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Middle Palaeolithic artefact migration due to periglacial processes; a geological investigation into near-surface occurrence of Palaeolithic artefacts (Limburg-Eastern Brabant coversand region, the Netherlands)

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Abstract

The original distribution pattern of Middle-Palaeolithic artefacts may be affected by tectonic movement, sedimentation and periglacial processes. This is e.g. the case in the coversand area of Limburg and Eastern Brabant (NL), where the occurrence of numerous finds in a SW-NE trending zone across the Roer Valley Graben is considered enigmatic. In order to elucidate the processes affecting the spatial distribution and the chance of recovery of such artefacts, we investigated a site in Nederweert. At this site, several Middle-Palaeolithic artefacts had been recovered earlier from unexpectedly shallow depths. A test pit profile and grain size analyses revealed that the shallow sediments at this site have been affected by intense, multi-phase cryoturbation, which has deformed the sand and loam layers and partially mixed them thoroughly. As a result, optically stimulated luminescence dating of these sediments yielded widely scattered single-aliquot equivalent dose distributions. Using a Finite Mixture Model (FMM), it was estimated that cryoturbation caused mixing of sediments deposited between 12 and 50 ka with sediment grains deposited between 60-150 ka. The latter material is probably the original context of the Middle-Paleolithic artefacts. Apparently, cryoturbation and potentially other periglacial processes have transported artefacts closer to the surface. Based on these results, we suggest that the occurrence of Middle-Palaeolithic artefacts is caused by (1) the tectonically-induced spatial distribution of layers of this age and (2) periglacial processes having caused migration of artefacts towards the surface. Although periglacial processes may facilitate finding Middle Palaeolithic artefacts, they may severely disturb the original context to such an extent that Middle Palaeolithic sites can no longer be identified. The results of this study form a basis for improving the Indicative Map of Archaeological Values that is used to predict the presence of archaeological sites. The insights gained are also relevant to other areas where Middle-Palaeolithic sites are affected by periglacial processes.

Keywords: Archaeological heritage management, Boxtel Formation, Cryoturbation, Middle Palaeolithic, Optical dating, Periglacial conditions, Pleistocene, Roer Valley Graben

Introduction

The archaeological record is the most invisible and hidden part of our cultural heritage. Most of the archaeological record is buried in the soil, or submerged under water. At the same time, this record is under threat from various processes. Some of these are anthropogenic (e.g. construction work, tillage and mining), others have a natural origin (e.g. erosion). In order to protect or excavate archaeological remains we need knowledge on their spatial distribution. Paradoxically, the sites that are usually conserved best – and therefore have the highest information potential – are buried in the subsoil and have yet to be discovered. To get an impression of the location of archaeological sites, archaeologists have developed prediction models. In general, two approaches are used to predict the presence of archaeological sites. The inductive approach relates known archaeological sites with environmental variables (e.g. the presence or absence of a geological unit). It derives generalisations about the location of archaeological sites that are used to predict zones in the landscape were sites are likely to be found. The deductive approach uses theory from geography, economy or biology to predict past human behaviour (e.g. land use) and by that the location of archaeological sites. In the Netherlands, both approaches have been used to construct a predictive model 1:50 000 model, called the 'Indicative Map of Archaeological Values' (IKAW) (Deeben et al., 1997; 2002).

Difficulties to construct predictive models increase with the age of the archaeological period. This certainly applies to the period before 35 ka, because it is not known to what extent pre *Homo sapiens sapiens* species behaved the same way as theories of modern human behaviour predict (Bettinger, 1991; Wobst, 1978). Moreover, the landscape and active geological processes have often changed profoundly since then and post-depositional geological processes may have altered the original distribution of archaeological sites.

The detection and protection of the archaeological heritage from the first period of hominid presence in the Netherlands (the Middle Palaeolithic, 300-35 ka) poses specific problems from the point of archaeological heritage management. In general, Middle-Palaeolithic sites are small and have a low density of recognizable artefacts due to depositional and post-depositional processes. Since archaeological prospection is most often based on borehole surveys, especially where the sites are covered with thick layers of sediments, such small sites are easily missed. Moreover, due to the limited survival of material other than charcoal and worked flint, the chance of recognizing a Middle-Palaeolithic site from borehole material is small.

In order to deal better with Middle-Palaeolithic archaeological remains in the context of archaeological heritage management, a robust conceptual model is needed that predicts the distribution of Middle-Palaeolithic sites and objects. The best approach to achieve this, is to establish a relationship between the known Middle-Palaeolithic record and the modern landscape. Relevant landscape characteristics can be deduced and subsequently applied to delineate areas with a higher chance of finding Palaeolithic sites or artefacts at – or within a certain depth range from – the surface. Such models rely heavily on a reconstruction of the landscape and associated soil conditions that determined human presence and activity in the past, as well as formation processes that affect the chance of survival of sites.

In the Netherlands, the evidence for the earliest presence of Hominids consists mostly of flint artefacts from the Pleistocene area. They were made by *Homo sapiens neanderthalensis* or its predecessor *Homo heidelbergensis*. Individuals from these side branches of human ancestry occurred scattered across Europe, from c. 500 until 120 ka (*heidelbergensis*) and from c. 150 until 35-30 ka (*neanderthalensis*), respectively (Rensink, 2005). Despite their prolonged presence, the amount of artefacts that is known is relatively low and consists mostly of dispersed surface finds. Probably a great number of Middle-Palaeolithic sites are covered by thick layers of sediment. In the Netherlands, the earliest excavated evidence for the presence of Hominids comes from the terrace gravels of the Meuse river. In the former Belvédère quarry, a number of concentrations of stone artefacts in a more or less continuous distribution of artefacts and bone fragments were excavated (Roebroeks, 1988; Van Kolfschoten & Roebroeks, 1985), probably representing the re-use of the landscape along the river Meuse for subsistence activities. The main archaeological level was dated to 250±20 ka by thermoluminescence methods (Huxtable, 1993). Also, numerous artefacts have been recovered from Middle-Pleistocene fluvial deposits of Rhine and Meuse; some of which have been displaced and reworked into the Saalian ice-pushed ridges (e.g. Stapert, 1991; Niekus & Stapert, 2005; Van Balen, 2006; Busschers et al., 2008). In the northern province of Drenthe, artefacts have been found in deposits overlain by a thin Saalian glacial till cover (Niekus & Stapert, 2005). Middle-Palaeolithic artefacts are also known from the North Sea floor (e.g. Stapert, 1981). The Dutch part of the North Sea floor in addition recently yielded a small skull fragment of the *Homo sapiens neanderthalensis* (Hublin et al. in press).

In the Limburg-Eastern Brabant coversand area and Limburg loess area, surface finds of Middle-Pleistocene artefacts indicate that layers containing such artefacts occur close to the surface in many areas (Glauberman, 2006; Rensink, 2005; Fig. 1). Development of a conceptual model for this region is hampered by a lack of knowledge of the archaeological formation processes and their influence on the distribution and occurrence of Middle-Palaeolithic artefacts.

In recent years, a major excavation of a prehistoric, Roman and Medieval settlement, and Iron Age and Roman cemeteries graveyards took place in Nederweert, in the zone where Middle Palaeolithic surface finds occur. During this excavation, several Middle-Palaeolithic flint artefacts were found (Hiddink 2005). This was unexpected for two reasons. Firstly, because the excavation methods used on large-scale cemetery or settlement sites with soil features, differs considerably from the methods appropriate for excavating Palaeolithic and Mesolithic sites. Hence, Middle-Palaeolithic artefacts are easily missed in such large-scale excavations and it is likely that only a small portion of the scattered artefacts were recovered (Deeben et al., 2006). Secondly, because of the location in the Roer Valley Graben, it was expected that sediments that could contain Middle-Palaeolithic artefacts occurred at depths of at least several metres, whereas 98% of the archaeological soil features in the settlement was less than 90 cm deep (Deeben et al. 2009). Occurrence of Palaeolithic artefacts very close to the surface suggests that either older deposits occur closer to the surface than previously thought, or artefacts have been transported to the surface by post-depositional natural or anthropogenic processes.

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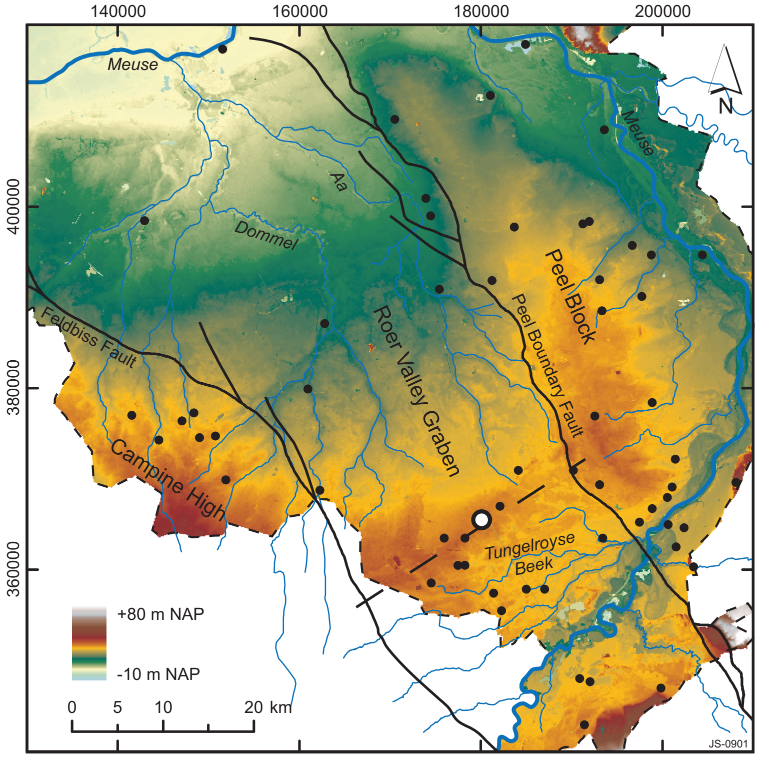

Fig. 1. Elevation map of the Limburg-Eastern Brabant coversand region, showing the position of major fault lines (black lines) and the SE-NW trending Weert-Nederweert coversand ridge (dashed black line). The known distribution of Middle-Palaeolithic artefacts is indicated by black dots, the location of the Nederweert research site is indicated by a white circle (adapted from: Deeben et al., 2009).

The present study aims at elucidating the processes affecting the distribution and chance of recovery of Middle-Palaeolithic artefacts. This is seen as a first step towards a predictive model for the distribution of Palaeolithic artefacts. We chose the Nederweert site, and focussed on determining (1) at what depth sediment layers dating to the Middle Palaeolithic occur, (2) whether processes – anthropogenic or natural – could be identified that may have brought Middle-Palaeolithic artefacts to within surface range and (3) whether a more precise dating of the artefacts would be possible.

Research area

Geology of the Limburg-Eastern Brabant coversand region

The subsurface of Limburg-Eastern Brabant coversand region is dissected by southeast-northwest trending faults, bounding a number of tectonic blocks that all have their own history of vertical movements. This zone of active faulting is known as the Roer Valley Rift System. The Roer Valley Graben is the central, strongest subsiding part of the rift system (Fig. 1) and contains a more than 200 m thick Quaternary sedimentary sequence in its north-central part. Until the first half of the Middle Pleistocene the Rhine and Meuse river systems discharged into this area, leaving a thick stack of generally coarse-grained fluvial deposits (e.g. Westerhoff, 2009). However, from the second half of the Middle Pleistocene onward, differential tectonic movements caused the rivers Rhine and Meuse to deflect their courses more to the east and leave the central part of the Roer Valley Graben without a large fluvial depositional system (Zagwijn, 1989; Van den Berg, 1994; Schokker et al., 2005).

Subsidence in the Roer Valley Graben continued, though not everywhere at the same pace (Fig. 2). Climate changes caused repeated shifts from a warm-temperate to a cold-periglacial climate. As a result of the interplay of tectonic movements and cyclic climate change, aeolian, fluvio-aeolian and small-scale fluvial deposits were formed. In shallow, humid depressions, 1-2 m thick organic deposits formed as well (Schokker & Koster, 2004; Schokker et al., 2004). This sequence of fine-grained and organic deposits is lithostratigraphically known as Boxtel Formation (Schokker et al., 2007; TNO, 2009).

The Middle to Late Quaternary deposits of the Boxtel Formation reach a maximum thickness of more than 30 m. However, subsidence has been significantly smaller along a southwest-northeast trending axis , perpendicular to the main faults, which is also expressed in the present-day topography (Fig. 1, 2). This area, known as the Weert-Nederweert coversand ridge, is characterised by the presence of coarse-grained Rhine and Meuse deposits at less than 10 m below the surface (Sterksel Formation and Beegden Formation, respectively; TNO, 2009). On top of these fluvial deposits, fine-grained fluvio-aeolian and organic deposits of the Boxtel Formation occur (Fig. 3), composed of alternating fluvial sand, fluvio-aeolian loamy sand and lacustro-aeolian loam (locally also known as 'Brabant loam'). The top 1-2 m usually consists of Middle to Late-Weichselian coversand. In the Weert-Nederweert area, this coversand is rather loamy and made up of alternating mm-cm thick fine sand and loam layers. It can be regarded as a wet-aeolian deposit that

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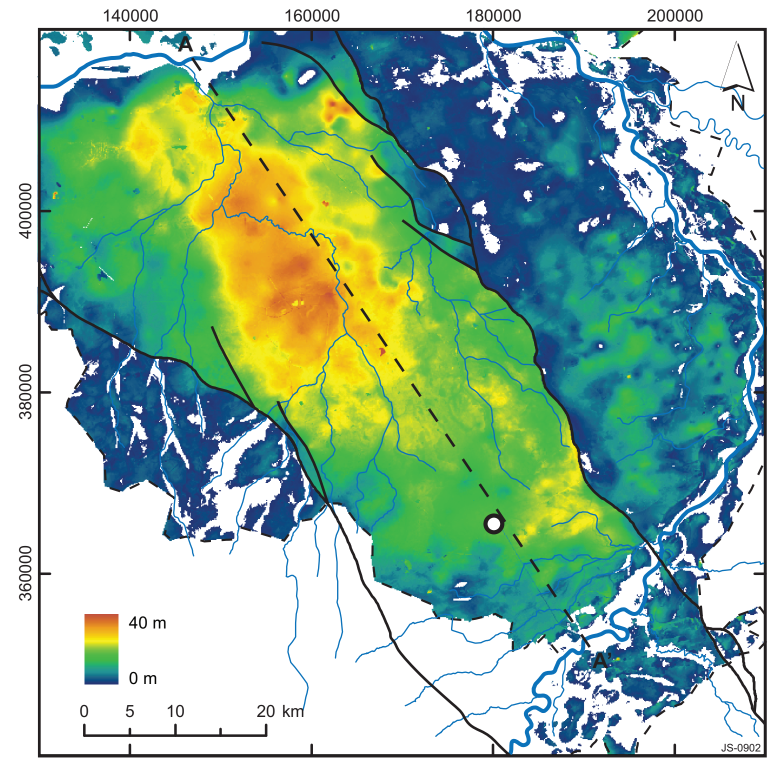

Fig. 2. Thickness of the Boxtel Formation and overlying deposits, indicating differential Middle to Late-Quaternary sedimentation within the Roer Valley Graben, mainly as a result of differential subsidence. The position of cross-section A-A' (Fig. 3) is indicated.

originated from deposition and adhesion of fine sand and loam on an alternating dry and moist surface, probably associated with the presence of permafrost and the formation of an active layer in summer (e.g. Ruegg, 1983; Schwan, 1986; Lea, 1990; Schokker & Koster, 2004).

Unlike other parts of the Roer Valley Graben, the coversand ridge of Weert-Nederweert is not dissected by small river valleys. It forms a plateau-like watershed between the catchments of the rivers Dommel and Aa, draining towards the northwest, and the catchment of the Tungelroyse Beek, draining towards the east. Due to poor drainage conditions, ombrotrophic peat bogs could expand from the Peel region onto the eastern part of the coversand ridge of Weert-Nederweert during parts of both the Eemian and Holocene interglacials (Mente, 1961; Schokker et al., 2004).

Middle-Palaeolithic artefacts in the Limburg-Eastern Brabant coversand region

Middle-Palaeolithic artefacts have been found scattered at the surface in the Limburg-Eastern Brabant coversand region (Rensink 2005; Fig. 1). The distribution appears to be related to the position in the present-day brooks and rivers. The only exceptions are an isolated occurrence on the Peel Block, and a series of finds on the coversand ridge of Weert-Nederweert.

It is attractive to explain the relation between Middle-Palaeolithic find spots and present-day rivers or brooks with a preference of hominids for fresh running water. Indeed, with only a few exceptions (e.g. Heijnens & Tijssen, 1982), the location of brooks and rivers in this area has remained the same since the end of the Middle-Palaeolithic. A single isolated find on the Peel Block may be explained by the near-surface occurrence of Middle-Pleistocene Meuse deposits of the Beegden Formation containing reworked flint artefacts from Limburg. On the Weert-Nederweert coversand ridge Middle-Palaeolithic deposits occur relatively close to the surface (cf. Figs 2, 3). However, these deposits are generally covered by 1-2 m thick Late Pleniglacial to Late Glacial loamy coversands, so the shallow existence of these deposits alone does not explain the surface finds of Middle-Palaeolithic artefacts in this area.

The Nederweert artefacts

The Nederweert site was excavated between 2000 and 2003 by the Archaeological Centre Vrije Universiteit – Hendrik Brunsting Stichting (ACVU-HBS). This excavation concentrated on soil features and artefacts from Iron age, Roman and Medieval periods. During mechanical digging, 21 older flint artefacts were found. Additionally, 19 artefacts were found during hand-digging and sieving. Finally, a single artefact was found at the surface by an amateur archaeologist. At least six of the artefacts date from the Middle-Palaeolithic (300-35 ka). The ages are based on flint technology, artefact type and natural modifications of the artefacts' surface, e.g. patina. They include two scrapers (0-1 and 8024-1) that were made with the so-called Levallois technique (Boëda, 1988; Van Peer, 1992; see Fig. 4a, b).

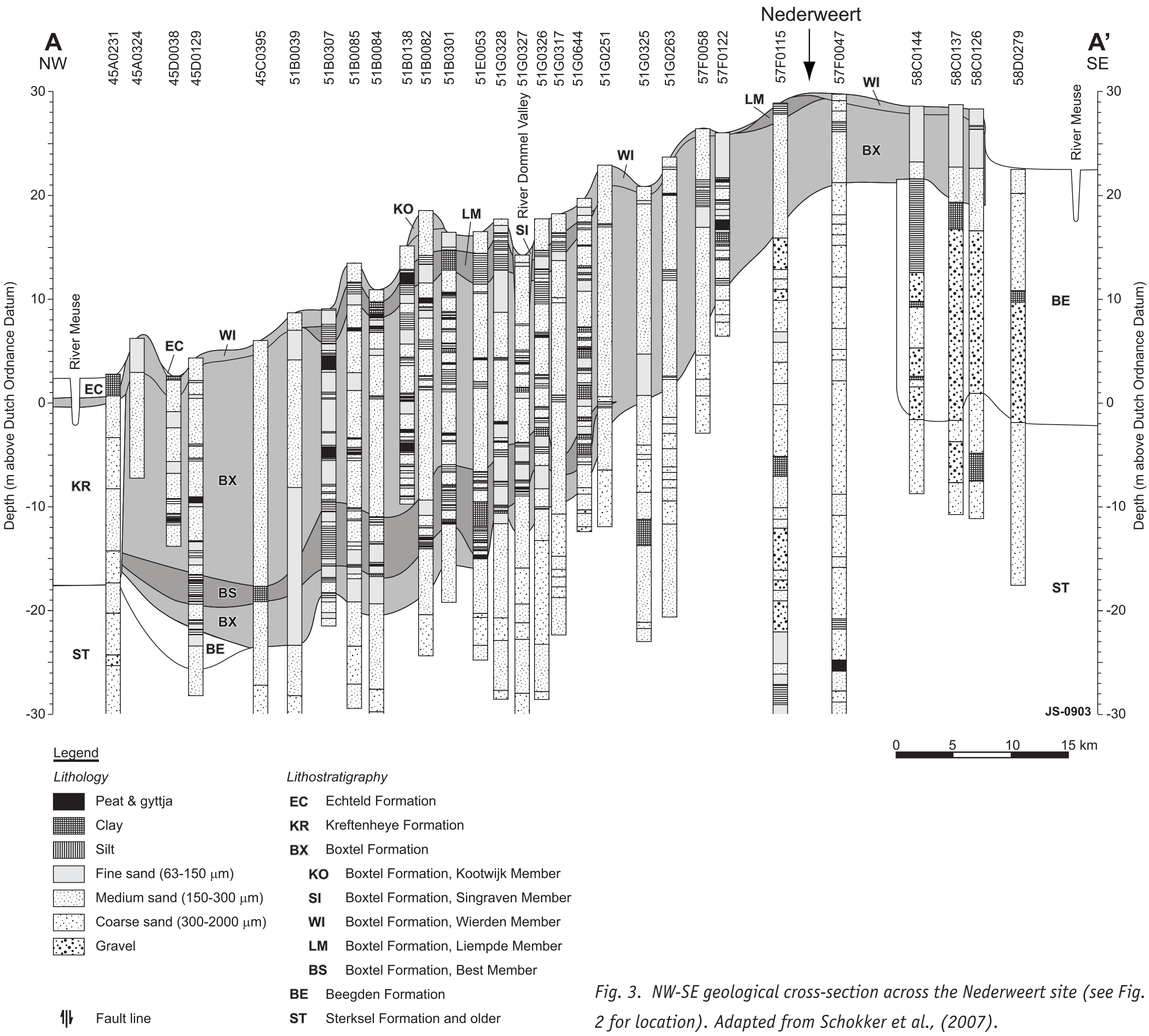

Fig. 3. NW-SE geological cross-section across the Nederweert site (see Fig. 2 for location). Adapted from Schokker et al., (2007).

Materials and Methods

Field work and grain-size analysis

Field work in September 2006 consisted of opening up a trench at the Nederweert location in the vicinity of the location where one of the Palaeolithic artefacts (8024-1) was found. The trench was on the edge of excavation pit 24 of the 2001-2003 ACVU-HBS excavation. The trench was 4.5 m long, 2 meter wide and reached a depth of c. 3 m. It had an east-west orientation. The north profile in the trench was recorded and used for sampling (see Fig. 5a, b). Seven samples were taken for OSL-dating and grain size analysis. Two additional samples for grain-size analysis were taken after a small section of the trench was excavated further to a depth of c. 4 meters. Grain size analyses were performed using a Malvern 2000 laser grain sizer at the TNO/ Deltares laboratory in Utrecht.

OSL analysis

Seven samples for optically stimulated luminescence (OSL) dating were taken from the trench (Fig 5a,b) to investigate the age of shallow sediments. OSL, or optical dating determines the age of the last exposure of sand grains to light. Thereby, the method determines the burial age of sediments. For an extensive review of the method and its applications we refer to Wallinga et al. (2007).

Optical dating is a trapped charge dating method applied to sand-sized quartz grains. Due to exposure to natural ionizing radiation during geological burial, charge (electrons and holes) becomes trapped in the crystal lattice of quartz grains. Upon (day-)light exposure during an erosion, transport and redeposition cycle, this charge recombines. Such recombination of charge can also be induced by artificial exposure to monochromatic light, and gives rise to a minute light emission, termed luminescence. The amount of trapped charge, and hence

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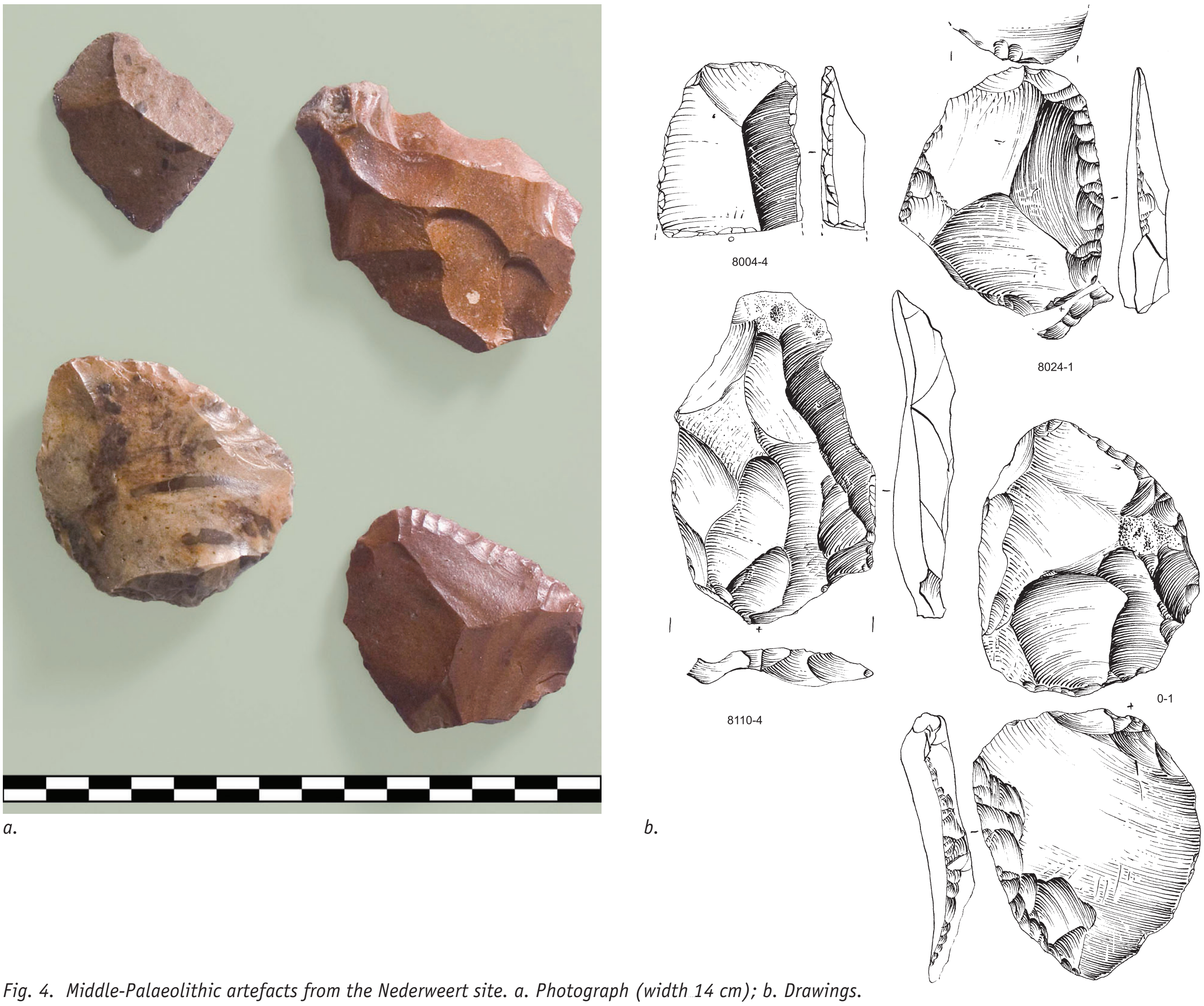

Fig. 4. Middle-Palaeolithic artefacts from the Nederweert site. a. Photograph (width 14 cm); b. Drawings.

the brightness of the luminescence signal, provides a measure of the duration since the last deposition and burial event. For optical dating two quantities are determined: 1) the amount of ionizing radiation delivered to the sample yearly (dose rate, Gy/ka), and 2) the total amount of ionizing radiation received by the sample since the last exposure to light (equivalent dose, Gy). The age of the sample (ka) is then obtained by dividing the equivalent dose by the dose rate.

Samples for optical dating were obtained by hammering opaque PVC tubes into the trench wall. In the darkroom of the luminescence dating laboratory, equipped with dim amber lighting, samples were split in two. Sediment from the outer ends of the tubes was exposed to light during sampling, and was used for dose rate determination. Sediment from the inner part of the tube was shielded from daylight throughout, and hence suitable for equivalent dose measurement.

For dose-rate estimation the samples were dried, ground, ashed and then cast in wax pucks for measurement on a high-resolution gamma spectrometer. We determined activity concentrations of K-40 and several radionuclides of the U and Th series. Activity concentrations were converted to infinite matrix dose rates using the conversion factors of Adamiec & Aitken (1998). The natural dose rate experienced by the grains was calculated from the infinite matrix dose rate using grain-size attenuation factors given by Mejdahl (1979). A contribution from cosmic rays was included based on the depth, following equations presented by Prescott and Hutton (1994). We assumed gradual burial to the present depth. A correction was made for attenuation of the dose rate by water using the attenuation factors given by Zimmerman (1971), assuming that water contents during sampling (5-15% by weight) were representative of those during geological storage. Attenuation due to organic material was also taken into account, but is of less significance due to low organic contents (all <2% by weight).

For equivalent dose measurement we extracted quartz grains of 180-212 µm through sieving and treatment with HCl, H_2O_2 and concentrated HF. HF treatment serves to dissolve other minerals than quartz and to etch the outer surface of the quartz grains. As a final step samples are sieved once more to reject grains that were heavily damaged by chemical treatment. Absence of an infrared stimulated luminescence (IRSL) signal following a laboratory beta dose confirmed the purity of the

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quartz extract. For equivalent dose estimation we adopted a single-aliquot regenerative dose (SAR) procedure, where each OSL measurement was preceded by an exposure to infrared (IR) light (Wallinga et al., 2002). IR exposure was included as a precaution to minimize a contribution from any remaining feldspar grains or inclusions to the OSL signal. Based on a preheat plateau test we selected a preheat of 260°C for 10 seconds, combined with a cutheat of 220°C. Dose recovery tests indicated that the adopted SAR protocol could accurately determine a laboratory dose (average dose-recovery ratio 1.02±0.02). Recycling ratios (average 1.000±0.004) indicated that the sensitivity correction functioned satisfactorily. Dose-response curves could be fitted with a single saturating exponential or single-exponential plus linear component, with the onset of saturation (D0) varying from 110 to 160 Gy. Measurements were made on subsamples (aliquots) containing a few tens of grains of quartz (1 mm diameter of each disc mounted with grains); only aliquots with recycling ratio's within 10% of unity were accepted for equivalent-dose analysis. To obtain statistically meaningful results measurements were repeated until at least 20 aliquots passed the rejection criteria for the upper four samples. For the lower three samples less aliquots were measured because the quartz OSL signal approached saturation and additional measurements would be too time consuming.

Results

Field observations

In the north profile of the excavation trench, nine different sediment units were observed (Fig. 5b). These are presented in Table 1. Most of the sediment units in the profile are heavily deformed. Blocks of sandy sediment of units 5 and 7 are embedded in the loam of unit 6. Their irregular and sharp boundaries give the impression that deformation at this location involved intact parts of units 5 and 7 floating in a churning mass of surrounding loam (Fig 5a). We interpret the complex deformation as a result of repetitive soil disturbance by freezing and thawing processes. The resulting structures are commonly refered to as cryoturbations.

Grain-size distributions

Within the grain-size analyses, two groups can be discerned (Fig. 6): The first group – samples 1,3,7 and 9 – consists of unimodal well-sorted fine sand, with a discrete peak between c. 80 and 200 micron. Only sample 3 shows some admixture of coarse sand (c. 800 micron), and several samples show a very minor silt component (c. 20 micron). The second group – samples 2, 4, 5, 6 and 8 – is much less well sorted. Although the overall pattern is generally bimodal or trimodal, all grain size classes between 1 and 2000 micorn are present in these samples. Several samples, especially 4, 5, 6 and 8 show many overlapping peaks in the silt range. As a result, their grain-size distribution almost seems to form a continuum.

The well-sorted samples are typical for sedimentary deposits in an environment with relatively little variation in their depositional energy: smaller grains were transported further, whereas larger grains were deposited earlier. Environments with larger differences in depositional energy often have bimodal distributions. Most samples in this unimodal group are from the blocks of units 5 and 7 that seem unaffected by cryoturbation, although it also includes sample 1 from unit 4.

Bimodal or trimodal distributions are often seen in laminated deposits. Alternating high- and low-energy depositional environments are reflected in alternating finer and coarser grained deposits. When sampling such deposits, it is unavoidable that different lamina with different grain – size properties are mixed, hence the bimodal or trimodal distributions. In the poorly sorted samples under discussion here, however, so many grain-size classes are mixed that it is unlikely that they reflect just a few lamina. Moreover, no lamination was observed in the sediments except layers 7 and 9 during fieldwork. Therefore it stands to reason that the poor sorting in these sediments was caused by cryoturbation – induced mixing. Probably, repeated freezing and thawing under periglacial conditions resulted in the mixing of material from several units, including loam and various types of sand. Poorly-sorted samples are mainly from the loam units 6 and 8. However, it also includes one sample (2) from unit 4, which seems to come from a unit 5 – block. Possibly, this sample contained not only sediments from the unit 5 block, but also from the matrix that lies behind.

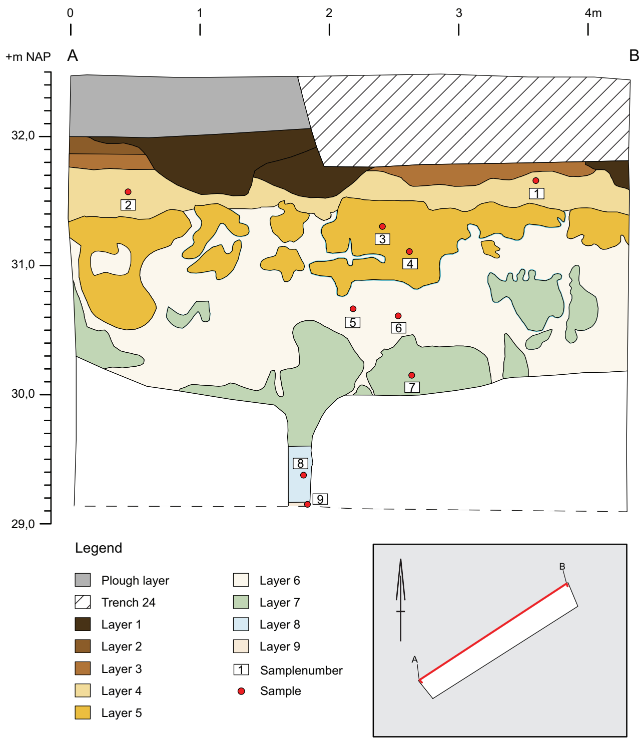
OSL dating

Dose rate measurements yielded no problems, and results ranged from 1.23 to 2.65 Gy/ka with values around 1.5 Gy/ka for most samples (see Table 2). These values are larger than those reported by Schokker et al. (2005) for Roer Valley Graben sediments, likely due to larger loam contents of the present samples.

Single-aliquot equivalent dose distributions showed wide scatter (see Fig. 7), much more than could be explained by the measurement uncertainty on individual estimates. Interpretation of the equivalent dose distributions depends on the cause of the scatter, and we will briefly discuss different possibilities:

1. The OSL signal of part of the grains was not reset at the time of deposition and burial due to inadequate light exposure (heterogeneous bleaching). Given the depositional environment of these sediments (aeolian and surface water) this explanation is unlikely.
2. The dose rate experienced by different grains deviates due to heterogeneity of the deposits. This may indeed play a role, but is unlikely to cause large scatter as observed for these samples (up to a factor of 5 between aliquots for OSL1 and 2).

a.

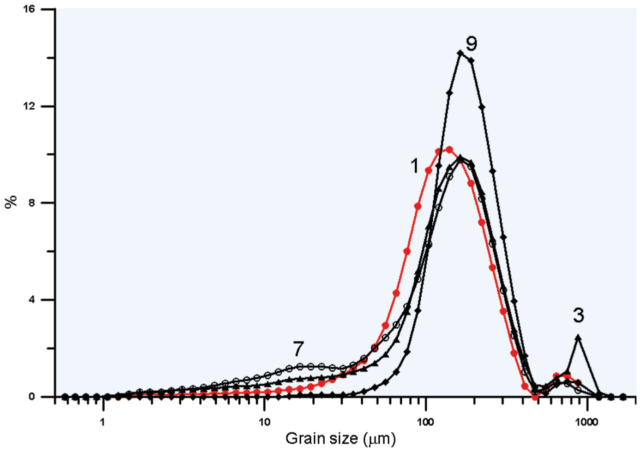


b.

Fig. 5. Nederweert test-pit. a. Photograph. b. Drawing with sample positions.

Table 1. Description of the sediment units in the north profile of the excavation trench.

	Field description (according to NEN 5104)	Interpretation
1	Darkbrown, weakly silty, moderately coarse sand	A-horizon of plaggen soil with several archaeological soil features
2	Light brown-grey, silty, moderately fine sand	Aeolian deposits; Bhs horizon
3	Dark yellow to light brown, weakly silty, moderately coarse sand	Aeolian deposits; transition from Bhs- to Ce-horizon
4	Light yellow, weakly silty, very fine non-layered sand with some fine gravel	Aeolian parent material with no visible soil formation
5	Orange-yellow, weakly silty, very fine sand with several thin sand layers. Contains spots and bands of iron oxides. Deformed	Wet-aeolian deposit, disturbed by cryoturbation
6	Lightblue, moderately silty, very fine sand to lightblue sandy loam. Deformed	Reworked loess deposit, disturbed by cryoturbation
7	Light grey-brown weakly silty sand; very finely layered with some very thin silt and sand layers and some iron oxide stains	Wet-aeolian deposit
8	Light blue, weakly silty loam	Reworked loess deposit
9	White, weakly silty, moderately fine to very fine laminated sand	Fluvial deposit



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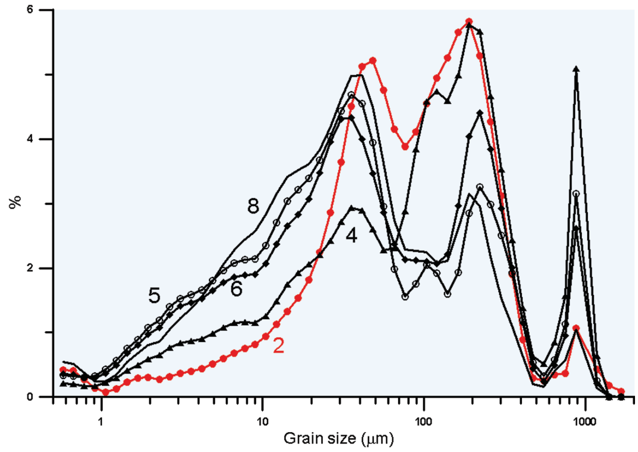


b.

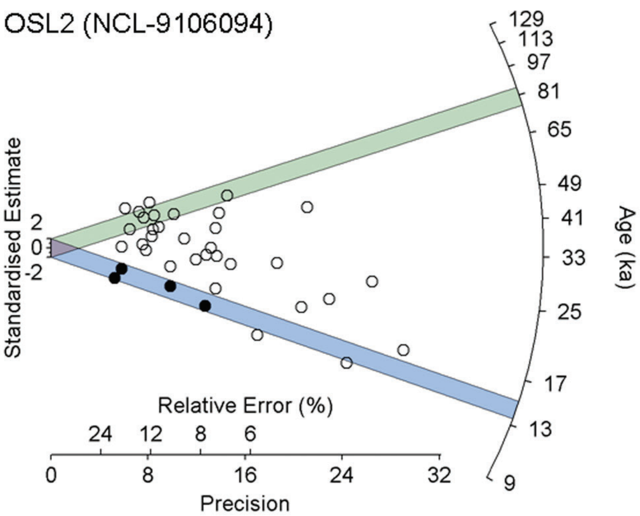
Fig. 6. *Grain-size distributions of Nederweert samples. Sample numbers are indicated. a. Well-sorted samples; b. Poorly-sorted samples.*

Table 2. Summary of optical dating results. Besides the dose rate and optical age, it is also indicated what part of the equivalent-dose distribution is assigned to the FMM component used.

Sample	Depth (m)	Unit	Sample name NCL	Dose rate (Gy/ka)	Age deposit* (ka)	FMM* (%)	Age admixture* (ka)	FMM* (%)
1	0.9	4	NCL-9106093	1.53±0.05	19-23	23-28	98-138	7-8
2	0.9	4	NCL-9106094	1.56±0.07	12-17	14-26	64-96	19-37
3	1.2	5	NCL-9106095	1.51±0.05	29-50	14-53	95-111	45-47
4	1.4	5	NCL-9106096	1.50±0.05	21-32	10-12	102-148	18-39
5	1.8	6	NCL-9106097	2.65±0.10	116±16			
6	1.9	6	NCL-9106098	1.98±0.08	104±12			
7	2.35	7	NCL-9106099	1.23±0.05	142±20			

* The age range includes two different FMM analyses, including 1 sigma uncertainty ranges.

** The percentage of single-aliquot equivalent dose results attributed to the component for the two FMM analyses.



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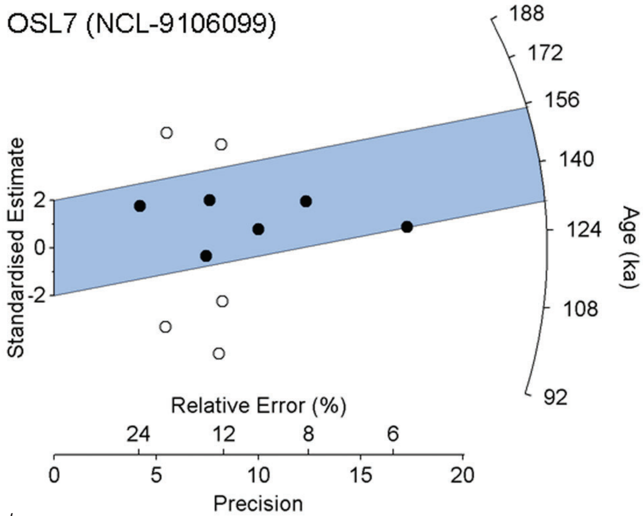

b.

Fig. 7. *Single-aliquot OSL age distributions for two samples presented as radial plots (similar plots for other samples in supplementary material). Only random uncertainties in equivalent dose estimation are incorporated. a. Sample OSL2 shows a wide scatter in results, with a well-defined lower boundary. Shaded areas denote the finite mixture model results for the time of deposition (blue shading) and the age of the admixture (green shading); b. Sample OSL 7 also shows wide scatter in results, but this is likely due to the OSL signal approaching saturation. The time of deposition is estimated from the average of the results (blue shaded band).*

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3. The OSL signal of the grains approaches saturation, hence small difference in the OSL signal give large differences in equivalent dose. This is the most likely explanation for the spread in results for the lower three samples (OSL 5-7). Yet, it cannot explain the scatter for the upper four samples (OSL 1-4), for which equivalent doses are well below the onset of saturation.
4. Grains of different depositional age have been mixed. There are clear signs of mixing of sediment units by cryoturbation for unit 5 from which samples 3 and 4 were obtained. For unit 4, cryoturbation is less obvious, but similarity of equivalent dose distributions for samples 1 and 2 compared to the two samples below suggests that mixing also occurred in this unit. Although the field observations suggest that intact blocks of sediment migrated, the length of the tubes used for OSL sampling makes it likely that the samples contain sediments of different units.

Based on our interpretation of the causes of spread in equivalent dose distribution, we can now apply suitable statistical approaches to determine the depositional age of the deposits, and the age of the sediments mixed in by cryoturbation (see Fig. 7 and supplementary material for single-aliquot OSL age distributions). For the lower three samples, where the OSL signal approaches saturation, a simple average of the single-aliquot equivalent dose estimates was regarded as the best estimate of the burial dose. We cannot exclude the possibility that mixing took place for these deposits as well, but equivalent-dose distributions in this dose range cannot be used for component analysis. Optical dating results suggest these deposits were formed between 90 and 160 ka. These ages should be interpreted with caution because OSL signals approach saturation, and mixing of sediments of different ages may have occurred.

For the upper four samples the Finite Mixture Model (FMM, Roberts et al., 2000) was employed to estimate both the burial age of the deposit (youngest FMM component), and the age of the grains mixed in from deeper layers through cryoturbation processes (oldest FMM component). Intermediate FMM components are artefacts of the OSL measurements on aliquots containing multiple grains, these components have no physical meaning.

In applying the FMM we assume that the luminescence signal of the aliquots is dominated by that of a small number of grains. This assumption is valid given the small aliquot size used (1 mm), and the small percentage of quartz grains that usually contributes to the signal (e.g. Duller et al., 2000). To apply the FMM model, we need to make an assumption to what extent all grains received the same natural dose rate. This is reflected in the choice of the overdispersion parameter sigma b. For small aliquots sigma b is usually taken around 10% (following Rodnight et al., 2005). To account for possible additional dose rate heterogeneity in the mixed deposits under study here, we also calculated results assuming more overdispersion (sigma b 20%). The latter setting results in larger grouping of aliquots (fewer components) and hence a slightly greater age for the youngest component and younger age for the oldest component. The ages reported here (Table 2) are based on the range of equivalent dose estimates obtained for the two different overdispersion settings used, and include 1 sigma uncertainty on either side. The percentage of single-aliquot equivalent-dose estimates attributed to a component, provides a measure of the robustness of the results. In all cases, however, equivalent dose estimates obtained through the FMM are less robust then those obtained by taking the mean of a tight distribution (e.g. undisturbed aeolian sand), because the estimate is based on a subset of the measurements and depends on the assumption made with regards to the overdispersion. The wide age ranges obtained and used throughout this publication reflect the crudeness of the age estimates, but suffice to provide the essential information for our study.

With regard to the estimates for the admixture ages, we note that the dose rate measured on the deposit may not reflect the dose rate experienced by the grains prior to mixing. Hence, the age of the admixture should be interpreted as a crude estimate of the burial age of those grains.

Optical dating results (Table 2, Fig. 8) suggest that sediments from 0.75 and 1.5 m depth (unit 4-5) were deposited between 12 and 50 ka. These deposits contain admixtures of grains deposited between 60 and 150 ka. Deposits below 1.5 m (unit 6-7) yield indicative OSL ages from 90-160 ka. We note that the age of the admixture facies in the upper samples is similar to the burial age of the sediments below, corroborating our assumption that the spread in equivalent-dose results is caused by mixing of sediments of different age.

Fig. 8. Optical dating results. The age of deposition is shown along with the age of the mixed material.

Discussion

Sediment mixing

The studied soil profile at the Nederweert site clearly shows that the original sediment layering was not retained (Fig. 5). Post-depositional processes disturbed the original subhorizontal bedding and caused several sediment units to be thoroughly mixed. At least three different deformation phases can be discerned: one affecting units 7, 6 and 5, one within unit 5 and one affecting units 5 and 4. These deformations involved upturning, blending and injection of strata. Based on the outline and spatial distribution of the deformations, as well as the time frame involved, we infer these structures to have been caused by repeated freezing and thawing of the soil. The scale of these structures does not necessarily involve the degradation of permafrost, but may also be the result of seasonal frost and thaw (cf. Vandenberghe, 1988).

Sediment mixing processes are corroborated by the results of the grain-size analyses in these units, generally showing bi-modal to multi-modal distributions (Fig. 6b). Especially the loam is probably thoroughly mixed; the sand blocks may have evaded mixing if they have remained frozen while the surrounding soil was thawed and maybe even completely liquified. Similar grain-size distributions have been found in sediment cores from the Boxtel Formation in the Roer Valley Graben (Schokker & Koster, 2004; Schokker et al., 2007). This indicates that post-depositional processes not only disturbed the sediment layering, but thoroughly mixed material from several layers. Moreover, even apparently homogeneous sediment units (e.g. unit 4) show poor sorting and multiple grain-size peaks in some of the samples. This means that deformation and mixing is not always macroscopically visible and that inferences on the genesis and optical age of the sediments should be made with great care. The deepest extent of cryoturbation was not reached in the profile pit. Still, it is clear that units are deformed over a depth of c. 1.5 meters at the least.

Age of the sediments and possible origin of Middle-Palaeolithic artefacts in Nederweert

The age of the sediment units 4 and 5 in the Nederweert-Rosveld profile indicates that the Middle-Palaeolithic artefacts that were found in association with the original Nederweert-Rosveld excavation were not in their original position. Two periglacial processes have likely played a role in bringing older sediments and associated artefacts closer to the surface:

Firstly, cryoturbation has clearly resulted in the deformation and mixing of sediment units from different periods, some of which may have contained Middle-Palaeolithic artefacts. The OSL-dating results indicate that it is likely that material from c. 60-150 ka was transported upwards by at least one meter, into units 4 and 5 and maybe even into the plough zone.

Secondly, stones (including artefacts) may be progressively transported to the surface as a result of the cumulative pushing action of the repeated formation of ice lenses directly underneath the stone. In a similar fashion, upward transport may also occur when the soil layers freeze progressively from the top downwards. Stones on or just underneath the boundary between frozen and unfrozen soil layers may be pulled upwards due to the expansion of the frozen soil material. Experiments have shown that these processes, generally termed upfreezing, may reach speeds of c. 5 cm per year at depths up to 20 cm, and 1-3 cm per year at greater depths (Chambers, 1967). We conclude that the occurrence of Middle-Palaeolithic artefacts close to the surface at Nederweert may well be caused by a combination of the shallow existence of deposits of Middle Palaeolithic age, cryoturbation and upfreezing.

Implications for spatial distribution of Middle-Palaeolithic artefacts and sites

The Nederweert site forms part of the SW-NE zone of Middle Palaeolithic surface-found artefacts. Given that this area coincides with the area in the Graben with the lowest subsidence rates – the Weert-Nederweert coversand rigde (Fig. 2) – we suggest that causes for these occurrences are similar to those inferred for the Nederweert site. Outside this zone, layers of Palaeolithic age are covered by younger sediments.

The significant role of periglacial processes in the transport of artefacts from deeper layers to the surface may have severe implications, on the chance of finding Middle Palaeolithic sites as a concentration of artefacts in stead of single scattered artefacts. Since periglacial conditions may have occurred in this area during large parts of the Weichselian, Middle-Palaeolithic sites may have been affected by cryoturbation, upfreezing and gelifluction processes repeatedly. These processes may not only induce vertical movement, but also sorting and lateral movement of artefacts. As a result, artefacts may become sorted in size, whereby microartefacts are transported downwards (Hilton, 1999; Johnson & Hansen, 1974). The strong impact of these processes make it unlikely that pristine Middle-Palaeolithic sites are still present in the Nederweert-region. Such sites have probably been affected to such an extent that spatial distributions and stratigraphy have been altered. It is even questionable whether they would still be recognizable as Palaeolithic sites.

For archaeological heritage management, this means that archaeological research needs to take into account the possible presence of Middle-Palaeolithic sites at near-surface depths. However, it is likely that such sites are affected by cryoturbation. Further North in the Roer Valley Graben, sites may occur at greater depths that were covered with sediment shortly after deposition. Such sites may have been affected less by periglacial processes, but will be harder to identify and locate.

Application in archaeological heritage management

The results of the present study can be applied in archaeological heritage management for temperate regions with Pleistocene sediments. In the Netherlands, the third generation of the Indicative Map of Archaeological Values (Fig. 9; Deeben et al., 1997, 2002; Deeben, 2008) is used to predict the presence of archaeological sites. For the Pleistocene areas of the Netherlands, the indicative value shown on the map is essentially based on an environment-to-site relationship, i.e. the calculated ratio between the number of archaeological sites present and the number of sites expected at each combination of soil type and groundwater level (Deeben et al., 2002). Information on both soil type and groundwater level are derived from the digital Soil Map of the Netherlands, scale 1 : 50,000 (De Vries et al., 2003). However, this approach is not ideal when predicting the presence of Middle-Palaeolithic or older archaeological remains, because:

- The depth of the soil survey is limited to 120 cm below surface. This implies that archaeological values that are present below that depth are not taken into account;
- The majority of Pleistocene deposits at the present land surface consists of Late Pleniglacial and Late-Glacial coversands, sometimes covered by man-made plaggen soils, driftsand or peat. The up-to several m thick coversand layer blanketed the pre-existing landscape. Therefore, present soil type and groundwater level do not necessarily reflect Middle-Palaeolithic site characteristics.

The limitations of the present method to construct indicative maps of the Pleistocene regions could be overcome by introducing time and depth-dependent maps, i.e. maps that are specific for an archaeological period and give information on the presumed depth of the accompanying palaeolandscape. To do so, geological data-handling and knowledge are of prime importance.

Reconstructing a regional predictive model for the presence of remains from a specific archaeological period involves four basic steps:

1. Composition of a detailed lithostratigraphic and chronostratigraphic framework based on the interpretation and correlation of well-dated key sites. Establishing a firm link between the archaeological and geological record at these sites is of particular importance.
2. Reconstruction of the environments in the palaeolandscape accompanying the archaeological period of interest and the depth below the present land surface. This step generally involves handling a large amount of geological data and may be alleviated by using modern subsurface modelling tools.
3. Translation into a predictive model by incorporating an environment-to-site relationship.
4. Validation of the model by performing indicative field research.

By incorporating information on the depth of a palaeolandscape into the model, the condition and possible disturbance of potential archaeological remains from that level can be

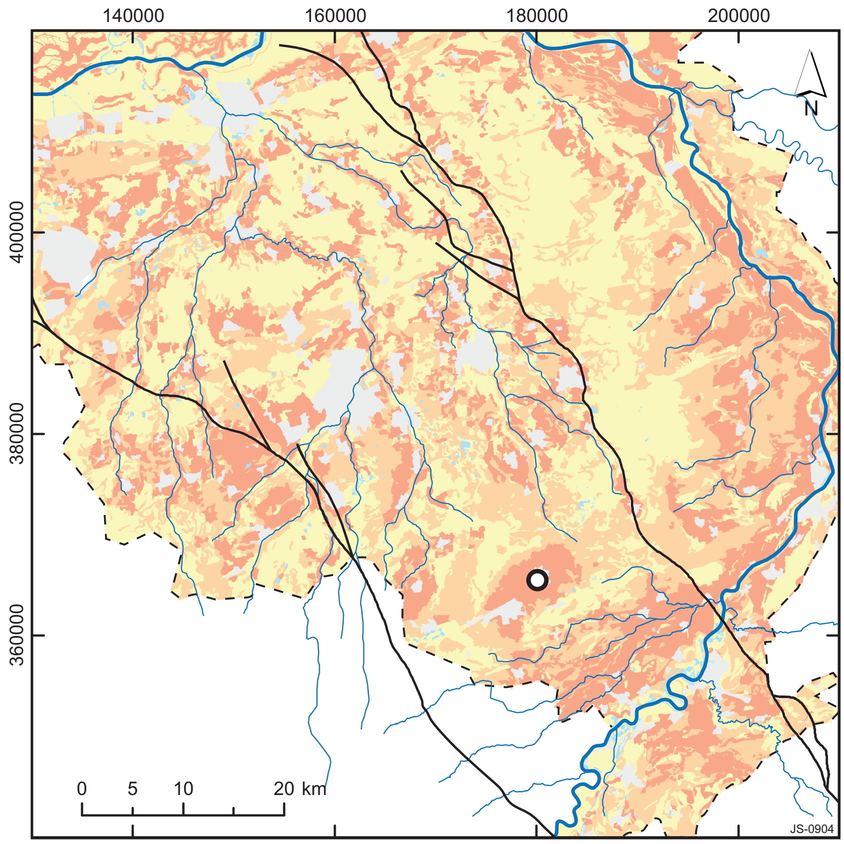

Fig. 9. Third generation of the Indicative Map of Archaeological Values (Deeben et al., 2008). Dark orange: high indicative value; light-orange: medium indicative value; yellow: Low indicative value.

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evaluated. The condition of archaeological material may have been heavily affected by physical and chemical weathering processes as well as anthropogenic disturbance, all of which are typically most severe at or immediately below the surface. Furthermore, in the case of planned anthropogenic disturbance to a certain depth, the area in which archaeological values are under threat can be easily delineated.

The research approach used in this study can thus be regarded as a first step towards a conceptual model that predicts the occurrence of Middle-Palaeolithic artefacts in the Limburg-Eastern Brabant coversand region. We expect that the insights gained are also relevant to other areas with Middle Palaeolithic sites that are affected by cryoturbation.

Conclusions

Middle-Palaeolithic artefacts have been found near the surface in a SW-NE zone across the Roer Valley Graben, coinciding with the Weert-Nederweert coversand ridge. The relatively shallow occurrence of Middle Palaeolithic sediments – and therefore of Middle-Palaeolithic surface-found artefacts – in this area is a direct result of differential tectonic movements in the Roer Valley Graben. Based on our investigations at Nederweert-Rosveld, we conclude that the artefacts likely originated from deposits of Middle Palaeolithic age located below c. 1.5 m below the surface. Artefacts were transported upward due to cryoturbation-induced deformation and mixing of these deposits with overlying younger material and possibly by additional upfreezing of the artefacts.

Our investigation has shown the possibilities of dating mixed sediment using OSL dating techniques, but also the limitations with regards to accuracy and precision. Although the results of this research are useful for developing better prediction models for the distribution of Middle Palaeolithic artefacts in surface range, it also emphasizes the need for developing techniques for dating mixed – e.g. cryoturbated – sediments. Also, the impact of periglacial processes on archaeological sites is an important issue for future research.

The research approach used in this study forms a first step towards a conceptual model that predicts the occurrence of Middle-Palaeolithic artefacts in the Limburg-Eastern Brabant coversand region. The insights gained are also relevant to similar environments elsewhere.

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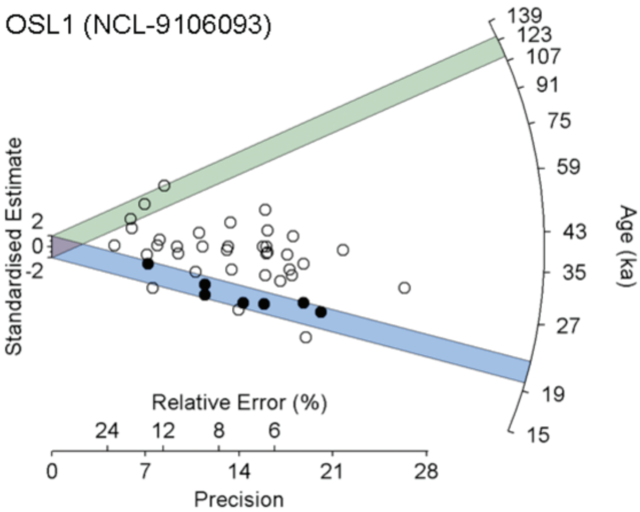
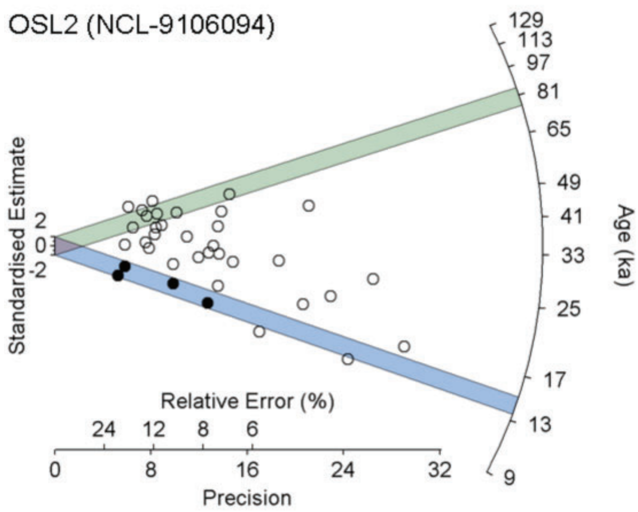
Supplementary material — Radial plots of OSL age distributions for all samples

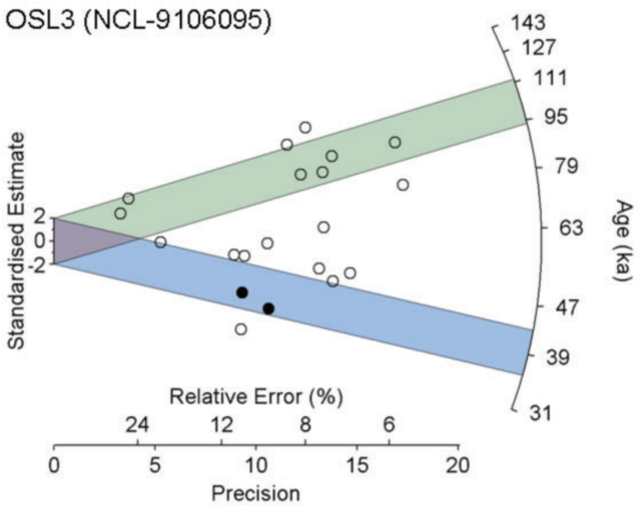
Optical dating age distributions

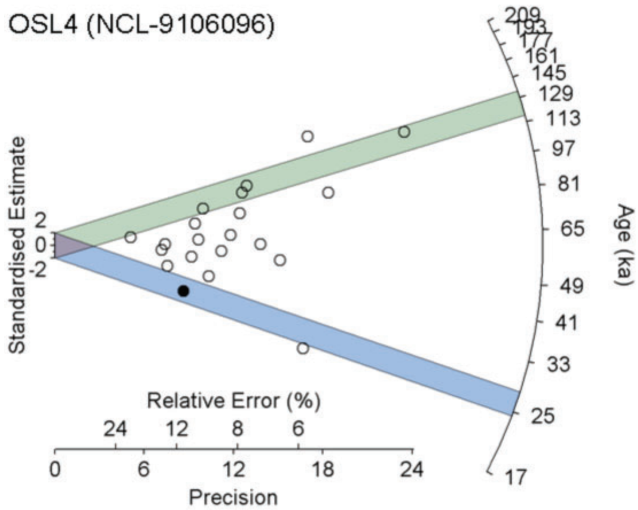
One of the main challenges in optical dating mixed sediments is the interpretation of the equivalent-dose distributions. For this study, we have used the Finite Mixture Model (FMM) as explained in the main text. In this electronic supplement we provide graphic representations of the equivalent-dose distributions for all samples. To facilitate interpretation, we show the distributions of age rather than equivalent dose. The relative uncertainty and precision however only include random uncertainties (measurement errors) on the equivalent dose.

For the upper four samples (OSL1-4) the blue bar indicates the age obtained for the youngest component of the FMM and the green bar for the oldest component (see Table 2 of main text for additional information). Both bars are centered on the mean of the age range obtained for overdispersion settings of 10% and 20%. The youngest component is interpreted to represent the depositional age, whereas the oldest component is indicative of the admixture age.









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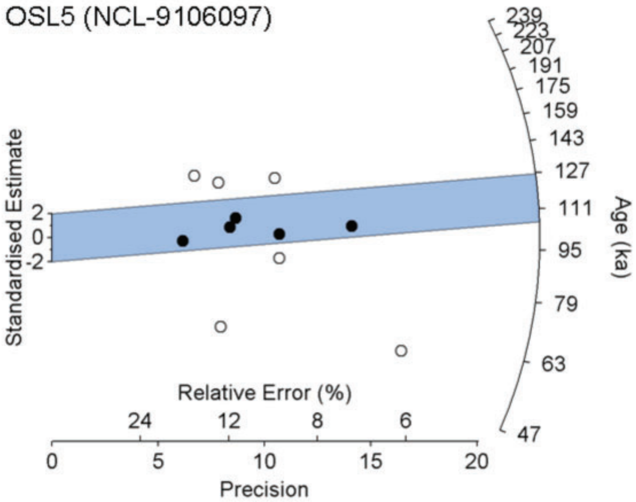
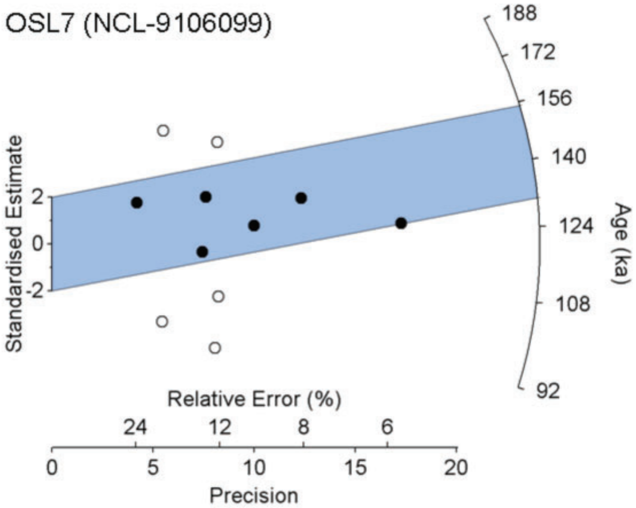
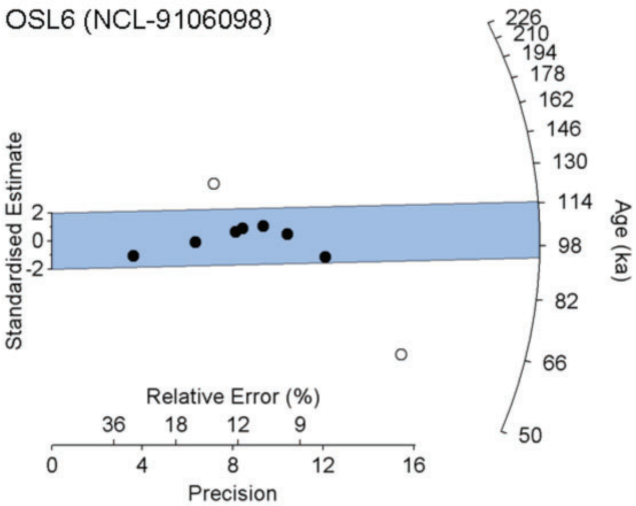
For the lower three samples (OSL5-7), equivalent doses are too close to saturation to justify application of the FMM. Here our best estimate is based on the mean of the distribution (indicated by the blue bar). Yet we cannot exclude the possibility that mixing took place for these deposits as well.







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