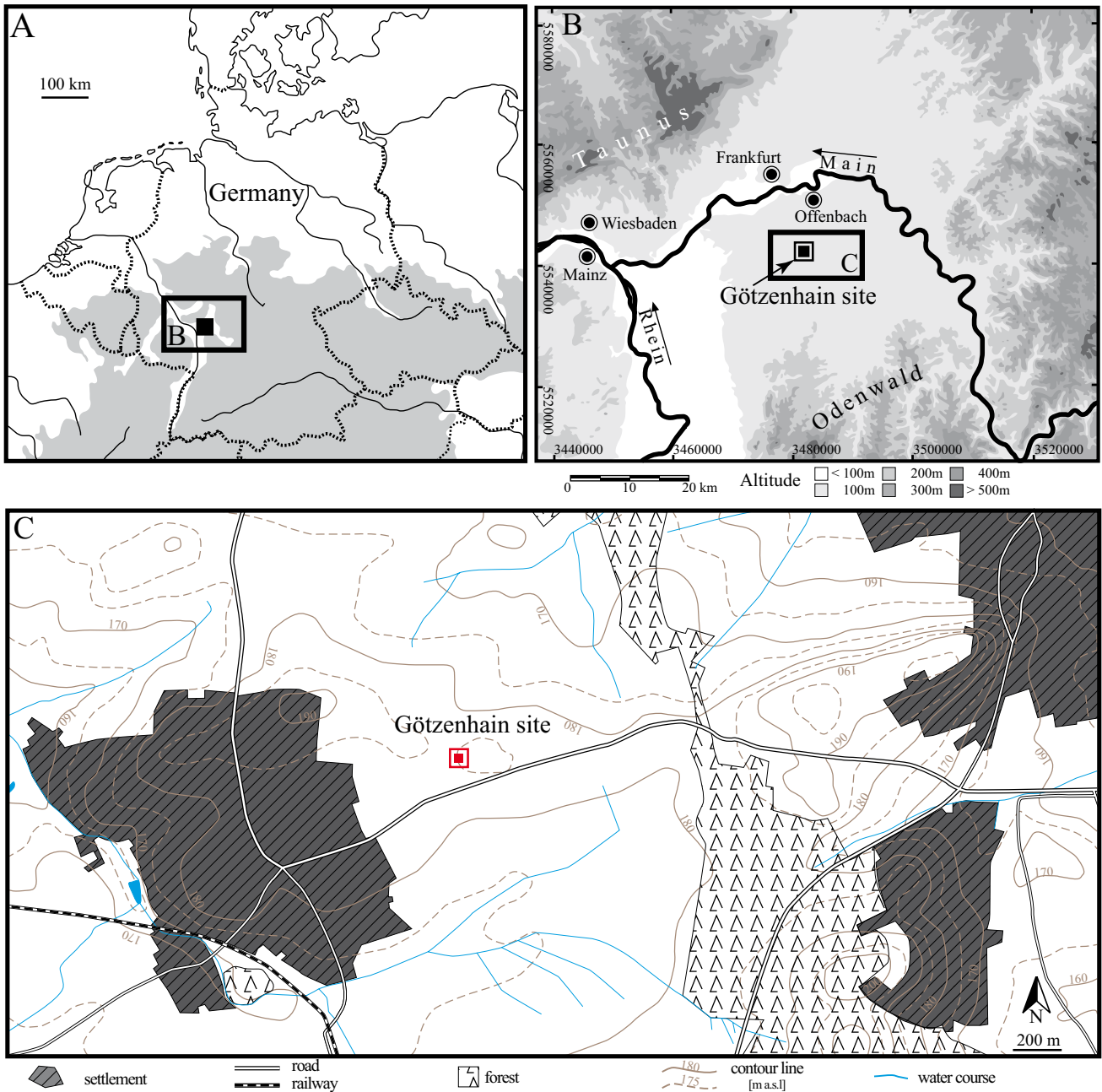


Fig. 1: Location of the Götzenhain site. A: Location in Germany; B: Location in the Rhine-Main area; C: Local topography.
 Abb. 1: Lage der Fundstelle Götzenhain. A: Lage in Deutschland; B: Lage im Rhein-Main-Gebiet; C: Lokale Topographie.

the short term character of the site. This is corroborated by the dominance of backed bladelets and burins. They probably indicate activities focusing on the reparation and hafting of hunting weapons. Unfortunately no bones are preserved but analogous to other sites (STEVENS et al. 2009a, 2009b) we assume that horse was the prey of choice. Typological elements such as Lacan burins (Fig. 2) indicate a close relationship of the Götzenhain assemblage to the Magdalenian sites of Andernach and Gönnersdorf (Fig. 5) located about 100 km to the northwest. However, the “Jurahornstein” used as raw material (Fig. 2) indicates an origin of the people in southern Germany who subsequently moved from the south along the river Rhine (TERBERGER, SERANGELI & WORTZ 2008).

3 Methods

The pedological and geochronological investigations are based on the two sampling trenches GOE1 and GOE2 (Fig. 6). While GOE1 was recorded on the western edge of the excavation area and is closely linked to the artefact scattering, GOE2 was recorded 150 m downhill the southern slope. One OSL sample was taken from profile GOE1 and three OSL samples were collected in stratigraphical order from profile GOE2. For pedological analysis every horizon recognisable was sampled for laboratory analysis (samples 1A–C; 2A–G). Gravels recorded in GOE2 were sampled to document their petrographic and surface features (sample GS1).

3.1 Pedological analysis

Pedological horizons were described and sampled using the German soil science standard ("KA5"; AG Boden 2005; Tab. 1). The soil colour was documented according to the Munsell Soil Colour Charts under moist conditions. After air drying, careful hand-crushing, humus and carbonate destruction (H₂O₂ 30%, HCl 10%) and dispersing with sodium phosphate, a combined pipette and sieving test was used to determine the grain-size distribution. Total carbon and nitrogen were measured by dry combustion (Elementar vario EL) at 1100°C in duplicates.

Main and trace elements were analysed on samples which were ground to a silty size using X-ray-fluorescence by the Geological-Palaeontological Institute of the University of Hamburg. Based on the X-ray-fluorescence results the ratio of Zr and Ti was calculated (SUDOM & ARNAUD 1971). The geological sample GS1 was macroscopically analysed with respect on surface properties and petrographic provenience.

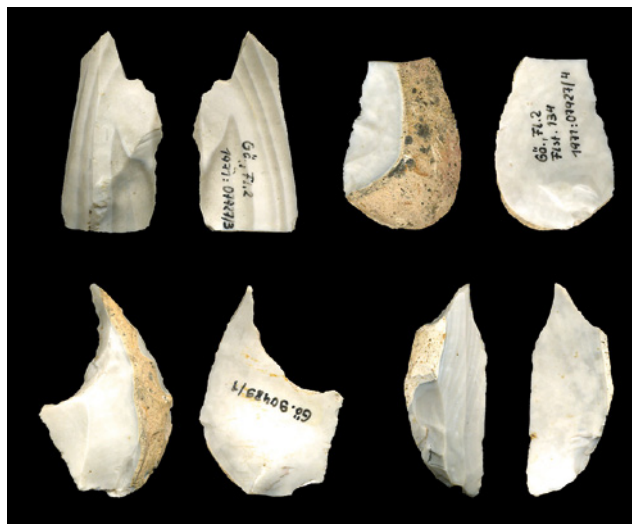


Fig. 2: Artefacts from Götzenhain site made of Jurahornstein; bottom left: Lacan burin.

Abb. 2: Artefakte aus Jurahornstein von der Fundstelle Götzenhain; unten links: Lacan-Stichel.

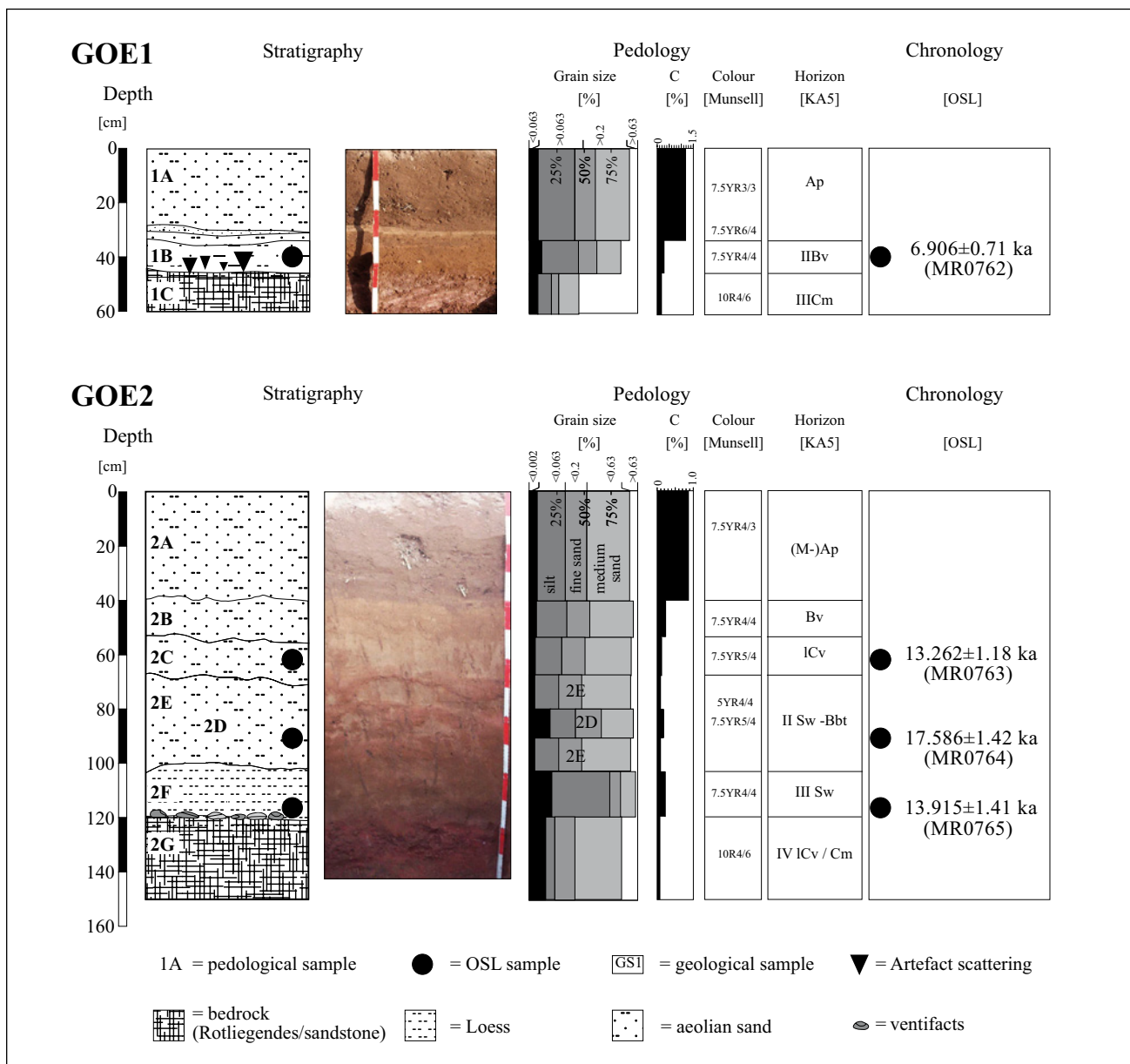


Fig. 3: Profiles GOE1 and GOE2 with stratigraphy, pedology and chronology. / Abb. 3: Die Profile GOE1 und GOE2 mit Stratigraphie, Pedologie und Chronologie.

Table1: Results of pedological analyses.

Tab.1: Ergebnisse pedologischer Analysen.

Sample-No., Horizon [KA5], Depth [cm]		GOE1			GOE2						
		1A Ap 0-35	1B II Bv 35-46	1C III Cm 46-60	2A [M-] Ap 0-40	2B Bv 40-53	2C ICv 53-66	2D II Sw-Bbt 66-108 Bbt- band	2E II Sw-Bbt 66-108 Matrix	2F III Sw 108- 120	2G IV ICv/Cm 120-150
GRAIN SIZE	Clay [%]	9.1	11.1	8.7	7.0	6.1	5.1	19.5	5.0	20.7	14.9
	Fine silt [%]	3.9	5.2	4.2	4.0	4.3	2.2	2.0	1.1	4.5	2.1
	Medium silt [%]	6.7	8.4	2.8	5.4	5.9	5.0	3.1	3.9	9.2	1.6
	Coarse silt [%]	20.9	22.0	5.0	16.4	18.0	17.1	18.4	17.6	39.8	4.4
	Fine sand [%]	19.6	15.9	6.6	20.4	21.7	20.7	24.2	21.5	10.4	18.2
	Medium sand [%]	30.7	22.3	19.1	38.5	39.3	43.1	29.0	44.5	13.1	43.3
	Coarse sand [%]	9.1	15.1	53.7	8.2	4.7	6.8	3.7	6.4	2.1	15.5
	Clay [%]	9.1	11.1	8.7	7.0	6.1	5.1	19.5	5.0	20.7	14.9
	Silt [%]	31.5	35.6	12.0	25.8	28.2	24.3	23.5	22.6	53.5	8.1
	Sand [%]	59.4	53.3	79.4	67.1	65.7	70.6	56.9	72.4	25.6	77.0
Texture class [KA5]	SI3	SI3	SI3	Su3	Su3	SI2	LS4	Su2	Lu	St2	
Substrate	aeolian sand ^{1,2}		bedrock	aeolian sand ^{1,3}			aeolian sand ^{1,3}		sandy loess ⁴	bedrock	
Ct [%]	1.20	0.30	0.20	0.90	0.20	0.10	0.20	0.10	0.20	0.10	
Nt [%]	0.11	0.03	0.02	0.09	0.03	0.02	0.03	0.02	0.03	0.02	
MAIN ELEMENTS	SiO ₂ [%]	84.19	83.91	79.77	86.41	88.39	90.67	82.18	90.63	77.10	81.70
	Al ₂ O ₃ [%]	6.08	7.44	10.40	5.53	5.29	4.76	7.63	4.43	9.66	8.46
	Fe ₂ O ₃ [%]	1.42	1.73	2.42	1.16	0.98	0.87	2.23	0.82	3.16	2.24
	MnO [%]	0.07	0.07	0.03	0.06	0.05	0.02	0.03	0.02	0.05	0.02
	MgO [%]	0.20	0.27	0.41	0.17	0.16	0.15	0.46	0.14	0.72	0.43
	CaO [%]	0.28	0.25	0.50	0.27	0.23	0.19	0.28	0.16	0.45	0.47
	Na ₂ O [%]	0.60	0.66	0.05	0.57	0.65	0.59	0.58	0.51	0.81	0.30
	K ₂ O [%]	2.18	2.37	2.81	2.08	2.04	1.93	2.27	1.87	2.43	2.63
	TiO ₂ [%]	0.39	0.48	0.39	0.32	0.32	0.27	0.35	0.22	0.57	0.29
	P ₂ O ₅ [%]	0.16	0.08	0.07	0.13	0.07	0.05	0.07	0.04	0.08	0.06
SO ₃ [%]	0.08	0.07	0.07	0.07	0.06	0.06	0.07	0.06	0.07	0.06	
TRACE ELEMENTS	Ba [ppm]	904	782	441	470	500	446	638	445	681	570
	Ce [ppm]	37	73	112	41	54	39	39	37	71	35
	Co [ppm]	3	4	3	0	2	3	3	1	10	5
	Cr [ppm]	41	40	29	36	29	25	40	26	61	29
	Cu [ppm]	10	7	11	7	3	3	9	1	12	10
	La [ppm]	15	46	69	23	33	32	24	21	40	24
	Nb [ppm]	15	19	10	14	13	12	19	12	24	8
	Nd [ppm]	18	27	35	16	20	12	15	15	28	15
	Ni [ppm]	10	9	20	2	1	1	16	2	25	19
	Pb [ppm]	21	15	12	15	14	6	15	2	15	9
	Rb [ppm]	80	87	124	72	70	60	88	59	92	102
	Sr [ppm]	90	99	113	85	80	69	69	60	78	103
	U [ppm]	6	9	6	3	2	5	6	3	6	4
	V [ppm]	42	38	49	44	33	19	41	29	63	43
	Y [ppm]	19	18	10	14	17	13	18	12	33	14
	Zn [ppm]	20	10	11	17	6	0	13	0	22	7
	Zr [ppm]	379	406	184	318	297	293	345	266	486	178
Ti/Zr-ratio [molar]	6.2	7.1	12.7	6.0	6.5	5.5	6.1	5.0	7.0	9.8	

1 "Lösssand" [according to AG Boden 2005]

2 "Sandlöss" according to Koch & Neumeister [2005]

3 "Treibsand" according to Koch & Neumeister [2005]

4 "Sandlöss" according to AG Boden 2005 and Koch & Neumeister 2005]

3.2 Optical dating

Luminescence dating was performed at the Marburg Luminescence Laboratory. All samples were sieved in dry conditions to the fraction of 38–63 μm . Subsequently, samples were treated with HCl (10 %), H₂O₂ (10 %) and Na₂C₂O₄ to remove carbonates, organic matter and clay. Polymineral samples were etched for two weeks in H₂SiF₆ to separate fine grained quartz. Measurements were carried out on an automated Risø TL/OSL DA 15 reader equipped with a 90Sr/90Y beta source delivering 0.1085 Gy/s to the sample. Equivalent dose (De) was estimated using a single aliquot regenerative (SAR) dose protocol (MURRAY & WINTLE 2000) with 50 s of blue stimulation at 125 °C and preheat temperature of 200 °C. The quartz OSL signal was detected through a Hoya U 340 filter (7.5 mm; transmission spectrum 290–370 nm).

A reference sample was used to determine the dose rate (D0) applying Neutron Activation Analysis (NAA). While the H₂O content measured in the samples seemed far too low, an estimated average moisture of 7 % was used for calculation.

4 Results

4.1 Pedological results

Profiles GOE1 and GOE2 (Fig. 3; Tab. 1) start with weathered bedrock (“Rotliegendes”) and the above-lying sections of both profiles are carbonate-free. The pedological sequence of GOE1, which represents the stratigraphy observed during the excavation, shows homogenous, nearly gravel-free sand of aeolian origin (“Lösssand” according to AG BODEN; “Sandlöss” according to KOCH & NEUMEISTER 2005) covering the bedrock. The upper part of this sequence is clearly mixed by ploughing. The soil can be classified as (partly eroded) Cambisol showing an Ap/Bv/Cm sequence of soil horizons. During excavation several gravels with ventifact appearance have been observed at the bottom section of the aeolian sand (SERANGELI & TERBERGER 2006, 52) and might be comparable to the blow-out layer with ventifacts in GOE2 by their stratigraphic position. The artefact scattering was documented at the lower part of the aeolian sand though some surface finds indicate that the scattering was already affected by ploughing.

In GOE2 the transition from bedrock to the overlying loess-like sediment (“Sandlöss” according to AG BODEN and KOCH & NEUMEISTER 2005) is marked by a dense layer of sharp faceted ventifacts (sample GS1) up to 9 cm

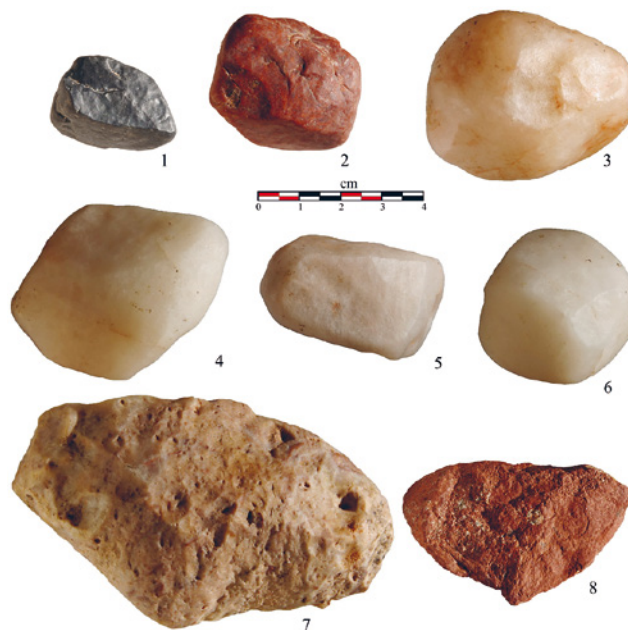


Fig. 4: Ventifacts from the base of profile GOE2 (sample GS1). 1: Lydit, 2: Quartz-Eisenkiesel, 3: Quartz-Jasper, 4–7: Quarz, 8: Rotliegendes (Siltstone).

Abb. 4: Windkanter von der Profilbasis aus Profil GOE2 (Probe GS1). 1: Lydit, 2: Quartz-Eisenkiesel, 3: Quarz-Jaspis, 4–7: Quarz, 8: Rotliegendes.

in diameter, which were determined to consist mainly of Quartz gravels with a few small Lydit gravels (Fig. 4). This blow-out zone is overlain by a loess-like sediment of 20 cm thickness. Above, sand of aeolian origin (“Lösssand” according to AG BODEN; “Treibsand” according to KOCH & NEUMEISTER 2005) occurs which is comparable to the find layer in profile GOE1. The uppermost 40 cm of profile GOE2 is the ploughing zone characterized by a relatively high organic content. While the zone up to 70 cm below the surface shows the typical sequence of a Cambisol with an (M-) Ap/Bv/ICv sequence, the following section shows properties of stagnant soil water (Sw-Bbt horizon).

4.2 Geochronological results

OSL dating (Tab. 2) of the aeolian sand in profile GOE1 yielded an age of 6.906 ± 0.71 ka (MR0762) while the sandy loess at the base of GOE2 yielded an age of 13.915 ± 1.41 ka (MR0765). The overlying aeolian sand in GOE2 was dated to 17.856 ± 1.42 ka (MR0764) while the uppermost aeolian sand in GOE2 yielded an age of 13.262 ± 1.18 ka (MR0763).

Table 2: Results of neutron activation analysis (NAA) and optically stimulated luminescence (OSL) dating.

Tab. 2: Ergebnisse der Neutronenaktivierungsanalyse (NAA) und der optisch-stimulierten Lumineszenzdatierung (OSL).

Sample	Depth [cm]	NAA			Dose rate [Gy ka ⁻¹]	Equivalent dose Gy	Luminescence age [ka] $\pm 1\sigma$	LabNo
		Uranium [ppm]	Thorium [ppm]	Potassium [ppm]				
1a	40	2.3 \pm 0.16	9.8 \pm 0.31	1.92 \pm 0.06	3.22 \pm 0.31	22.21 \pm 1.40	6.906 \pm 0.71	MR0762
2a	60	1.5 \pm 0.11	5.7 \pm 0.19	1.57 \pm 0.05	2.52 \pm 0.25	33.46 \pm 1.43	13.262 \pm 1.18	MR0763
2b	90	1.5 \pm 0.10	5.4 \pm 0.17	1.57 \pm 0.05	2.49 \pm 0.20	44.44 \pm 1.01	17.856 \pm 1.42	MR0764
2c	115	2.7 \pm 0.16	11.1 \pm 0.34	1.86 \pm 0.06	3.51 \pm 0.40	48.87 \pm 2.65	13.915 \pm 1.41	MR0765

5 Discussion

Luminescence dating is generally accepted as providing reliable results about sedimentation ages especially when performed on quartzes of aeolian deposits (MURRAY & OLLEY 2002; PREUSSER et al. 2008). Nonetheless the ages from profile GOE2 are inconsistent when compared to their stratigraphical position and need explanation. Furthermore the dating of the aeolian sand in GOE1 to the Mid-Holocene seems contradictory to the embedded Late Palaeolithic artefacts.

Regarding the data used to calculate the ages in profile GOE2 (Tab. 2) we argue that the results of the D_E -determination are correct giving a smaller equivalent dose (D_E) for sample GOE2b compared to the older sample GOE2c. The reason for the older age of sample GOE2b has to be seen in a significantly lower dose rate (D_0) used for age calculation. We argue that due to the bedding of sandy and loamy layers the sample taken from that horizon might not have been representative for a correct D_0 -determination. Therefore we reject the age of 17.856 ± 1.42 ka (MR0764) as an age overestimation.

The remaining datings from GOE2 indicate that the basal sandy loess deposition occurred within a time range of approx. 15.3 to 12.5 ka when including the spans of uncertainty. The underlying layer of ventifacts (GS 1; Fig. 5) and the absence of older loess sediments points to a phase of intensive wind erosion preceding the dated accumulation. A chronological connection to the Beuningen gravel bed as a marker horizon for intensive surface deflation in Western Europe dated to 20 ka to 15 ka (FRECHEN & VAN DEN BERG 2002) or 18 ka to 14 ka (KASSE et al. 2007) might be possible and would fit very well into the suggested time model. Comparing this dated accumulation of loess to other luminescence dated stratigraphies along the Rhine (Fig. 5D), continuing aeolian sedimentation during this period is present in all profiles, except Mainz-Weisenau and Nussloch, with considerable rates of mass accumulation until 13 ka as calculated by FRECHEN, OCHES & KOHLFELD (2003). A finer resolution into subphases must be rejected due to the high span of dating uncertainty.

An accumulation of younger aeolian sands after 14.5 ka is in good accordance to supraregional models showing sandy aeolian activity during the colder phases of the Late Glacial Period (Dryas I, II, III) especially in the area of the European sand-belt more to the north (SCHIRMER 1999). The phases of aeolian activity were interrupted by periods of stability and pedogenesis during warmer periods accompanied by more dense vegetation (e.g. KASSE 2002; KOSTER 2005; KOLSTRUP 2007; HILGERS 2007; KAISER et al. 2009). While the nearby luminescence stratigraphy of Mainz-Gonsenheim (RADTKE & JANOTTA 1998; Fig. 5D) revealed several phases of sandy aeolian accumulation separated by palaeosols and the Laacher See-tephra, a precise attribution of the aeolian sands in Götzenhain to one of the phases / chronozones fails due to the absence of any comparable chronomarker and the span of uncertainty.

Mid-Holocene accumulation of aeolian sand as derived from profile GOE1 (MR0762: 6.906 ± 0.71 ka) can hardly be explained by natural causes like a climatic deterioration during this period but is more likely to result from human impact. Coinciding with the Early Neolithic cultures of Late Linear Pottery (LBK) or Rössen, we suppose that local hu-

man impact, triggering forest clearance and land use which is evident for this period (KALIS, MERKT & WUNDERLICH 2003), has caused sediment reactivation. This assumption might be corroborated by the occurrence of charcoal of oak (*Quercus*) in the excavation area (analysis: A. KREUZ, Wiesbaden).

A correlation of sedimentation ages to the archaeological results at the site at Götzenhain is supported by the improved chronology of the Late Magdalenien from the sites of Gönnersdorf and Andernach (Fig. 5B; STREET, BAALES & WENINGER 1994; STEVENS et al. 2009a). All sites are comparable in typological aspects. We argue that the settlement occurred during the beginning of the accumulation of the sandy loess dated by sample GOE2c. Ongoing accumulation of aeolian sediments might have supported the preservation of the artefact scatter in the excavation area (GOE1). The archaeological analysis of the artefact distribution supports the idea that the Neolithic disturbance was limited to a small area and did not affect the site in total. A summarizing model concerning the stratigraphy and chronology at Götzenhain based on the aspects discussed here is presented in Fig. 6.

Acknowledgements

We are indebted to the two anonymous reviewers and the editor in chief Holger Freund, who provided valuable help to improve the manuscript significantly. Furthermore we thank Ralph Pedersen for improving our English. The X-ray-fluorescence analyses were kindly performed at the responsibility of Bernd Stütze, Geological-Palaeontological Institute of the University of Hamburg.

References

- AG BODEN (2005): Bodenkundliche Kartieranleitung. 5. Auflage. – 438 S.; Hannover (BGR).
- BOSINSKI, G. (2008): Urgeschichte am Rhein. – 534 S.; Tübingen (Kerns).
- FRECHEN, M. & VAN DEN BERG, M. (2002): The coversands and timing of Late Quaternary earth quake events along the Peel Boundary Fault in the Netherlands. – *Netherlands Journal of Geoscience*, 81: 61–70.
- FRECHEN, M., OCHES, E. & KOHLFELD, K. (2003): Loess in Europe – mass accumulation rates during the Late Glacial Period. – *Quaternary Science Reviews*, 22: 1835–1857. DOI: 10.1016/S0277-3791(03)00183-5.
- HILGERS, A. (2007): The chronology of Late Glacial and Holocene dune development in the northern Central European lowland reconstructed by optically stimulated luminescence (OSL) dating. – 440 S.; Köln (PhD-Thesis University of Cologne).
- JÖRIS, O., SCHMITZ, R., THISSEN, J. (1993): Beek: ein Special-Task-Camp des Magdalénien. Neue Aspekte zum späten Jungpaläolithikum im Rheinland. – *Archäologisches Korrespondenzblatt*, 23: 259–273.
- KAISER, K., HILGERS, A., SCHLAACK, N., JANKOWSKI, M., KÜHN, P., BUSSEMER, S. & PRZEGIELTKA, K. 2009: Palaeopedological marker horizons in northern central Europe: characteristics of Lateglacial Usselo and Finow soils. – *Boreas*, 38: 591–609. DOI: 10.1111/j.1502-3885.2008.00076.x
- KALIS, A., MERKT, J. & WUNDERLICH, J. 2003: Environmental changes during the Holocene climatic optimum in central Europe – human impact and natural causes. – *Quaternary Science Reviews*, 22: 33–79.
- KASSE, C. (2002): Sandy aeolian deposits and environments and their relation to climate during the Last Glacial Maximum and Lateglacial in northwest and central Europe. – *Progress in Physical Geography*, 26: 507–532. DOI: 10.1191/0309133302pp350ra
- KASSE, C., VANDENBERGHE, D., DE CORTE, F. & VAN DEN HAUTE, P. (2007): Late Weichselian fluvio-aeolian sands and coversands of the type locality Grubbenvorst (southern Netherlands): sedimentary environments, climate record and age. – *Journal of Quaternary Science*, 22: 695–708. DOI: 10.1002/jqs.1087
- KOCH, R., NEUMEISTER, H. (2005): Zur Klassifikation von Lösssedimenten nach genetischen Kriterien. – *Zeitschrift für Geomorphologie N.F.*, 49: 183–203.

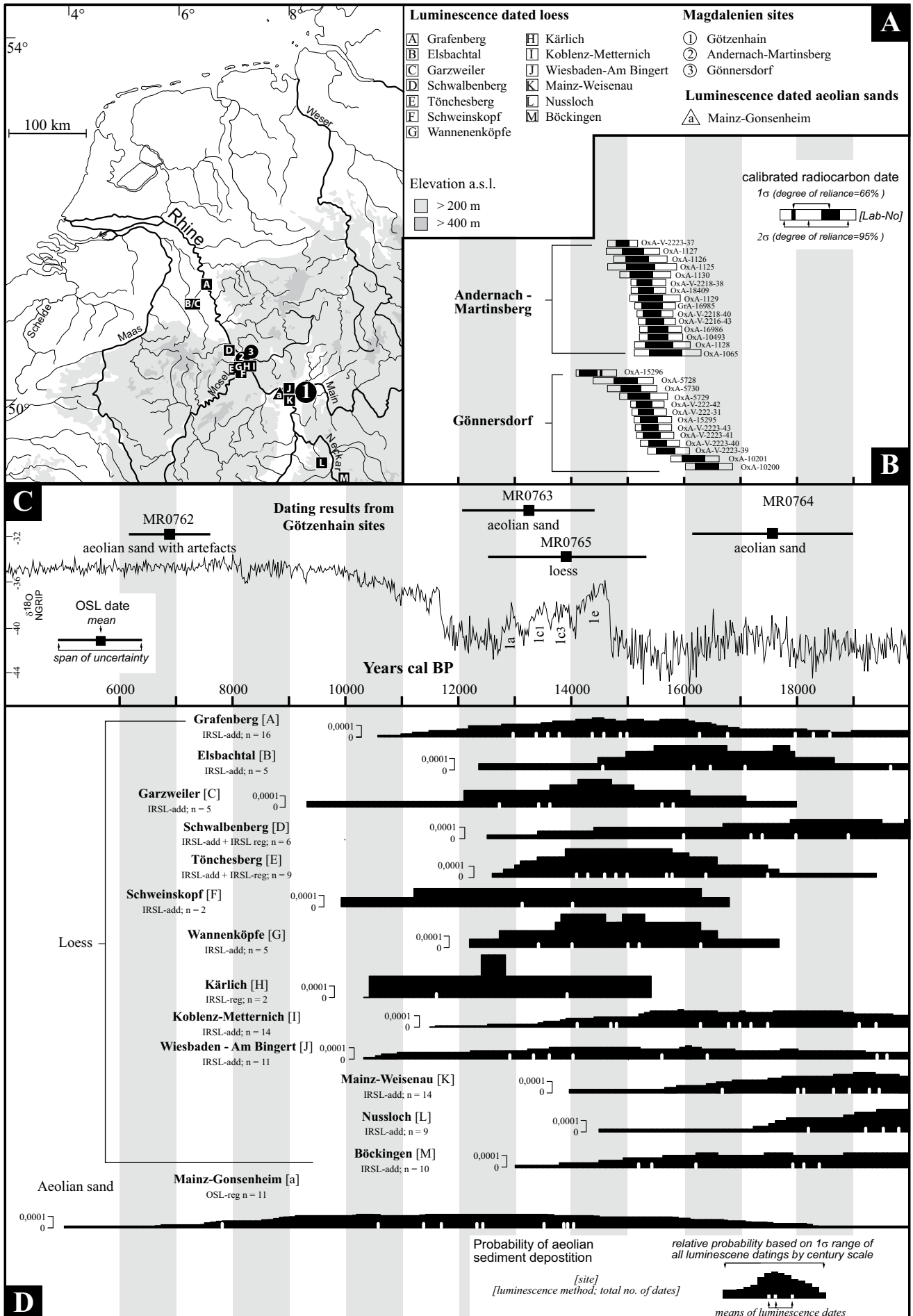


Fig. 5: Dating results of the Götzenhain site compared with other archaeological sites of Magdalenien age and dated aeolian stratigraphies in the Rhine-Main-Neckar area. A: Map of luminescence dated aeolian sediments and ^{14}C -dated Magdalenien sites in the Rhine-Main-Neckar area; B: ^{14}C -dates from archaeological sites in the Rhine area (cf. Stevens et al. 2009a) indicating the time of Magdalenien settlement; C: OSL-datings from Götzenhain site compared to NGRIP $\delta^{18}\text{O}$ time series as temperature indicator (NGRIP-Members 2004; data source: <http://www.iceandclimate.nbi.ku.dk>); D: Luminescence datings of loess (Frechen, Oches & Kohlfeld 2003) and aeolian sand (Radtke & Janotta 1998) plotted by the relative probability of aeolian sand accumulation at every sequence based on the 1σ span of luminescence dating uncertainty.

Abb. 5: Datierungsergebnisse von der Fundstelle Götzenhain im Vergleich mit anderen archäologischen Fundstellen des Magdalenien und datierten äolischen Stratigraphien im Rhein-Main-Neckar Gebiet. A: Karte der lumineszenzdatierten äolischen Sedimente und ^{14}C -datierten Fundstellen im Rhein-Main-Neckar-Gebiet; B: ^{14}C -Datierungen archäologischer Fundstellen im Rheingebiet, die Aufschluss über das Alter magdalenienzeitlicher Besiedlung geben (cf. Stevens et al. 2009a); C: OSL-Datierungen von Götzenhain in Gegenüberstellung mit den NGRIP $\delta^{18}\text{O}$ -Daten als Temperaturindikator (NGRIP-Members 2004; data source: <http://www.iceandclimate.nbi.ku.dk>); D: Lumineszenzdatierungen von Lössen (Frechen, Oches & Kohlfeld 2003) und Flugsanden (Radtke & Janotta 1998) dargestellt als relative Ablagerungswahrscheinlichkeit für jede Sequenz auf Grundlage der Intervalle der einfachen Standardabweichung.

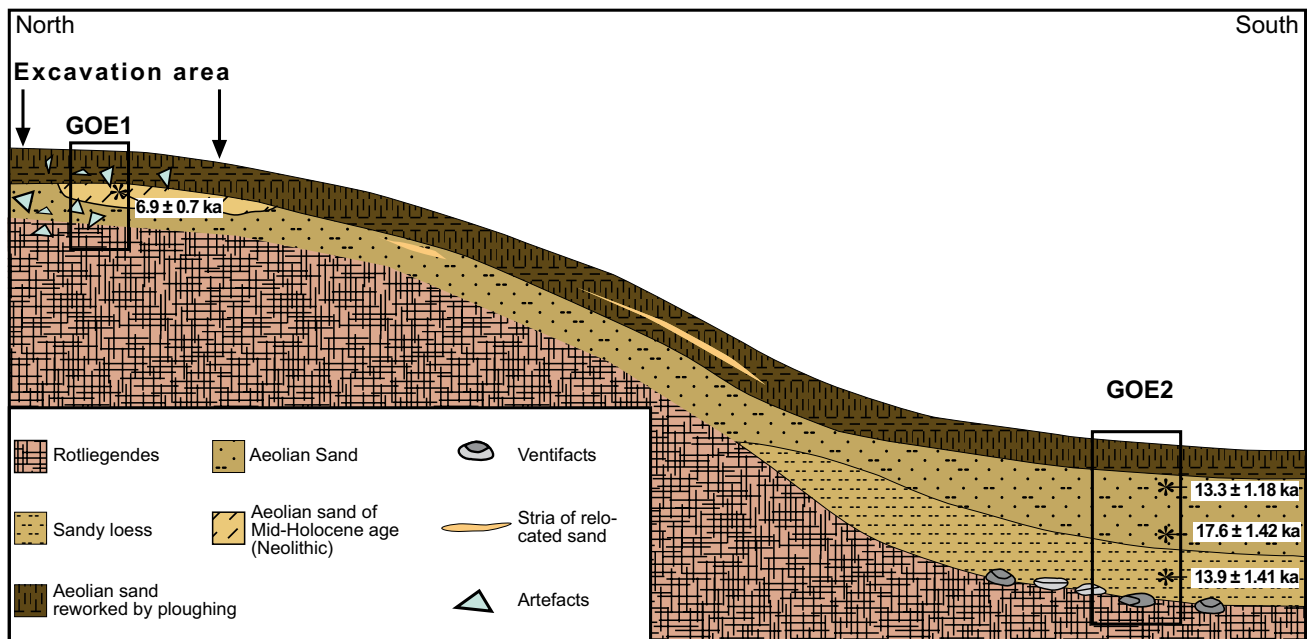


Fig. 6: Summarising schematic model of sediment stratigraphy and chronology as well as the occurrence of artefacts and ventifacts at the Götzenhain site based on the results from profiles GOE1 and GOE2.

Abb. 6: Zusammenfassendes Schema der Sedimentabfolge und ihrer Chronologie sowie der Artefakt- und Windkanterverbreitung an der Fundstelle Götzenhain.

- KOLSTRUP, E. (2007): Lateglacial older and younger coversand in northwest Europe: Chronology and relation to climate and vegetation. – *Boreas*, 36: 65–75. DOI: 10.1111/j.1502-3885.2007.tb01181.x
- KOSTER, E. A. (2005): Recent advances in luminescence dating of Late Pleistocene (cold-climate) aeolian sand and loess deposits in Western Europe. – *Permafrost and Periglacial Processes*, 16: 131–143. DOI: 10.1002/ppp.512
- MURRAY, A., WINTLE, A. (2000): Luminescence dating of quartz using an improved single-aliquot regenerative dose protocol. – *Radiation Measurements*, 32: 57–73. DOI: 10.1016/S1350-4487(99)00253-X
- MURRAY, A., OLLEY, J. (2002): Precision and accuracy in the optically stimulated luminescence dating of sedimentary quartz: a status review. – *Geochronometria*, 21:1–16.
- NORTH GREENLAND ICE CORE PROJECT MEMBERS (2004): High-resolution record of Northern Hemisphere climate extending into the last interglacial period. – *Nature* 431: 147–151. DOI: 10.1038/nature02805
- PREUSSER, F., DEGERING, D.; FUCHS, M.; HILGERS, A., KADEREIT, A., KLASSEN, N., KRIBETSCHKE, M., RICHTER, D.; SPENCER, J. (2008): Luminescence dating: basics, methods and applications. – *Quaternary Science Journal*, 57: 95–149.
- RADTKE, U., JANOTTA, A. (1998): Ein Beitrag zur Beurteilung der Aussagekraft von Lumineszenzaltern für die Datierung von spätpleistozänen und holozänen Dünen anhand des Laacher See-Tuffes (12.900 J.v.h.): Der Testfall „Düne Main-Gonsenheim“ – *Kölner Geographische Arbeiten* 70: 19–45.
- ROSENSTEIN, A. (1998): Vor mehr als 12.000 Jahren – Jäger und Sammler des Magdalenien in Dreieich. – *Landschaft Dreieich - Blätter für Heimatforschung*: 17–32.
- SCHIRMER, W. (1999): Dune Phases and fossil soils in the European sand belt. – In: Schirmer, W. (eds) *Dunes and fossil soils*. GeoArchaeoRhein 3: 11–42; Münster (LIT).
- SERANGELI, J., TERBERGER, T. (2006): Sondierungen an der Magdalenien-Fundstelle von Götzenhain-Ost, Kreis Offenbach. – *Mitteilungen der Gesellschaft für Urgeschichte*, 15: 49–61.
- STEVENS, R. E., O'CONNELL, T. C., HEDGES, R. E. M., STREET, M. (2009a): Radiocarbon and stable isotope investigations at the Central Rhineland sites of Gönnersdorf and Andernach-Martinsberg, Germany. – *Journal of Human Evolution*, 57: 131–148. DOI:10.1016/j.jhevol.2009.01.011
- STEVENS, R. E., GERMONPRÉ, M., PETRIE, C., O'CONNELL, T. C. (2009b): Palaeoenvironmental and chronological investigations of the Magdalenian sites of Goyet Cave and Trou de Chaleux (Belgium), via stable isotope and radiocarbon analyses of horse skeletal remains. – *Journal of Archaeological Science*, 36: 653–662. DOI:10.1016/j.jas.2008.10.008
- STREET, M., BAALES, M., WENINGER, B. (1994): Absolute Chronologie des späten Paläolithikums und des Frühmesolithikums im nördlichen Rheinland. – *Archäologisches Korrespondenzblatt*, 24: 1–28.
- SUDOM, M. D., ARNAUD, R. J. (1971): Use of Quartz, Zirconium and Titanium as indices in pedological studies. – *Canadian Journal of Soil Science*, 51: 385–396.
- TERBERGER, T., SERANGELI, J.; WOERTZ, P. (2008): Eiszeitjäger aus dem Süden – ein 15.000 Jahre alter Lagerplatz bei Dreieich-Götzenhain. – *hessen-ARCHÄOLOGIE* 2008: 20–24.