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Fires at Neumark-Nord 2, Germany: An analysis of fire proxies from a Last Interglacial Middle Palaeolithic basin site

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Few sites with evidence for fire use are known from the Last Interglacial in Europe. Hearth features are rarely preserved, probably as a result of post-depositional processes. The small postglacial basins (<300 m in diameter) that dominate the sedimentary context of the Eemian record in Europe are high-resolution environmental archives often containing charcoal particles. This case study presents the macroscopic charcoal record of the Neumark-Nord 2 basin, Germany, and the correlation of this record with the distinct find levels of the basin margin that also contain thermally altered archaeological material. Increased charcoal quantities are shown to correspond to phases of hominin presence—a pattern that fits best with recurrent anthropogenic fires within the watershed. This research shows the potential of small basin localities in the reconstruction of local fire histories, where clear archaeological features like hearths are missing.

Keywords: fire use, Last Interglacial, charcoal, heated flint, burned bone

Introduction

Recent years have seen a heated debate over when in the deep history of the human lineage hominins started to use fire on a regular basis for purposes such as cooking and thermoregulation. Some workers have suggested that early *Homo erectus* was already a proficient fire user by 1.8 million years ago (Carmody and Wrangham 2009; Wrangham 2009; Gowlett and Wrangham 2013). Reviews of the European evidence (Roebroeks and Villa 2011) and from the Levant (Shimelmitz *et al.* 2014) however suggest that there was no habitual fire use there until much later, from approximately 350,000 years ago onward, despite some singular early contenders like Gesher Benot Ya'aqov (Goren-Inbar *et al.* 2004; Alperson-Afil and Goren-Inbar 2010). Using and producing fire is not necessarily the same (Sorensen *et al.* 2014), and Sandgathe and colleagues (2011) hypothesize that only modern humans at the very end of the Late Pleistocene were able to produce fire at will, rather than being dependent on natural fires or kindling them over prolonged periods of time. While much of this debate is about the chronology of fire use, there is also little information about the specific types of fire use, both on- and off-site, i.e., within domestic "camp site" settings as well as in the surrounding landscape (Scherjon *et al.* 2015). From at least the late Middle Pleistocene onward some Neandertals used fire to synthesize birch bark pitch (Koller *et al.* 2001; Mazza *et al.* 2006) while studies of microfossils from dental calculus have shown that some late Neandertals were cooking plant food (Henry *et al.* 2011).

As illustrated by the database on European Middle and Late Pleistocene fire use compiled by Roebroeks and Villa (2011), the evidence is heavily dominated by rock shelter sites from cold- to cool-stage settings, while the long sequences in the Levant discussed by Shimelmitz and colleagues (2014) are likewise all from karstic settings. With the exception of a few early sites with possible evidence for fire use, like Beeches Pit, U.K. (Gowlett *et al.* 2005; Preece *et al.* 2006), precious little is known of warm-temperate interglacial fire use in open-air sites, simply because such sites are rare.

The archaeological record of the European Last Interglacial (or Eemian) is strongly biased toward open-air sites, and more specifically, freshwater localities, whether rivers or small postglacial basins

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(mostly <300 m in diameter) (Speleers 2000; Roebroeks and Speleers 2002; Gaudzinski 2004; Gaudzinski-Windheuser and Roebroeks 2011). In these open-air contexts, evidence for fire use is often swiftly removed by natural processes (Sergant *et al.* 2006), particularly near freshwater localities. Lighter elements, such as ash and charcoal, are especially easily subjected to transport. Heated (and as a result often fragmented) lithics and burned faunal remains can also be susceptible to natural transport in freshwater contexts when we consider the potential of fragmentation by large herbivore bioturbation in combination with the often sloping margins of these environments. While evidence for anthropogenic fire use may still be present on a site, its lack of spatial coherence makes it more difficult to distinguish from natural fires, as caused by volcanic eruptions, spontaneous combustion, and especially lightning (Roebroeks and Villa 2011; Sandgathe *et al.* 2011; James *et al.* 1989). While the margins of basin localities may not provide the ideal context for preserving in situ hearths or fireplaces because of relatively low sedimentation rates and erosion, as well as increased disturbance by water and animals, the deeper parts of these basins are usually characterized by relatively continuous sedimentation, which can result in thick deposits with comparatively less post-depositional disturbance (Pop *et al.* 2015). These basin deposits provide rich environmental records instrumental in providing a biostratigraphic (pollen) record as well as environmental reconstructions of the local vegetation (e.g., Bakels 2012, 2014; Kuijper 2014; Pop and Bakels 2015). They also trap charcoal particles produced in the immediate vicinity of the basin and, depending on the size of the particles, the wider landscape (e.g., Scott 2010 and references therein). The time-depth of these basin records varies with basin size and shape, as well as with subsidence and compaction, but often covers large parts of the Eemian Interglacial (e.g., Neumark-Nord 1 and Gröbern [Litt 1990a, 1990b; Seifert 1990]) (FIG. 1). The thick undisturbed deposits in these basins have the potential to document, apart from natural fire events, fires associated with hominin presence—especially when accompanied with other lines of evidence, like thermally altered lithics and faunal remains.

Unlike many Mesolithic basin localities in Europe (Bos *et al.* 2006; Mighall *et al.* 2008; Innes *et al.* 2010), Eemian freshwater localities have not been systematically sampled for charcoal thus far. Evidence for fire, whether anthropogenic or natural, is often limited to find levels with diffuse scatters of charcoal, as at Neumark-Nord 1 (Mania *et al.* 1990; Brühl and Mania 2003), Grabschütz (Mania *et al.* 1990), Lehringen (Deibel-Rosenbrock 1960; Thieme *et al.* 1985), and Burgtonna (Schüler 1999), while charred hazelnut fragments accompany such scatters at Rabutz (Toepfer 1958) (FIG. 1). Also, not systematically sampled, but nevertheless tantalizing, is the evidence for anthropogenic use of fire provided by the Last Interglacial site of Taubach. Here, several layers yielding large amounts of charred material (the so-called *Brandschichten*) were identified, containing fire-reddened pieces of travertine, charcoal and

Figure 1 Location of Neumark-Nord 2 and other Eemian sites mentioned in the text relative to the maximum ice extents of the Saalian and Weichselian glaciers. Modified from Speleers 2000.

charred bones, which at the time of discovery were interpreted as hearths (Klopfleisch 1883; Götze 1892). The fact that this fieldwork took place in the early days of the discipline needs to be considered, but analysis of the faunal material has shown that part of the humanly modified bone assemblage indeed shows evidence of burning (Bratlund 1999). Similar layers of charred material have been found at the interglacial site of Ehringsdorf (Behm-Blancke 1960), but the excavated lower travertines have been shown to date to the penultimate interglacial complex (OIS 7), rather than to the Eemian (Blackwell and Schwarcz 1986). In short, well-documented evidence for anthropogenic fire use during the Eemian is very limited in Europe. In this paper, evidence for the anthropogenic use of fire from the Eemian Interglacial site of Neumark-Nord 2 will be presented and discussed.

Neumark-Nord 2

The site of Neumark-Nord 2, located ca. 170 km southwest of Berlin, Germany (FIG. 1), is situated in a former lignite quarry that was exploited until the early 1990s. This exploitation led to the discovery of two small Late Pleistocene basin structures that formed due to the activity of a brown coal diapir. Neumark-Nord 1 (NN1; ca. 26 ha) was investigated from the 1980s onward (Mania *et al.* 1990), mainly through a large number of very short archaeological interventions. The Neumark-Nord 2 site (NN2; ca. 2 ha) (FIG. 2), on which this study focuses, was extensively and systematically excavated between 2004 and 2008, preceding the inundation of the former quarry for the creation of a large recreational lake. The fine-grained silt loams of the small-sized NN2 basin infill contain several find levels (NN2/3, NN2/2, NN2/1) yielding ca. 23,000 lithics and 125,000 faunal remains. The find-bearing segments of these find levels are situated primarily on the margin area and gently slope into the basin area where they increase in thickness and decrease in find density. Approximately 10 m from the southernmost part of the excavations, *Hauptprofil* 7 (HP7) exposes the complete basin sequence (FIGS. 2, 3). From this profile samples were taken for environmental reconstructions and dating purposes (Sier *et al.* 2011; Strahl *et al.* 2011; Bakels 2014).

Absolute dating shows that the NN2 find levels pertain to the Last Interglacial age, with a weighted average thermoluminescence (TL) date of 121,000 ± 5000 B.P. (Richter and Krbetschek 2014), which matches stratigraphic and palaeomagnetic observations (Sier *et al.* 2011; Strahl *et al.* 2011). Pollen analysis shows that the basin infill documents the complete vegetation succession of the Eemian Interglacial (Sier *et al.* 2011; Strahl *et al.* 2011; Bakels 2014). The environment surrounding the basin ranged from semi-open vegetation, with the margins of the basin covered with species characteristic of grasslands and disturbed/trampled soils, to a light deciduous forest vegetation (Pop and Bakels 2015). Analysis of the lithic assemblage shows that on-site knapping was carried out using hammerstones and flint nodules derived from local glacial deposits (Pop 2014; G. Langejans, personal communication 2015). The faunal assemblage contains the remains of more than 100 large ungulates, in which horse, bovids and red deer dominate. The assemblage is heavily cut-marked and fragmented, providing evidence that butchering took place at the locale, while bone breakage patterns indicate marrow extraction (Kindler *et al.* 2014).

The site of Neumark-Nord 2 offers the opportunity to study not only archaeological fire evidence from the excavated margin of the basin, including thermally altered lithics and faunal remains, but also a more than 7,000 year-long environmental record from the basin itself, which contains macroscopic charcoal and charred seeds. However, "to evaluate the fire history of ancient occupations we are limited by the amount and quality of the available data" (Alperson-Afil 2012: 111). This certainly applies to this case study, as reconstructing fire histories was never the primary objective of the Neumark-Nord 2 rescue excavations, which instead focused on the archaeological material present at the margins of the small basin and its chronological and environmental setting. Hearth features, often the focal point of fire studies, were not observed at the site. Thermally altered flint artifacts and faunal remains were found mostly in the sieving residue and therefore identified as such after the rescue excavation, during subsequent material analysis. Furthermore, the sediment samples taken from the basin area were aimed primarily at palynological and malacological analyses, but ancillary counts of other macro-remains retrieved from the samples, including macroscopic charcoal and charred seeds, were eventually carried out as well (Kuijper 2014).

Despite the limitations set by excavation and sampling strategies and the complicated sedimentary history of the basin (Hesse and Kindler 2014; Pop *et al.* 2015), the Neumark-Nord 2 record allows an in-depth assessment of the fire evidence from an Eemian Interglacial locality. This study addresses a very straightforward question: are the fire proxies the product of Neandertal fire use, the result of natural (forest) fire(s), and/or a combination of both processes? By looking at the quantity, vertical distribution, size, and species representation of the charcoal and charred seeds from the basin area, as well as at the thermally altered lithics and faunal remains found during excavation of the basin

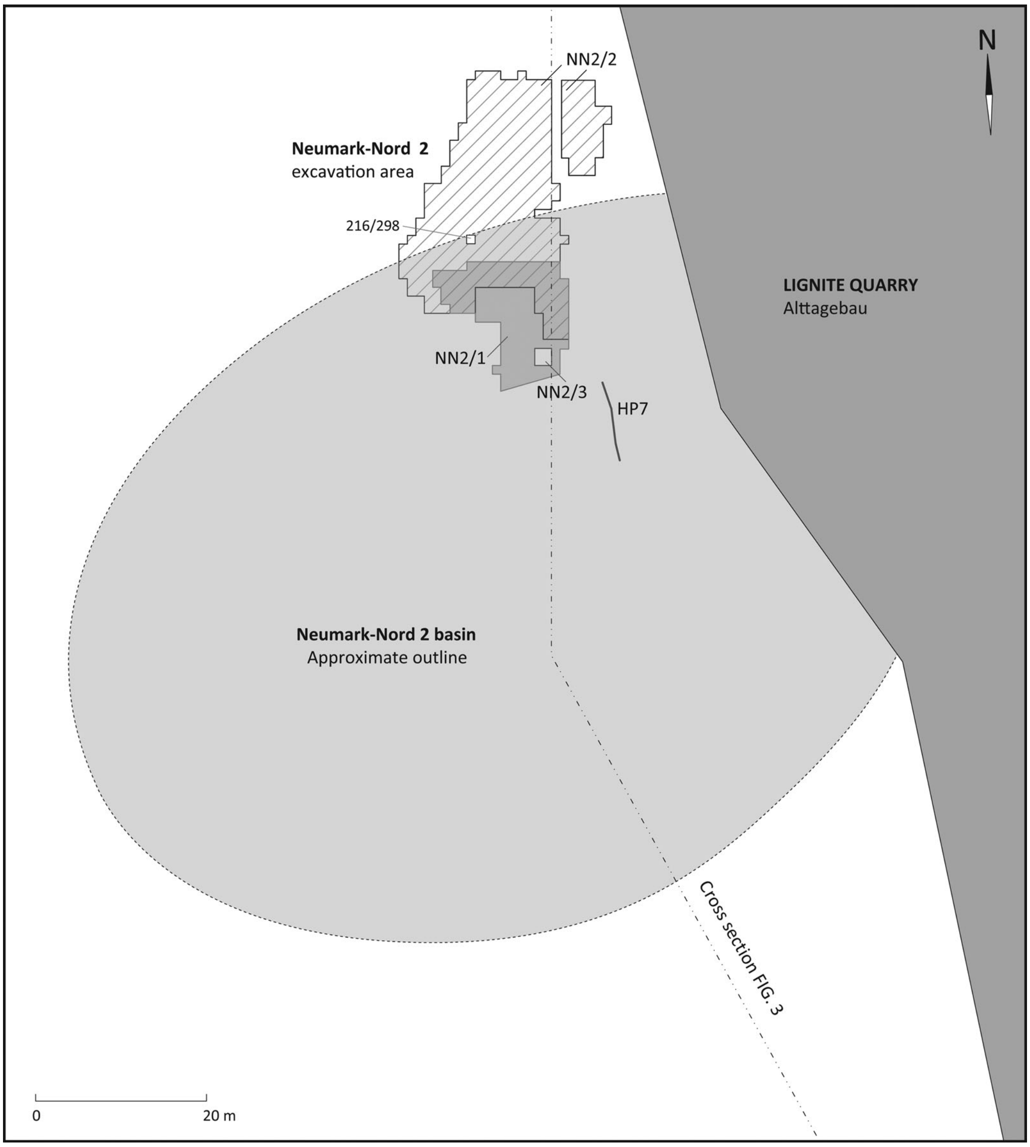

Figure 2 Position of the Neumark-Nord 2 excavation area and *Hauptprofil* 7 (HP7) in relation to the approximate outline of the former basin. The eastern part of the basin was missing before excavation due to mining activity (dark gray). The former Neumark-Nord 1 basin is situated ca. 200 m southeast, within the main lignite quarry area. The cross-section line refers to Figure 3.

margin, it may be possible to establish proximity, frequency, and scale/type of the fires in question. As the environmental data from the basin area can be linked unambiguously to the archaeological find levels at the basin margin, it is also possible to study the correlation between these datasets: are charcoal

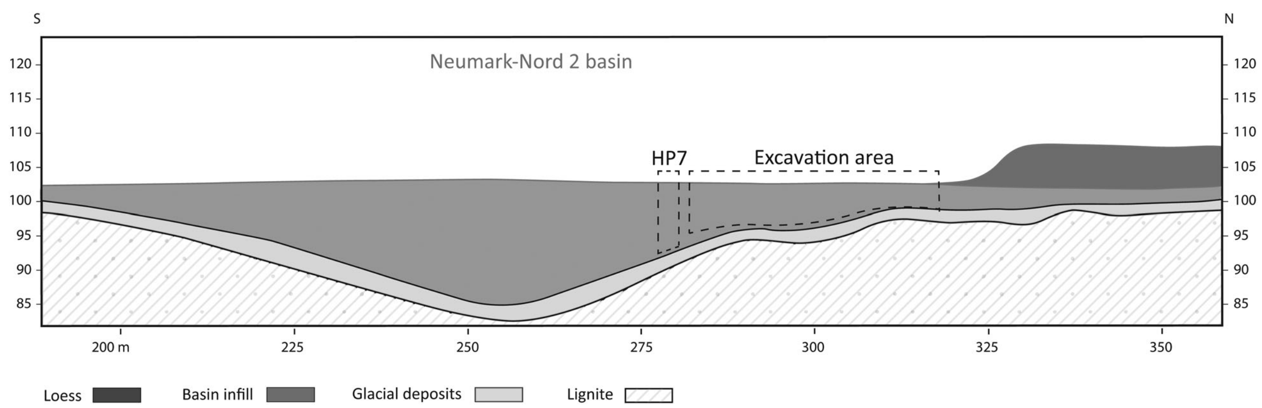

Figure 3 Schematic north-south cross-section of the Neumark-Nord 2 (NN2) basin, showing the position of *Hauptprofil* 7 (HP7) and the NN2 excavation area. Modified from Sier *et al.* 2011.

concentrations correlated to phases of hominin presence and absence as reflected in the archaeological record, including thermally altered lithics and faunal remains? Both the individual datasets (from the basin- and excavation-area) and their relationship may provide evidence for either a natural or anthropogenic origin of the fire proxies.

Materials and methods

The fire proxies from the excavation area at the margin of the NN2 basin (FIGS. 2, 3) consist of thermally altered lithics and mammalian faunal remains. Heated flint artifacts were retrieved from find levels NN2/2 and NN2/1 (FIG. 4). The heated flint artifacts were identified during lithic analysis following the excavation using a combination of several criteria: discoloration, the presence of cracking (*craquelé*), "pot lid" fractures, and/or fracture negatives (Sergant *et al.* 2006) (see Results, below). As for the faunal material, only the remains from find levels NN2/3 and NN2/2 have been systematically analyzed for thermal modification thus far, and were identified on the basis of color and fracturing characteristics (e.g., Shipman *et al.* 1984; Stiner *et al.* 1995).

The lithostratigraphic units and associated find levels at the basin margin could be followed downslope and correlated with the units identified at HP7, an 11 m high profile within the basin located between the excavation area and the basin center (Hesse and Kindler 2014; Pop *et al.* 2015) (FIGS. 2, 3). From this profile macroscopic charcoal and charred seeds have been retrieved. From unit 5 upward, five-liter samples (n=120) were taken at 5 cm intervals along the profile and subsequently sieved using increasingly fine mesh sizes of 5, 2, 1, and 0.5 mm. The macroscopic charcoal particles and charred seeds were separated from other residues and counted using a Wild M7a microscope at magnifications of 6–30×. Taxonomic determination of the charcoal fragments larger than 1 mm was done using a Leitz Ortholux II microscope at magnifications of 100–200×, as well as a Wild M7a microscope. The species determination of the charred seeds was done using a Wild M7a microscope. One location within the excavation area at the basin margin (excavation square 216/298) (FIG. 2) was also sampled, in two-liter samples, and analyzed for macroscopic charcoal and charred seeds following the same methods outlined above (see Kuijper 2014).

Results

Fire proxies from the excavation area

Fire proxies from the excavation area consist of thermally altered lithics and faunal remains, as well as macroscopic charcoal and charred seeds sampled at excavation square 216/298.

LITHICS

The lowermost find level NN2/3 (FIG. 4) was only excavated over 4 sq m (FIG. 2) and yielded a small lithic assemblage of 63 pieces, none of which show signs of having been heated. Find levels NN2/2 and NN2/1, excavated over significantly larger areas (491 and 191 sq m, respectively) (FIG. 2), yielded more substantial lithic assemblages and are discussed in more detail.

The NN2/2 flint assemblage (n = 14,539) contains 344 heated flint artifacts (2.3%). The characteristics of the heated flint elements range from "weakly" (reddish shine, isolated cracks) to "moderately" (pot-lid fractures, cracks, and color changes) and "heavily" heated (white to gray discoloration) (Sergant *et al.* 2006). Thermal modification is more frequently occurring among chunks (8%; see Online Supplement 1) which are by definition difficult-to-orientate, angular (fragmented) pieces. This pattern is most likely caused by fragmentation as a result of heating. Of the flakes and chips, 1.6 and 2.5%, respectively, were affected. Cores and tools show characteristics indicative of heating as well, but in lower percentages (<1%).

The horizontal distribution of the heated flint artifacts from NN2/2 shows a strong concentration in the center of the excavation area, following the overall distribution of flint artifacts across the site (FIG. 5A). The vertical distribution of the heated flint artifacts within the NN2/2b subunits is presented in Table 1. Due to decreasing sedimentation, the stratigraphy of these subunits shows a decreasing complexity from south to north, resulting in different subunit sets depending on the location within the site (Hesse and Kindler 2014; Pop *et al.* 2015). The northern area contains 2.6% heated artifacts, but subunits could not be distinguished. The northeastern area contains 2.2% (BO), 3.6% (BU) and 1.9% (B, a conflation of layers BO and BU) heated artifacts. On average the percentage of heated flints from this sector (2.7%) is comparable to the northern sector. In the middle sector, percentages fluctuate between 1% (B1) to 3.4% (B2). Taken together the percentage of heated artifacts in the middle sector is comparable to the northern and northeastern sectors with 2.5%. There seems to be a decline in heated artifacts in the southern sector with an average of 1.6% heated artifacts. In this sector the percentage of heated flints from the individual subunits ranges from 2.9% (B1/B2) to zero heated flint artifacts (B1, B3u).

Find level NN2/1 yielded eight heated lithics from a total assemblage of 2,404 pieces (0.3%). The lithics can be subdivided into assemblages from layers NN2/1c (n = 1931) and NN2/1b (n = 473), of which seven (0.4%) and one (0.2%), respectively, are heated. The

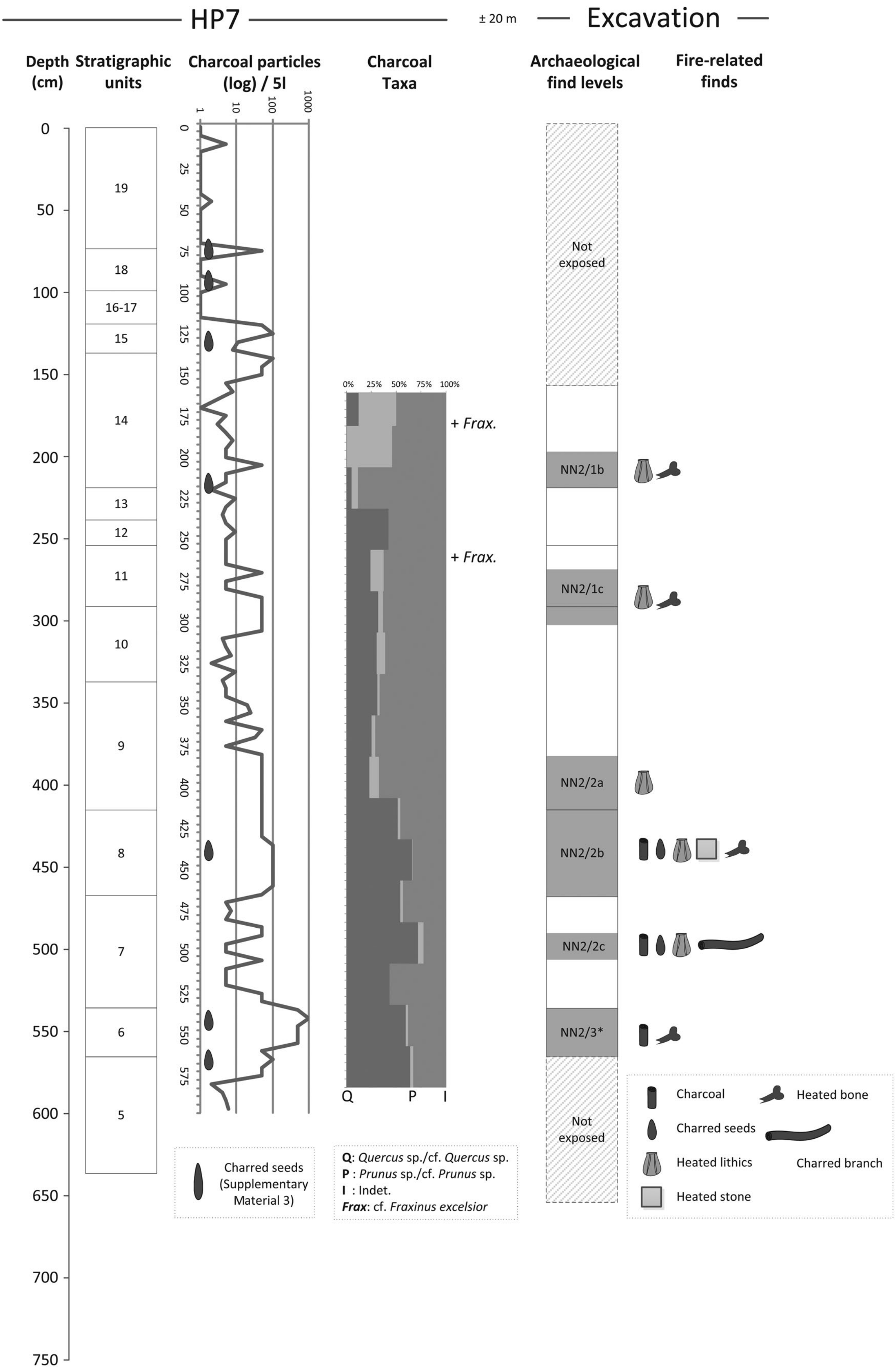

Figure 4 ***Hauptprofil 7*** **(HP7) with the concentration of charcoal (particles/5 l) on a log scale; the position of charred seeds (Online Supplement Table 3); the identified charcoal taxa; and the position of the find levels with main find concentrations (in gray) at the basin margin relative to HP7, including heated lithics, burned faunal remains, and other fire-related finds.**

characteristics of the identified heated pieces fall in the "weakly" to "moderately" heated categories (cf. Sergant *et al.* 2006). The typology of the pieces is limited to debitage elements (flakes and chunks).

Table 1 Absolute and relative quantities of heated flint artifacts per layer of the NN2/2b find level.

Sector	Layer	Artifacts	Heated	%
North	B	1591	41	2.58
Northeast	B	478	9	1.88
	BO	1113	24	2.16
	BU	1089	39	3.58
	Total	*2680*	*72*	*2.69*
Middle	B1	597	6	1.01
	B1/B2	691	10	1.45
	B2	2253	77	3.42
	B3	2891	69	2.39
	B3B	330	7	2.12
	B3U	247	7	2.83
	Total	*7009*	*176*	*2.51*
South	B1	123	0	0.00
	B1/B2	241	7	2.90
	B2a	350	5	1.43
	B2a/B3o	147	3	2.04
	B3o	1734	25	1.44
	B3m	633	11	1.74
	B3u	31	0	0.00
	Total	*3259*	*51*	*1.56*

The distribution of the heated flint artifacts overlaps with the general higher concentration of artifacts in NN2/1, situated in the southern part of the excavated area (FIG. 2).

FAUNAL REMAINS

Both NN2/3 and NN2/2 have been investigated for the thermal alteration of faunal remains. The faunal remains of NN2/1 have not been analyzed systematically, but did yield thermally altered elements (L. Kindler, personal communication 2015). NN2/3 contains six thermally altered faunal elements, which is 3.1% of the total faunal assemblage (n = 191). Of the sample of 16,351 faunal remains from the NN2/2 faunal assemblage, 298 are thermally altered (1.8%). Black or clear white discolorations indicate burning. Due to heat-induced changes it was not possible to determine the taxa of most burned faunal remains.

The distribution of the burned faunal remains (FIG. 5B) differs from the distribution of the heated unburned faunal remains and heated lithics (FIG. 5A). This may be explained by the higher overall frequency of small faunal remains/fragments in this area, which may be the product of in situ fragmentation. Like the heated lithics, burned faunal remains can be found in all subunits of the NN2/2 find level (TABLE 2). The northern area (B) yielded the lowest percentage of heated elements with 0.4%. The other areas (Mid and South) yielded higher average (or mean) percentages ranging from 1.8 to 2.3%, but individual subunits within these areas show strongly varying percentages ranging from 1.2 to 4%.

MACROSCOPIC CHARCOAL

Macroscopic charcoal was encountered in the excavation area within find levels NN2/3, NN2/2, and NN2/1 (Laurat and Brühl 2009; L. Kindler, personal communication 2015), but was only systematically

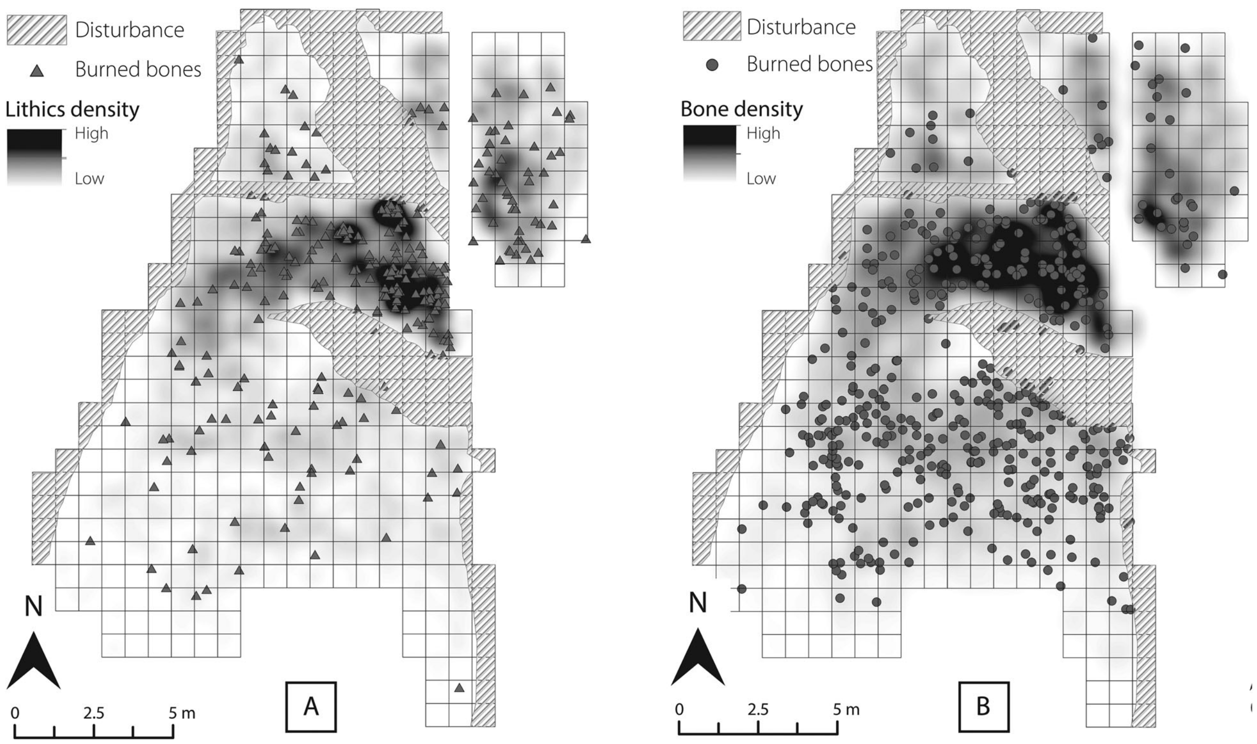

Figure 5 Map of NN2/2b. A) Thermally altered lithics on top of the overall (kernel) distribution of lithics; B) Thermally altered faunal remains on top of the overall (kernel) distribution of faunal remains.

Table 2 Absolute and relative quantities of burned faunal remains per subunit of the NN2/2b find level.

Sector	Layer	Bones	Burned	%
North	B	7666	33	0.43
Northeast	B	3431	42	1.22
	BO	11972	195	1.63
	BU	14459	414	2.86
	Total	*29862*	*651*	*2.18*
Middle	B1	2591	32	1.24
	B1/B2	5657	71	1.26
	B2	12586	306	2.43
	B3	18279	302	1.65
	B3B	2207	35	1.59
	B3U	1933	22	1.14
	Total	*43253*	*768*	*1.78*
South	B1	1340	24	1.79
	B1/B2	2675	81	3.03
	B2a	2759	52	1.88
	B2a/B3o	1355	16	1.18
	B3o	15997	409	2.56
	B3m	5394	99	1.84
	B3u	272	11	4.04
	Total	*29792*	*692*	*2.32*

recorded and collected at excavation square 216/298 of find level NN2/2 (FIG. 2). The sampled subunits of units 7 and 8 show fairly constant charcoal concentrations, with the exception of subunit C (TABLE 3). Four dispersed, larger charcoal and charred wood elements were recorded at NN2/2 (Online Supplement 2), the largest around 140 cm in length (FIG. 6). The outside of this oak branch (*Quercus* sp.) is charred, while the inner part of the piece is not.

Table 3 Charcoal and charred seed concentration per layer of the NN2/2 find level at excavation square 216/298.

NN2/2 Layer	Unit	Sample size (l)	Charcoal particles	Charcoal particles / liter	Charred seeds
B1	8	2	100	50	3
B3 upper	8	2	100	50	0
B3 middle	8	2	100	50	0
B3 lower	8	2	100	50	0
C	7	5	100	20	3

The fact that such a large piece of wood has preserved may be facilitated by the charring on the outside, protecting the inner, uncharred, part (Braadbaart and Poole 2008). The other (non-systematically) recorded occurrences of charcoal include several 1 to 5 mm fragments (n = 11) retrieved from the 4 sq m excavation of find level NN2/3, which can all be identified as *Quercus* sp.

CHARRED SEEDS

Six charred seeds were found at excavation square 216/298 (Online Supplement 3). Only two could be identified: *Vicia* sp. (subunit C) and *Corylus avellana* (subunit B1).

Fire proxies from the basin area

Fire proxies from the basin area consist of macroscopic charcoal and charred seeds, both systematically sampled at HP7 between 10 to 25 m from the main find concentrations of the excavation square's three find levels (FIG. 2).

MACROSCOPIC CHARCOAL

The lower size limit of the macroscopic charcoal retrieved from HP7 is determined by the smallest mesh size used during sieving, 0.5 mm (500 µm), while the maximum size of recovered particles lies around 5 mm. Most particles lie within the 1 to 2 mm size range. The charcoal fragments do not show edge rounding.

The vertical distribution of the macroscopic charcoal of HP7 is shown in FIG. 4. After initially low charcoal concentrations (<10 particles/5 l), lithostratigraphic unit 6 shows the largest peak of the sequence, with densities of 1000 particles/5 l. In unit 7 the number of charcoal particles is significantly lower, but fluctuates between samples with less than 10 particles/5 l and peaks of ca. 50 particles/5 l. Unit 8 starts with increased and stable counts of around 100 particles/5 l, and shows a slight decrease in its upper third. This continues in the lower part of unit 9, while in its upper part concentrations decrease

Figure 6 Charred oak branch (*Quercus* sp.) measuring 140 cm in length, found in find level NN2/2c.

to less than 10 particles/5 l. In unit 10 values increase to 50 particles/5 l in the upper part, which is maintained in lower unit 11, after which values decrease to less than 10 particles/5 l. Concentrations are the same in units 12 and 13 and most of unit 14, with the exception of one peak in the lower part of unit 14 and higher concentrations in the uppermost part of the same unit. After this concentrations are (close to) zero, with the exception of one peak at the top of unit 18.

Charcoal particles larger than 1 mm were submitted to taxonomic analysis. All of the charcoal particles originate from deciduous trees. About half (51.9%) of the charcoal particles could not be identified further. The other half of the charcoal is dominated by *Quercus* sp. and cf. *Quercus* sp. (42.4%) (FIG. 7). *Prunus* sp. and cf. *Prunus* sp. represent 5.6%. The remaining 0.2% is cf. *Fraxinus excelsior*. The large "indet." category of deciduous charcoal may contain a significant, but unquantifiable, amount of *Corylus*, as it is the dominant taxon in the pollen record and very difficult to identify microscopically as its characteristic features (scalariform openings) are often lost when charred (van Rijn 1999). The representation of *Quercus* sp., *Prunus* sp., and "indet." along the sequence is shown in Figure 4. Overall a decrease of *Quercus* sp. charcoal is visible along the studied part of the profile, and a concomitant increase of charcoal of *Prunus* sp. and other deciduous ("indet.") trees.

CHARRED SEEDS

Charred seeds of various species were found at HP7. Like the charcoal, the highest concentration of charred seeds can be found in unit 6, representing 80% of the total assemblage (FIG. 4) (details in Online Supplement 3). The rest of the charred seeds are incidental occurrences with only slightly increased counts in units 5 and 15. The charred seeds of unit 6 and the assemblage in general are dominated by charred seeds of Poaceae (true grasses). Other

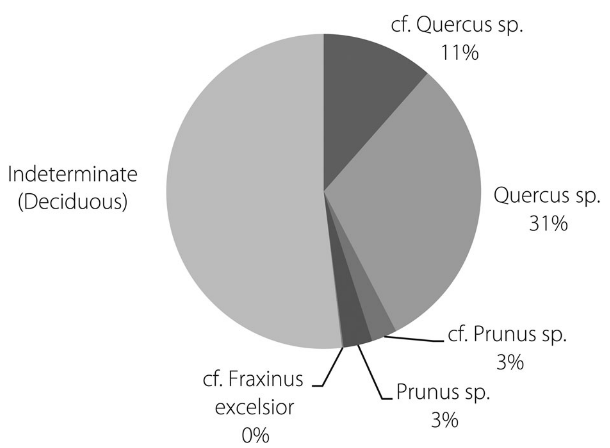

Figure 7 Identified charcoal taxa (n = 1984) recovered from *Hauptprofil* 7 (HP7).

frequently occurring species in the lower part of the profile are *Carex* sp., *Fabaceae* sp. and *Medicago* sp. (see Online Supplement 3). Also notable is the presence of a charred acorn fragment of *Quercus* sp. and a charred pit of *Prunus spinosa* (Kuijper 2014). The seeds from the upper part of the profile are mostly from *Asperula* sp./*Galium* sp.

Discussion

Thermally altered flint artifacts and faunal remains

Within the excavated sequence thermally altered flint and faunal remains occur in low quantities (2.3 and 1.8% of the totals, respectively), but show a recurring presence: they occur in find levels NN2/3 (thermally altered faunal remains only), NN2/2, and NN2/1 (FIG. 4), and in the subunits of find levels NN2/2 and NN2/1 (TABLES 1, 2). The absence of heated flint artifacts in NN2/3 can be attributed to chance, given the low percentages observed in other find levels. The spatial distribution of the often small-sized, thermally altered flint and faunal remains in find level NN2/2b largely follows the distribution of the unheated and unburned material (FIG. 5), which includes larger faunal remains, flint artifacts, and manuports up to 1 kg in weight, and therefore show no evidence for any form of downslope size sorting (see Pop *et al.* 2015). Furthermore, in this and other find levels, sedimentary features indicative of high energy transport are lacking (Hesse and Kindler 2014; Mücher 2014; Pop *et al.* 2015). This indicates that the thermally altered lithics and faunal remains found at the basin margin are, like the rest of the archaeological assemblage, of local origin, i.e., they have not been subjected to significant reworking.

Macroscopically observable alterations on lithic artifacts, as documented for the Neumark-Nord 2 assemblage, are indicative of heating temperatures of at least 300–350°C (Sergant *et al.* 2006; Richter 2007; Richter *et al.* 2011), which is confirmed for the pieces submitted to a TL heating plateau test (Richter and Krbetschek 2014). Thermal fracture, as observed on many of the studied pieces, has been shown to take place when the material is exposed to temperatures in excess of 400°C (Purdy and Brooks 1971; Domanski *et al.* 1994; Domanski and Webb 1992; Buenger 2003). Although clear-cut correlations between specific characteristics of heating and precise temperatures do not exist (Richter *et al.* 2011), the observed heavily altered flint artifacts (being calcined and strongly fragmented) are very likely to have been exposed to significantly higher temperatures than the minimum temperatures indicated above (i.e., > 300–400°C). The heat induced alterations observed on the faunal remains of Neumark-Nord 2 include black and white discoloration with minor grayish or bluish parts (stages 4/5), which are roughly indicative of temperatures above 600°C (cf. Shipman *et al.* 1984). Further evidence for relatively high heating temperatures affecting the archaeological material is provided by several large-sized rocks showing discoloration and cracked surfaces (F. Reidsma, personal communication 2016). A pilot study aimed at identifying heated rocks using a luminescence heating plateau test confirms that material with these characteristics has indeed been heated (F. Reidsma, personal communication 2014).

The recurring presence of thermally altered archaeological material of local origin can be interpreted as multiple, temporally distinct, fire events taking place at or close to the gently sloping margin of this small postglacial basin.

Macroscopic charcoal and charred seeds

The charcoal from the basin area documented at NN2 concerns macroscopic charcoal particles between 0.5 to 5 mm in size. As the calcareous silt loams of the NN2 basin infill were deposited by overland flow and animal activity took place at the margin of the basin (Sier *et al.* 2011; Pop and Bakels 2015; Pop *et al.* 2015), we can expect that both caused fragmentation of the charcoal through mechanical (transport, bioturbation, sediment pressure; Scott and Damblon 2010) and chemical weathering (soil alkalinity; Braadbaart *et al.* 2009). Rounding has not been observed on the charcoal particles, which can be a consequence of limited transport and/or in situ fragmentation, especially when charcoal has been produced by high temperatures (Scott 2010 and references therein).

Many studies have demonstrated that microscopic charcoal (< ca. 200 μm) is easily transported by air and may therefore represent regional fire events, while large (macroscopic) charcoal (> ca. 200 μm) is mostly of local origin (i.e., originating from within the watershed) (Clark 1988, 1990; MacDonald *et al.* 1991; Clark and Royall 1995; Whitlock and Millspaugh 1996; Clark and Patterson 1997; Tinner *et al.* 1999; Carcaillet *et al.* 2001; Gardner and Whitlock 2001; Higuera *et al.* 2005), particularly larger sized particles (> 500–1000 μm) (Ohlson and Tryterud 2000; Lynch *et al.* 2004), as predominantly recovered from Neumark-Nord 2. However, more recent work studying charcoal transport over larger distances, shows that macroscopic charcoal may be transported over several kms (Tinner *et al.* 2006; Peters and Higuera 2007). We therefore cannot a priori exclude the possibility that part of the macroscopic charcoal, particularly the smaller size classes, was transported from beyond the watershed into the basin by thermal updrafts associated with large-scale forest fires (Clark 1988, 1990). However, where they occur within the sequence, charred seeds and larger charcoal fragments (FIG. 4) provide evidence for the local nature of fire events, increasing the likelihood of the macroscopic charcoal originating from a fire within the watershed as well.

Macroscopic charcoal concentrations within the HP7 stratigraphy (FIG. 4) vary strongly between very low (< 10 particles/5 l), low to moderate (50–100 particles/5 l), and high concentrations (1000 particles/5 l). The difference between the concentrations in unit 6 and the rest of the sequence is especially noteworthy. Although sedimentation rates varied during the deposition of the basin infill (Sier *et al.* 2011; Pop *et al.* 2015), they cannot fully explain the large differences in charcoal concentrations. Nor is there evidence for variability in the preservation of charcoal within the sequence. The variability in charcoal concentrations could therefore indicate differences in the scale or frequencies of local fires, or contribution of local and extra-local sources.

Analysis of the macroscopic charcoal larger than 1 mm in size shows that all of the recovered charcoal originates from deciduous trees and therefore represents heavy fuels. These species are all represented in published pollen spectra of the site (Sier *et al.* 2011; Strahl *et al.* 2011; Bakels 2014). The marked decrease of *Quercus* sp. at the expense of other deciduous species is reflected in the pollen record of NN2 (Sier *et al.* 2011; Bakels 2014) and the Eemian vegetation development at other sites (e.g., Turner 2002). Notable however is the high percentage (> 50%) of *Quercus* sp. charcoal in units 7 and 8 (PAZ IVa), when compared to its representation in the pollen spectra (10–20%). This apparent overrepresentation in the charcoal record in comparison with the pollen record may be a consequence of differential pollen production between taxa, differential preservation of either pollen or charcoal between taxa, preferential use of *Quercus* sp. by hominins as a fuel, or a combination of these factors.

The macroscopic charcoal recovered from the Neumark-Nord 2 basin originates from heavy fuels, in this case deciduous tree species, of which oak is the best represented. The macroscopic charcoal has most likely been produced within the watershed of this small postglacial basin, as the fragmented particles co-occur with charred seeds and a charred branch, although (limited) input from extra-local sources cannot be excluded.

Correlation between thermally altered archaeological finds and charcoal

Using documented exposures, the lithostratigraphic units at HP7 could be followed directly upslope to the find levels exposed at the excavation area (Hesse and Kindler 2014; Pop *et al.* 2015). This made it possible to correlate the charcoal record with distinct phases of hominin presence and absence at the basin margin, as well as the associated thermally altered lithic artifacts and faunal remains found between 10 to 25 m upslope (FIG. 4). It is striking that where the two datasets can be compared (i.e., excluding units 15–19), find levels correlate with increased charcoal deposition in the basin. Inversely, phases of inferred hominin absence correspond to low charcoal concentrations in the basin. Phases of increased presence of (heavy fuel derived) charcoal particles in HP7 also correlate with the thermally altered lithics and faunal remains within the find levels, which provides unambiguous evidence for the local, recurrent presence of fire at Neumark-Nord 2. These patterns are strongly suggestive of a direct correlation between hominin activity and fire activity within the basin environment.

Two potential explanations can be brought forward to explain this correlation. Hominins may have visited the site after forest fires, whether naturally or anthropogenically lit (e.g., potentially exploiting the resource increase associated with more open environments, like edible plants and grazing game), or the fire proxies are directly associated with small-scale anthropogenic (controlled) fires during phases of hominin presence.

Although a strong case has already been made for vegetation characteristics being affected by large herbivores when the basin was providing a sufficient supply of fresh water (Pop and Bakels 2015), it may be worthwhile to investigate the correlation between charcoal concentrations and the openness of the surrounding vegetation (as reflected in the proportion of arboreal and nonarboreal pollen). Online Supplement 4 shows that semi-open environmental conditions always correspond to increased charcoal concentrations. However, the converse is not true: the increased charcoal concentrations of NN2/1b and the extremely rich find level NN2/2b do not correspond to increased vegetation openness, while the increased charcoal concentrations are similar to those associated with find levels that do correspond to increased vegetation openness. Therefore, for the middle and upper parts of the sequence there seems to be a link between hominin presence and charcoal irrespective of vegetation openness. Furthermore, within find level NN2/2b, the various layers each yield heated lithics, associated with more or less moderate, but continuous, charcoal input into the basin. These patterns favor a scenario in which the identified increased charcoal concentrations are a direct result of recurrent fire use by Neandertals, whose presence in these find levels is primarily attested by large assemblages of lithic artifacts, and cut-marked and heavily fragmented remains of dozens of large mammals. The moderate charcoal peaks, most likely produced by anthropogenic fires, are present against a low, but continuous, background signal which may represent charcoal input from extra-local sources or, more probably, slightly reworked charcoal from previous fire events or the input from other phases of occupation at the basin other than the ones documented in the excavated area.

Although the charcoal peak of unit 6 correlates with archaeological find level NN2/3, the character of this peak, indicative of substantially larger charcoal concentrations compared to the rest of the sequence, suggests an increase in frequency or scale of fire activity within the basin environment. This may indicate one or more natural fires burning heavy fuels within the watershed, a high frequency of or large-scale anthropogenic fires, or a combination of both natural and anthropogenic fires. Roebroeks and Bakels (2015) speculated that the patterns may reflect intentional burning of the landscape, as it co-occurs with a strong increase in non-arboreal pollen, i.e., an opening up of the landscape, providing space for oak and hazel and their edible hazelnuts and acorns. Unfortunately, little evidence is available from the basin margin, as the small-sized excavations of the find level correlating to unit 6, NN2/3, yielded a small lithic and faunal assemblage of which only a few faunal remains show signs of thermal alteration. The fact that none of the lithic artifacts have been visibly affected by the fire, may be due to the small sample size or that most of the fire activity predated the deposition of the archaeological finds.

The absence of hearth features

If the fire evidence from NN2 has an anthropogenic origin, why were fireplace-related features not observed during the excavations of the basin margin? Hominin occupation of the basin margin seems to have coincided with phases of increased water presence within the basin (Pop and Bakels 2015; Pop *et al.* 2015). This correlation may have introduced several disturbing factors which possibly influenced the preservation of hearth features. During these phases water input took place by overland flow, most likely facilitated by a saturated subsoil (Mücher 2014; Pop *et al.* 2015). Overland flow is especially able to transport lighter elements like charcoal, ash, and heated sediments (e.g., Scott 2010), i.e., the remains of most hearth features. Furthermore, large ungulates visited the basin margin, as indicated by animal footprints and indirectly by the presence of *Polygonum aviculare* (Laurat *et al.* 2007; Bakels 2014), especially when the basin provided a sufficient water supply (Pop and Bakels 2015). The activity of these mammals caused a decreased vegetation cover, increasing the effect of overland flow, while their treading also reworked sediments and promoted downslope dispersal. Trampling also fragmented heated lithics, burned bone, and charcoal, making them more vulnerable to transport. In the case of charcoal, fragmentation through soil alkalinity may have played a similar role (Braadbaart *et al.*

2009). The combined effect of trampling and overland flow might have been instrumental in obscuring or obliterating evidence for fire use, especially when it consisted of unstructured, single-phase fireplaces.

Conclusion

The Neumark-Nord 2 record allowed a detailed study of fire evidence from a European basin locality dating to the warm-temperate Eemian Interglacial—a period with very different environmental conditions than the preceding glacial periods, and very limited evidence for hominin fire use thus far. The recurring presence of thermally altered archaeological material indicates that multiple, temporally distinct, fire events took place on the gently sloping margin of this small postglacial basin. The macroscopic charcoal recovered from the basin area originates from heavy fuels and most likely from fires taking place within the watershed of the basin. These fires most likely burned where the thermally altered lithics and bones were found, 10 to 25 m from the sampling location of the charcoal. A common origin for the thermally altered material from the margin and the macroscopic charcoal from the basin area is supported by the correlations between these two datasets. The interrelationship between fire proxies on the one hand and phases of hominin presence on the other is best explained by recurrent use of fire by hominins active at the basin margin, carried out in conjunction with flint knapping and the extensive processing of dozens of large herbivores. The reasons for a lack of discernable hearth features in a basin context like Neumark-Nord 2, which may have been relatively ephemeral to begin with, includes overland flow, which readily transports fine-grained sediments and lighter fire residues alike, and animal trampling, which may disturb features and cause further fragmentation of fire proxies.

Although hearth features were absent in the open-air setting of Neumark-Nord 2, the relatively straightforward datasets used in this research provide patterns that are highly suggestive of recurrent hominin use of fire at the margins of the Neumark-Nord 2 basin. Nevertheless, the presented arguments could be strengthened with a better control of heating temperature estimates, for example, by employing micromorphological and X-ray Diffraction (XRD) analysis of the faunal remains with macroscopic signs of thermal alteration. Spectrometric analysis of NN2 faunal material is in progress potentially to identify low temperature thermal alterations. More detailed information on the source area of the charcoal from the basin can be acquired by comparing the macroscopic charcoal record and the microscopic charcoal record obtainable from the existing pollen slides. Lastly, luminescence analysis of the fire-cracked rocks from Neumark-Nord 2 as well as experimental research on similar rock types may provide further indications of heating temperatures and, equally important, elucidate the potential use of fire at the locality. Both the data presented here as well as the possibilities for further research illustrate the potential for reconstructing hominin fire use in an open-air, water-laid setting like Neumark-Nord 2.

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