Neandertal adaptations to Interglacial conditions – a case study from the Eemian site Neumark-Nord 2 (Germany)

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1. Introduction

1.1 Hominin adaptations to Pleistocene environments

Evidence for hominin presence in Europe goes back more than one million years before present (Arzarello et al., 2009; Carbonell et al., 2008; Garcia et al., 2013; Muttoni et al., 2013; Toro-Moyano et al., 2013). Over one million years, hominins in Europe have been exposed to several glacial/interglacial cycles of increasing amplitude, characterized by extreme climatic conditions ranging from polar deserts to warm, forested conditions comparable to our current warm period, the Holocene. Before half a million years ago evidence for hominin presence is limited, while the evidence is more substantial for the following half a million years (Roebroeks, 2006, 2001; Roebroeks and Van Kolfschoten, 1994), despite featuring some of the most severe climatic fluctuations of the Pleistocene epoch (McManus, 2004). These climatic fluctuations significantly affected the dominant vegetation of European landscapes and, higher up in the food chain, faunal communities that roamed these Pleistocene environments. These climatic and environmental changes must have had a significant impact on all facets of hominin life, including subsistence, mobility and technology. How did hominins deal with these environmental changes? During the last half a million years, the material legacy (predominantly the remains of butchered animals and the stone tools used) of two hominin lineages can inform us on hominin adaptations to environments of which some seem quite "agreeable", i.e. richly vegetated environments characterized by temperate climatic conditions, while others appear to be harsh and unforgiving, glacial environments with little vegetation and soils sometimes frozen solid by permafrost. These two hominin groups and their material remains, which have been studied extensively over the last few centuries, are *Homo neanderthalensis* (Neandertals) and *Homo sapiens* (modern humans).

Neandertals are the probable descendants of an "Out of Africa" event taking place roughly a million years ago (Hublin, 2014). Around that time, the European continent was colonized by *Homo heidelbergensis*-like populations, from which Neandertals eventually evolved. When this divergence took place is still uncertain, but Neandertal features are already visible in the 400 ka old fossils from Sima de los Huesos, which are generally ascribed to *Homo heidelbergensis* (Arsuaga et al., 2014). The oldest "classic" Neandertal fossils can be dated to around 200 ka (Hublin, 2009), after which their more or less continuous presence in Europe can be traced to about 40 ka (Higham et al., 2014; Hublin, 2014). This large time period covers the Saalian complex with both interstadial and stadial (full glacial) conditions, the Eemian Interglacial characterized by climatic conditions comparable to the current interglacial, and the Weichselian glacial. The distribution of Neandertal fossil remains covers an area from Portugal in the west to the Altai Mountainsin the east, and from the Netherlands/Germany in the north to Israel in the south (Villa and Roebroeks, 2014). Based on the age and distribution of the Neandertal sites known at the time, Gamble (1987) suggested that Neandertals were, despite their inferred physiological cold adaptations (Holliday, 1997; Trinkaus, 1981), only able to maintain themselves in intermediate conditions, between full glacials and full interglacials, during which the landscape was dominated by a very productive steppe-tundra. The environmental rigidity of Neandertals proposed by Gamble was challenged by Roebroeks and colleagues (1992) who showed that Neandertals were present in a wide range of environmental settings, including interglacial ones.

The range expansion of modern humans from their African homelands into Eurasia took place somewhere between 125 and 50-60 ka (e.g. Armitage et al., 2011; Mellars et al., 2013) and the earliest sites in Europe suggest that they arrived there around 50 ka (Hublin, 2012). The oldest dated fossil from Peştera cu Oase has an age of 42–37.8 kyr cal. BP (Trinkaus et al., 2003). In Europe, Upper Palaeolithic modern humans replaced the resident Neandertal population and the associated Mousterian technocomplex. Despite their

African origin, anatomically modern humans were able to thrive under relatively harsh conditions of the pleni- (or "full") -glacial (MIS 3 and 2). They were the first hominin species to colonize marginal areas like arctic and subarctic latitudes, except for the coldest part of the Weichselian, when even the northern plains seem to be devoid of human presence (Housley et al., 1997; Roebroeks, 2000; Verpoorte, 2009). They also colonized strongly continental (Klein, 2009) and tropical environments (Aubert et al., 2014). After the very cold conditions of the Last Glacial Maximum (MIS2), modern human populations were confronted with a major transition to interglacial climatic conditions and forested environments. As modern humans only show gradual physiological changes during their 200 kyr existence (*ibid.*), their ability to adapt to a plethora of environments and climatic conditions has been attributed to technological and social developments associated with modern human behaviour, whether this was the result of a gradual process or a punctuated event (d' Errico and Stringer, 2011; Klein, 2009; Klein and Edgar, 2002; Marean et al., 2007; McBrearty and Brooks, 2000).

Due to the dominance of cold climatic conditions during the Middle and Upper Pleistocene, as well as colder conditions characterizing the time period of the replacement of Neandertals by modern humans, a lot of attention has been paid to environmental tolerances on the "cold" side of the climatic spectrum. These long (moderately-) cold periods are interspersed by the short and warm interglacial periods, which are characterized by a forested vegetation type as well as different faunal communities. These environmental conditions, from a modern-day temperate-climate perspective may seem a major improvement over the glacial conditions during the Saalian (MIS 6) and Weichselian (MIS4-2), but interglacial conditions provided their own unique set of challenges (Bailey et al., 1989; Gamble, 1986). During the current interglacial, the Holocene, the presence of modern humans in these forested environments is well-established by numerous sites of Mesolithic hunter-gatherers (e.g. Bailey and Spikins, 2008); a way of life that persisted until the advent of agriculture. Adaptations to these new environments are thought to have affected subsistence strategies, mobility patterns, lithic technology, and land-use strategies (e.g. Holst, 2010; Price, 1987; Street et al., 2009, 2001). The Last Interglacial, the Eemian, has been well-studied from a climatological and environmental point of view, due to the current interest in climate change and its similarity to the present interglacial. As with the Mesolithic, the transition to the environmental conditions of the Last Interglacial is a large departure from the tundra and steppe environments that covered most of Europe during the preceding glacial.

How did Neandertals maintain themselves in these fairly different Eemian interglacial environments? In order to answer this question we need to rely on two datasets. First of all, the environmental record of this period, including (but not limited to) data on climatic conditions, vegetation, as well as faunal communities. These environmental conditions reconstructed from them offered both opportunities as well as challenges that may have affected hominin behaviour. In order to understand how Neandertals adapted to Eemian Interglacial environments, we have to rely on a second dataset: the archaeological record of this relatively short "slice" of Pleistocene time.

Large-scale excavations at Neumark-Nord 2 (Saxony-Anhalt, Germany; figure 1) have uncovered an extremely rich archaeological record that could be dated to the Eemian Interglacial (Sier et al., 2011). The

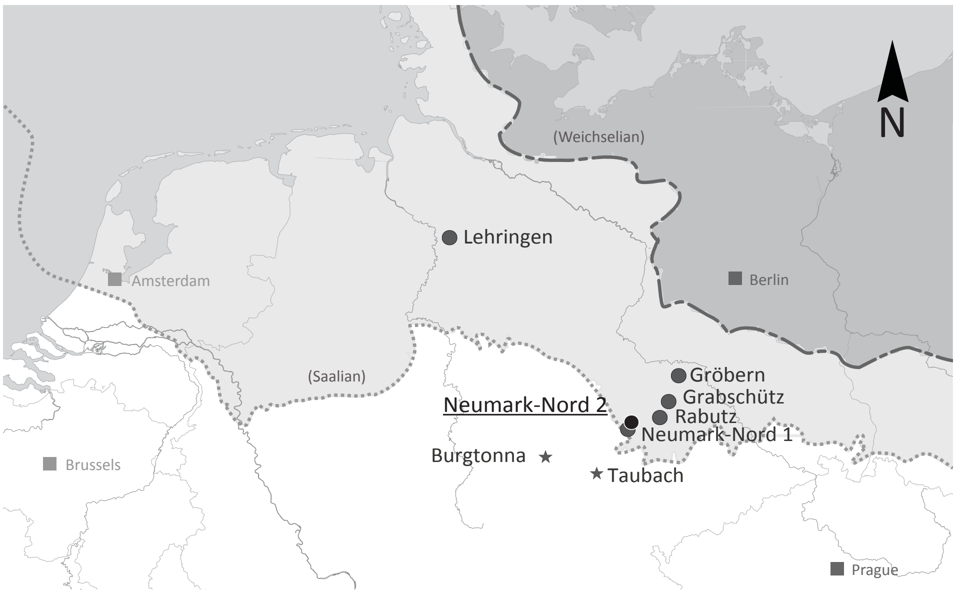

Figure 1: Geographical position of Neumark-Nord 2 and other Eemian sites mentioned in the text (circles: sedimentary basin sites, stars: travertine sites) relative to the maximum ice extents of the Saalian and Weichselian glaciers. Modified after (Speleers 2000).

fine-grained infill of this post-glacial basin yielded multiple find levels that contained large faunal and lithic assemblages, as well as a rich environmental record that can be correlated with the archaeological find levels (Gaudzinski-Windheuser et al., 2014; Gaudzinski-Windheuser and Roebroeks, 2014). With its large archaeological and environmental record, the site Neumark-Nord 2 allows a detailed study of hominin behaviour in an Eemian environmental context. This recently excavated site will therefore be used as a case study in this research. The next section will first provide an overview of what is already known about the environmental conditions during the Eemian, including its duration, climatic conditions and vegetation, as well as patterns of hominin presence and behaviour during this period, as reflected in the archaeological record.

1.2 The Eemian Interglacial

1.2.1 Definition and characteristics

The term “Eemian” is often loosely correlated to the Last Interglacial (MIS5e) known from marine records, which is characterized by high sea levels and warm climatic conditions (Shackleton, 1969; Turon, 1984). Initially, the term Eemian was used to label stratigraphic units containing molluscs characteristic of warm ‘Lusitanian’ and even Mediterranean seas, as found at early exposures at Amersfoort and Amsterdam in the Netherlands (Harting 1874, 1875). The deposits underlying the Eemian were recognised to be the product of a glaciation (Lorié, 1887), but a climato-stratigraphic framework in which multiple alternating cold and warm units could be positioned was still lacking. Around the turn of the century two glacials (the ultimate and penultimate) were identified in the Alpine region on the basis of geological research. This formed the basis for the first climate-stratigraphic subdivision of the Quaternary: “Riss” for the penultimate glaciation, “Würm” for the last glacial period (Penck and Brückner, 1901-1909), and “Riss-Würm” for the intermediate warm stage. As the framework became adopted across Europe, the latter warm stage was equated with the biostratigraphically defined Eemian. As research developed, further nomenclatures were introduced in Northern Europe to identify regional stages correlated to the Alpine division system (e.g. Van der Vlerk and Florschütz, 1953). Eventually, the Saalian-Eemian-Weichselian division (Woldstedt and Duphorn, 1950) became the most common in the area affected by Scandinavian ice-sheets: northern, northwestern and central Europe (Bosch et al., 2000).

Following the identification of the Eemian deposits on the basis of their mollusc content, focus shifted to the palynological content of equivalent terrestrial deposits. These were shown to consistently contain a pollen sequence that was characteristic of developing woodlands, most notably with *Corylus* (hazel) in early stages and *Carpinus* (hornbeam) later on (Jessen & Milthers 1928). In contrast, the preceding Saalian and succeeding Weichselian deposits yielded pollen characteristic of an open steppe vegetation. The occurrence of arboreal taxa within Eemian deposits shows a specific succession, which makes it possible to subdivide it into several biostratigraphic units (Menke and Tynni, 1984; Selle, 1962; Zagwijn, 1961). This typical succession of tree taxa is relatively uniform, as it can be found in pollen sequences across Europe (Behre and Lade, 1986; Turner, 2000; Zagwijn, 1989). The overall vegetation succession is as follows (table 1): after the dominance of high herb taxa and some dwarf birch and –willow in the final Late Saalian, the temperate conditions of the Eemian Interglacial are first signalled by an expansion of woodland and forests dominated by birch (Pollen Assemblage Zone (PAZ) I following Menke and Tynni 1984) and birch-pine (PAZ II). This is rapidly followed by increases in deciduous taxa with first (mixed) oak forests (PAZ III) and later hazel (PAZ IV). Yew is present in varying numbers at different sites in PAZ IV. Characteristic of the Eemian succession is the rapid expansion of hornbeam (PAZ V) in the middle part of the interglacial, which is lacking in the Holsteinian and the Holocene (Turner, 2000). Different explanations have been put forward for this rapid development of hornbeam, including edaphic factors, climatic conditions, and distance to refugia, but the ability of hornbeam to create and thrive under shade-rich conditions most likely outcompeted other species (*ibid.*). The later part of the Eemian succession shows the dominance of first spruce and fir (PAZ VI), and after that a boreal forest with predominantly pine and to a lesser extent birch and fir, but also more open areas with heather

Table 1: Eemian pollen assemblage zones (following Menke & Tynni 1984, their counted or estimated (*) duration (following Müller 1974), and their division into an early, middle and late part.

Eemian	Pollen assemblage zones (Menke & Tynni 1984)	Duration (Müller 1974)
Late	VII Pinus VI Pinus-Picea-Abies	~2000* ~2000*
Middle	V Carpinus	~4000*
Early	IVb Corylus IVa2 Quercus-Corylus IVa1 Quercus-Ulmus-Corylus III Pinus-Quercus II Pinus-Betula I Betula	1000-1200 1150 450 200 100

and sphagnum moss (PAZ VII). From varve counts at the sites of Bispingen and Quackenbrück, the duration of the individual pollen assemblage zones is known (table 1) and the duration of the complete sequence spans some 10 to 11 kyr (Müller, 1974; Hahne et al., 1994).

In terms of its chronology, the Eemian vegetational sequence is tied to a regional sea-level high stand in the North Sea (e.g. Zagwijn, 1996, 1983), but this high stand lasts shorter than the MIS 5e peak in the deep sea record. Also the onset of the Eemian is not exactly that of the onset of MIS 5e. This shows that the Eemian and the Last Interglacial (as known from marine, coral, speleothem and ice-core records) are not exactly equivalent. Several studies have stressed the varying offsets in the timings of the interglacial marine isotope record and that of the terrestrial record of continental Europe, in terms of start dates, end dates and the total duration (Kukla et al., 1997, 2002; Sánchez Goñi et al., 2005; Shackleton et al., 2003). Loss of global ice volume and ocean warming, as reflected in marine isotope records, preceded the dominance in tree vegetation by about 5 kyr in Portugal (Sánchez Goñi et al., 2005, 1999; Shackleton et al., 2003). Sier and colleagues have established a further offset of c. 4.5 kyr for the onset of the Eemian in northwestern and central Europe. Their age-model places the whole of the Eemian in the second half of MIS 5e, with age estimates of 121 ka for its start and 110 ka for its end (Sier et al., 2014, 2011). In this age model, the transition from PAZ V to VI correlates to that of MIS 5e to 5d at c. 115 ka (Sier et al., 2015).

Various climatological reconstructions have been provided for the Eemian interglacial, based on oxygen isotope records from marine cores, ice cores and speleothems, as well as on terrestrial pollen records. Initial oxygen isotope studies of the Greenland ice cores (GRIP, Dansgaard et al. 1993) seemed to show significant fluctuations in the ice volume, but the layering of the ice near the base was disturbed (Chappellaz et al., 1997; Grootes et al., 1993). Other cores from Greenland (NGRIP, NEEM) do not show these fluctuations (Andersen et al., 2004; Dahl-Jensen et al., 2013). The recently published NEEM core indicates an early peak in temperature, followed by a gradual decline during the middle and late phases of the interglacial (Dahl-Jensen et al., 2013). The terrestrial record consists of palynological records from sedimentary basins with an Eemian Interglacial infill. Palynological studies using the modern analogue technique show a transition within the Eemian from oceanic to more continental conditions with the onset of the *Carpinus* phase (Field et al., 1994). The used method has however been criticized for its lack of reliable modern analogues (Kühl and Litt, 2003). The competing indicator species method does not show these mid-Eemian decreases in January temperatures, but rather uninterrupted warm conditions for most of the Eemian (Zagwijn 1996, Aalbersberg & Litt 1998). A newer method using probability density functions rather than threshold values negates changes in the climate dependency of a certain taxon. This method applied to Bispingen and Gröbern (both in Germany) shows a rapid rise of temperatures to above present-day values in the early Eemian and during the mid-Eemian higher precipitation levels, slightly lower winter temperatures, and no dramatic fluctuations (Kühl et al., 2007; Kühl and Litt, 2003). These results match those reconstructed for La Grande Pile (France) using the modern analogue method (Cheddadi et al., 1998) as well as the pollen records reviewed by Helmens (2014, and references therein) and terrestrial isotope studies (Boettger et al., 2000). Near the end of the interglacial there is a significant drop in winter temperatures and precipitation (Helmens, 2014; Kühl et al., 2007; Kühl and Litt, 2003).

The multidisciplinary analyses characterize the Eemian as a 10 to 11 kyr long period in which most of the European middle latitudes are covered with a deciduous forest vegetation, that shows a succession typical for this specific interglacial. The climatic conditions are relatively stable and overall comparable with the Holocene, although slightly higher temperatures are documented for the early part of the interglacial. As stressed by Gamble (1986), environmental settings as described above only represent 8% of Middle and Upper Pleistocene time. Of these periods with interglacial conditions, the Eemian can be considered one of the more pronounced in terms of high temperatures, achieved early within the interglacial, and overall oceanic climatic conditions.

There has been much debate about the ability of Neanderthals to cope with these extreme conditions. From an environmental point of view, the exact structure of the Eemian vegetation is a key point in this discussion. Based on pollen data, Eemian environments seem to be dominated by a closed forest vegetation (e.g. Zagwijn, 1989). However, most Eemian sites yielded faunal assemblages with both species characteristic of forested environments as well as open environments (van Kolfschoten, 2002, 2000). This seems to suggest mixed or mosaic environments, which is at odds with the palaeobotanical record (van Kolfschoten, 2000). Different interpretations have been given for this discrepancy. Some researchers interpret it as the presence of open patches created by fires, storms, floods, and grazing herbivores, the latter especially along interglacial rivers (Roebroeks and

Speleers, 2002; Svenning, 2002). Others emphasize the effect of the subcontinental conditions that characterize the area from which most sites are known (Svenning, 2002; van Kolfschoten, 2000). According to Vera, primeval interglacial forests were generally more open, due to the effect of grazing herbivores (Vera, 2000, 1997). Despite these different interpretations of the structure of the Eemian vegetation, there is a general agreement that wooded environments played a dominant role in the Eemian interglacial landscape.

1.2.2 Research history

Gamble was among the first to question the ability of hominins to exploit forested environmental conditions (Gamble, 1987, 1986). Despite its high primary production, deciduous forests are dominated by biomass not suitable for hominin consumption, because it is too expensive to process or only seasonally available (Gamble, 1986; Kelly, 1983). Secondary biomass would also have been affected by forested conditions, resulting in lower densities of animals (smaller herds) and a more dispersed distribution (Frenzel, 1985; Kelly, 1983). Furthermore, megafauna species have a low reproductive rate, which makes them vulnerable to overexploitation (Gamble, 1987). At the time Gamble developed his theory, scavenging was thought to be the primary mode of subsistence for pre-modern hominins (Binford, 1985; Gamble, 1987) which would have been difficult with the lack of fall-out from large herds normally found in more open environments. For these reasons, as well as the lack of unambiguous Eemian sites at that time, Gamble stated that Neandertals were not living in closed forest conditions, and preferred intermediate conditions between full glacials and interglacials (Gamble, 1987, 1986).

These arguments were countered by Roebroeks and colleagues based on a limited number of unambiguous Eemian sites, mostly located in eastern Germany (see figure 1), as well as on sites from earlier interglacials (Roebroeks et al., 1992). Later, with clear evidence of Neandertal hunting available (Gaudzinski, 2004; Gaudzinski and Roebroeks, 2000), the practical objections to hominin exploitation of forested environments were taken away – hominins were not dependent on natural deaths within large herds. As many Eemian sites yield solitary carcasses of large herbivores (Lehringen, Thieme et al., 1985; Gröbern and Neumark-Nord, Mania, 1990), it has been suggested that Neandertal hunting focused on the larger and mega herbivores which would have been less expensive to exploit than smaller sized prey (Gaudzinski, 2004; Gaudzinski-Windheuser and Roebroeks, 2011). Most of these individuals were either young or weakened animals, rather than prime age individuals (Gaudzinski-Windheuser and Roebroeks, 2011). The limited number of sites from this time period and the lack of sites from Western Europe presented, and still present, an interpretative challenge. Both environmental preferences and research/preservational biases have been considered as possible explanations for the low number of known sites.

Some researchers interpreted the lack of sites from western Europe and the handful of sites from eastern Europe as evidence that Neandertals preferred the mosaic structures of the vegetation which would have been more prominent in the continental interior of Europe, while Neandertals were not able to maintain themselves in the more closed forest vegetation of western Europe (Ashton, 2002; Gamble, 1999). Arguments against a preference for environments only found in eastern Europe were soon provided by the discoveries at Caours, France (Antoine et al., 2006; see figure 1), and a general lack of evidence for a significant vegetation gradient between eastern and western Europe, with a possible exception of the early part of the Eemian (Gaudzinski-Windheuser and Roebroeks, 2011). Furthermore the oceanic conditions that characterize interglacial periods did not seem to have a negative impact on hominin occupation of western Europe before the Eemian.

The fact that only a limited number of Eemian archaeological sites are known has been attributed to research- and preservational biases (Roebroeks and Speleers, 2002; Speleers, 2000). Gamble emphasized the lack of Eemian sites by comparing it with the Mesolithic record (1986). However, unlike the Mesolithic sites, Eemian sites cannot be identified based on the typology of lithic artefacts. The mammalian fauna of the Eemian is typical for interglacial periods, but not unique and can therefore not be used to attribute deposits to this time period (Roebroeks and Speleers, 2002). The identification of Eemian deposits relies on combining stratigraphic correlation of environmental data and/or absolute dating methods (Roebroeks et al., 1992). Especially pollen analysis plays an important role in this respect, but this technique requires good conditions of preservation and records of sufficient length. Well-preserved and sufficiently long pollen sequences are often found in the relatively thick Eemian deposits of sedimentary basins. The landscape between the maximum limits of the Saalian the Weichselian glaciations is littered with small basins inherited from the Saalian deglaciation, often containing interglacial deposits. These have not been destroyed by the invasive Weichselian ice-sheet front in the Last Glacial, because the ice did not reach as far south as before. Most *sensu stricto* Eemian archaeological sites (figure 1) are known from this particular setting and are therefore the most important source of information on Neandertal activities in Eemian environments, although it also introduces a context-dependent bias. The identification of Eemian deposits in the area is further facilitated by the Saalian till deposits that function as a stratigraphic marker. These factors may explain the lack of sites from the UK, as its postglacial landscape has been overridden and disturbed by the Weichselian glacier, reaching a similar maximum extent as during the Saalian (Turner, 2000). Whether sites were there to begin with can however be disputed, as the high sea levels of the Eemian may have kept Neandertals at the continent in the first place (Ashton, 2002).

Known Eemian localities beyond the Saalian ice limit include travertine contexts, which are mostly radiometrically dated to this time period. A concentration of such travertine localities can be found in eastern Germany (Gaudzinski-Windheuser and Roebroeks, 2011). Sites from fluviatile contexts are rare. If they preserve pollen, sequences are often too short to identify them as being of Eemian age (Turner, 2000). Nevertheless, recent excavations at Caours, France, yielded large faunal and lithic assemblages from fluviatile deposits that can be dated to the climatic optimum of the Eemian by a combination of radiometric dating, malacological studies and terrace stratigraphy (Antoine et al., 2006). The upland areas in between these different types of sediment traps are generally characterized by younger soil erosion and therefore not likely to preserve Eemian deposits.

Apart from context-dependent conservation and the variable identifiability of deposits dating to the Eemian Interglacial, the known number and distribution of Eemian sites is further affected by the availability of exposures. The large scale open-cast lignite mining in eastern Germany played an important role in this respect. These mining activities exposed many Eemian basin localities of which some also yielded archaeological material. Especially the area around Leipzig and Halle is well-known for its large-scale exploitation of lignite. Quarrying exposed several Eemian basin localities with an archaeological record (Rabutz, Grabschütz, Gröbern and Neumark-Nord 1: Mania et al., 1990; Toepfer, 1958; Weber, 1990). In a similar vein, the exploitation of travertine localities from the 18th century onwards and interest of collectors led to the discovery of Pleistocene faunal assemblages as well as archaeology, including material that can be attributed to the Eemian Interglacial (e.g. Taubach). Furthermore, the quality of the documentation of the finds from lignite and travertine quarries varies greatly due to the usually challenging conditions associated with a rescue excavation conditions and/or the early discovery of archaeological material within the history of the research field (Gaudzinski-Windheuser and Roebroeks, 2011).

1.2.3 Research questions

The overview of the current knowledge on Eemian environmental and archaeological records shows there are still gaps that hamper our understanding of Neandertal adaptations to Eemian interglacial environments. Although it is generally accepted that Eemian environments were predominantly covered by a forest vegetation, the exact openness of this vegetation when Neandertals inhabited these landscapes remains unclear, while this environmental variable has the potential to put severe constraints on subsistence opportunities. Not yet discussed, but also of importance, are the consequences of changing environments for the availability of raw materials for tool production. On the one hand more vegetated environments would have decreased the visibility of lithic resources (Wenban-Smith, 1998), despite the abundance of Saalian till deposits in the subsoil (e.g. Eissmann, 2002). On the other hand, forested environments would have provided abundant raw materials, not only for tool production (e.g. the Lehringen spear; Thieme et al., 1985), but also pyrotechnology. Therefore: *what are the environmental characteristics of the landscapes in which Neandertals were present during the Eemian Interglacial and what challenges did they pose?*

Based on the archaeological record, Neandertal presence in Eemian environments is well-established. The information on Neandertal behaviour during the Eemian Interglacial is however based on the discovery and excavation of a small number of sites, a situation that strongly contrasts with the abundance of Mesolithic sites known from the beginning of the present interglacial (Bailey and Spikins, 2008). The limited number of known Eemian sites can to a large extent be attributed to biasing factors, including post-depositional processes (Roebroeks and Speleers, 2002; Speleers, 2000), but nevertheless limits our understanding of Neandertal adaptations to interglacial environments. Patterns observed in the record, like the dominance of small kill-and-butchering sites of especially large mammals (Gaudzinski, 2004), may reflect adaptations to Eemian Interglacial environments, but may also be a product of the limited number of exposures, not reflecting the full range of Neandertal behavior within the Eemian landscape. Therefore, *the question of strategies and technologies employed by Neandertals to meet the challenges set* *by Eemian Interglacial environments requires more research.*

Necessary are archaeological sites that can address both issues by providing detailed information on hominin behaviour within its environmental context. The case study site Neumark-Nord 2 is not merely a “dot” of Neandertal presence on the map of known Eemian localities, but is able to provide a better understanding of both the environmental conditions during phases of hominin presence as well as strategies and adaptations to these environments. The next section will introduce the case study site and expound on its information potential and special position within the body of known Eemian localities, before introducing the Neumark-Nord 2 specific issues that will be addressed by the following chapters.

1.3 Neumark-Nord 2 case study

1.3.1 Introduction

Neumark-Nord 2 is, like most other Eemian basin localities, located in a specific area of Europe located between the maximal ice extent of the Saalian and Weichselian glaciers (figures 1, 2), where there are sufficient sediment traps and where there have been ample opportunities for discovery through the large scale exploitation of lignite deposits. Despite the strong similarities with other Eemian basin localities, it does show some important differences, which make Neumark-Nord 2 an ideal case study for testing existing and providing new hypotheses regarding Neandertals adaptations to Eemian Interglacial environments. This includes its exceptionally large, well-preserved, stratified, diverse and well-dated archaeological record that can be situated within an extensive and detailed environmental record, providing information on the basin conditions, the environment surrounding the basin and the time depth of the archaeological find levels. Furthermore, its close association with the neighbouring and substantially larger Neumark-Nord 1 basin allows us to provide environmental reconstructions on a larger scale and study hominin activity in the wider Neumark-Nord environment.

1.3.2 Geological background

The Neumark-Nord site complex is situated in the lignite quarry Mücheln (figure 3) in the valley of the river Geisel, which flows into the river Saale about 15 km south of Halle, Germany (figure 2). The 15 km long and 5 km wide Geisel valley is formed in the *Merseburger Buntsandsteinplatte* which outcrops at the northern side of the valley and is overlain by the *Müchelner Muschelkalkplateau* on the southern side (figure 4). The longitudinal basin structure was formed through subsidence of the subsoil caused by various processes including movement within the deeper lying Zechstein deposits, as well as by tectonics (Thomae and Rappsilber, 2010a). During the Tertiary the area was situated in a vegetated coastal zone of a shallow sea, which eventually led to the formation of lignite during the subsequent 4-8 million years (*ibid.*). These brown coal deposits lie at the base of the Pleistocene deposits that fill the basin structure forming the Geisel Valley and play an important role in the preservation as well as the discovery of the Eemian deposits in the Neumark-Nord area. The preservation of (identifiable) Eemian deposits is related to the presence of several smaller basin structures within the Saalian till. These basin structures formed at the end of the Saalian glacial

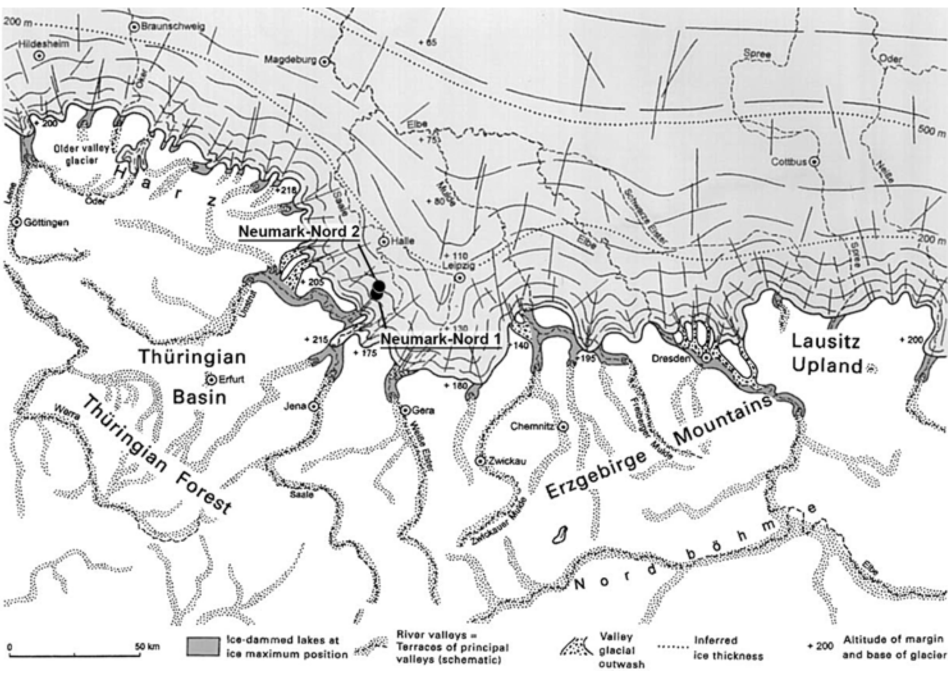

Figure 2: Detailed map showing the position of the Neumark-Nord sites in Eastern Germany relative to the maximum ice extent of the Saalian glacier. Modified after Eissmann (2002).

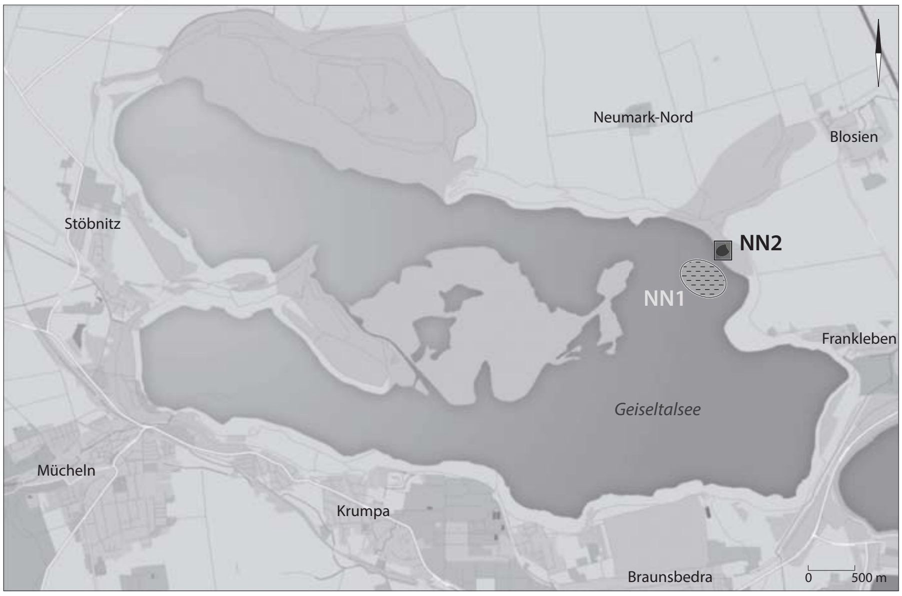

Figure 3: The position of the Neumark-Nord 2 basin in the former lignite quarry which is now a recreational lake (the Geiseltalsee). The former Neumark-Nord 1 basin is shown situated ca. 200 meters SE of Neumark-Nord 2.

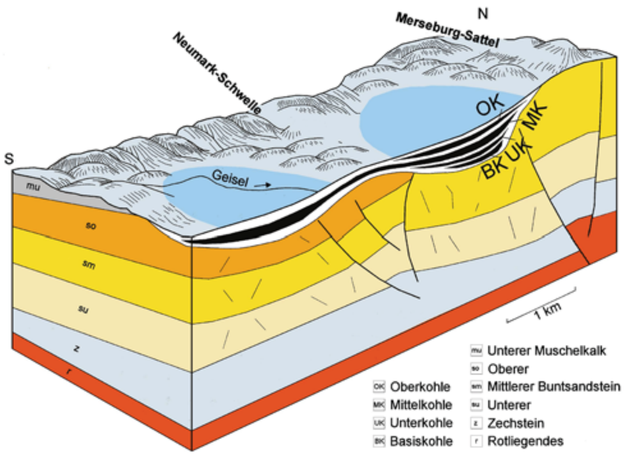

Figure 4: Cross-section of the Geiseltal showing the lignite deposits overlying the Merseburger Buntsandsteinplatte, with the latter outcropping at the northern side. The Müchelner Muschelkalkplateau outcrops on the southern side. After Thomae & Rappsilber (2010).

(MIS6), when increasing temperatures created a diapir of lignite deposits (Thomae, 1990). These basins were subsequently filled with fine-grained silt loams during the Eemian Interglacial. During the Weichselian the area was covered with thick loess deposits, sealing off the interglacial basins and the deposits that they contain.

1.3.3 Lignite exploitation, discovery and excavation of Neumark-Nord basins

The lignite deposits in the Geisel valley have been exploited over a 300 years period, until the mid-1990s. The exploitation of these lignite deposits, exposing Eocene and Pleistocene deposits, attracted natural historians and collectors, especially from the 19th century onwards. In particular the mammal and molluscan fauna of the Middle and Upper Pleistocene were extensively studied, including the find of a complete steppe mammoth (*Mammuthus trogontherii*) of Saalian age from the Pfännertal area (Toepfer, 1957).

The first Neumark-Nord basin (NN1; see figure 3) was discovered in 1985 by quarry geologist Thomae during lignite mining activities. A team led by Mania studied the basin deposits from a geological and archaeological point of view (Mania et al., 1990). In 1995 mining activities made it impossible to continue the excavations. At the NN1 basin, formed within the Saalian till, an infill of 15 meters of lacustrine and peat deposits was documented, yielding a very rich floral and faunal record. The floral record characterizes the environment as semi-open with both forested patches, as well as more open areas (Mania et al., 2010, 2008; Mania and Thomae, 2013). The fauna recovered from the basin area includes a large number of articulated carcasses of elephant, rhinoceros, and bovids and especially fallow deer, accompanied by few, large, unretouched flakes. Furthermore, scatters of mostly fragmented faunal remains and lithic artefacts, including retouched tools and cores, were found at the margin of this basin in two separate find levels or *Uferzonen*, indicating the presence of hominins at the basin locality (Mania, 1990). The interglacial sequence is overlain by loess deposits. As the research took place during mining activities, the excavations only covered small parts of the 24 ha. large basin and were undertaken under a certain amount of time pressure (Gaudzinski-Windheuser et al., 2014). Some have claimed an intra-Saalian (MIS6) age for the Neumark-Nord 1 basin infill, based on stratigraphic observations, environmental arguments and absolute dating (Karelin, 1997; Mania, 1998; Mania et al., 2010, 2008, 2004; Mania and Thomae, 2013). The environmental and stratigraphical arguments have however been refuted and the TL date dismissed because of methodological errors (Litt 1992; Strahl et al., 2011).

The significantly smaller and shallower Neumark-Nord 2 basin (2 ha.; figure 3) was discovered in 1995 by Mania at the end of the Neumark-Nord 1 excavations, ca. 200 meter northeast. Geoelectrical measurements and geological drillings made it possible to reconstruct the subsoil morphology of a large part of the basin (Thomae and Rappsilber, 2010b), while the eastern part of the former basin was already missing due to mining activity in the adjacent quarry (*Alttagebau*; figure 5). When excavations of this basin started, lignite quarrying had already ended. Initially only the early Weichselian NN2/0 find level was excavated, starting in 2003, but the construction of a geological trench exposed find level NN2/2. Excavations of this find level started in 2004 and yielded large amounts of flint artefacts and faunal remains. The excavation of these find levels was initially carried out by the *Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt* only, but from 2006 onwards excavations took place in cooperation with the Archaeological Research Centre and Museum for Human Behavioural Evolution (Monrepos) of the *Römisch-Germanisches Zentralmuseum* (Germany) and the Faculty of Archaeology of Leiden University (The Netherlands). At the end of the excavations an area of 492 m2 (figure 5) was excavated, exposing not only the NN2/2 find level, but also two other find levels: the older Neumark-Nord N2/3 and the younger Neumark-Nord 2/1 find levels. Although a pre-Eemian age has been proposed for NN2/2 (Mania and Thomae, 2013), pollen analysis, amino acid racemization of Bithynia opercula, TL and OSL dates, as well as stratigraphical and palaeomagnetic observations, clearly show that the complete basin infill, including find level NN2/2, dates to the Eemian Interglacial (Gaudzinski-Windheuser and Roebroeks, 2014; Sier et al., 2011; Strahl et al., 2011).

After the mining activities stopped in the late 90's, the large quarry was redeveloped as a large recreational lake, the *Geiseltalsee*. Already before the excavations of Neumark-Nord 2 started, water was being diverted from the Saale and Unstrutt to fill the former quarry with water. As a consequence, the Neumark-Nord 2 fieldwork was essentially a rescue excavation. During the excavations of Neumark-Nord 2 the flooding of the quarry continued. Around 2008 the excavations were terminated due to the high water levels, while the flooding continued until the target of 98 m ü NN (above sea level) was reached and a 18.9 km^2 lake created (figure 3). By this time NN1 was completely

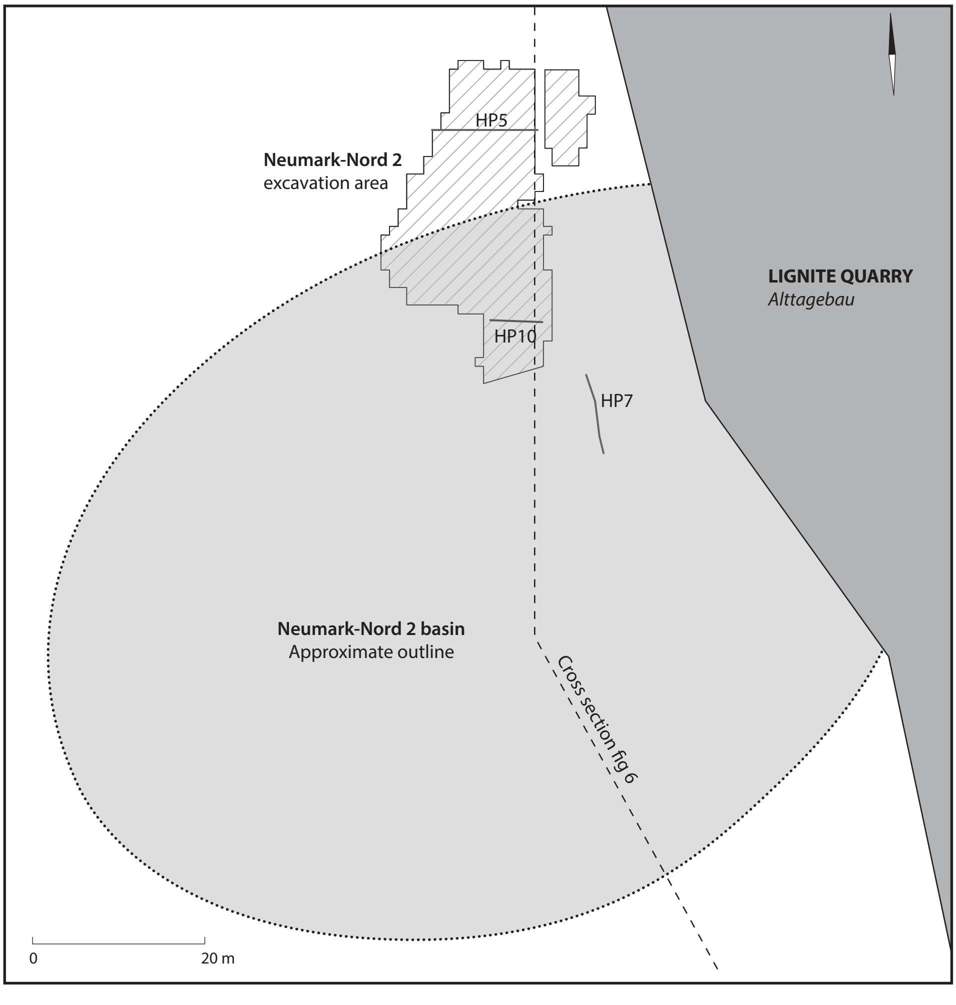

Figure 5: Position of the excavation area and sampling areas in relation to the approximate outline of the former Neumark-Nord 2 basin (dotted line). A cross-section of the intersecting (dashed) line is shown in Figure 6. The eastern part of the basin has been removed by mining activity (dark grey area).

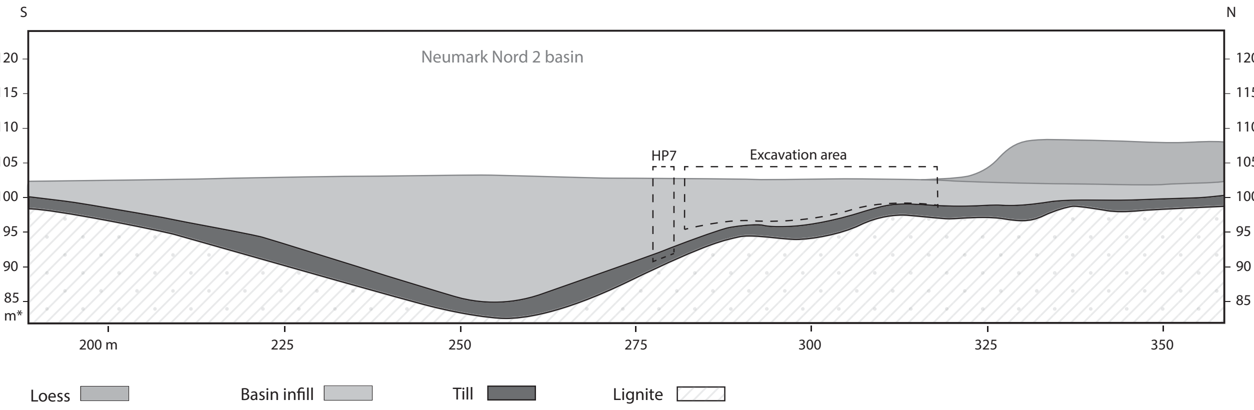

Figure 6: Schematic North-South cross-section of the Neumark-Nord 2 basin, showing the position of HP7 and the excavation area (Modified from Sier et al., 2011). The basin infill is shown situated between the basal Saalian till deposits and overlying Weichselian loess.

flooded, with the location of NN2 situated at the margins of the newly created lake.

1.3.4 Neumark-Nord 2

The Neumark-Nord 2 basin (figure 6) is formed in till deposits through a lignite diapir that caused deformation of the subsoil. The till deposits are of Saalian age, more specifically the Zeitz-phase of the Drenthe stadial (Strahl et al., 2011; Wansa and Radzinski, 2004). The basin infill is represented by calcareous silt loams which reach a thickness of 7 meter near the centre of the basin at *Hauptprofil* 7 (figures 5, 6). At this location 19 lithological units (figure 7) have been identified (Mücher, 2014; Sier et al., 2011) as well as sampled for micromorphology, various environmental proxies and dating techniques. The micromorphological analysis (Mücher, 2014) shows that the calcareous silt loams were predominantly deposited by overland flow, often in standing water, but also by colluviation. It further showed that the sedimentation process was relatively continuous, apart from two phases of incipient soil formation (unit 10 and 12) and that disturbance of the sediments through bioturbation is limited. The incidental presence of gypsum crystals in the upper part of the sequence (unit 9-10; 12-14) indicates phases of dry conditions in the basin; it is possible that the basin

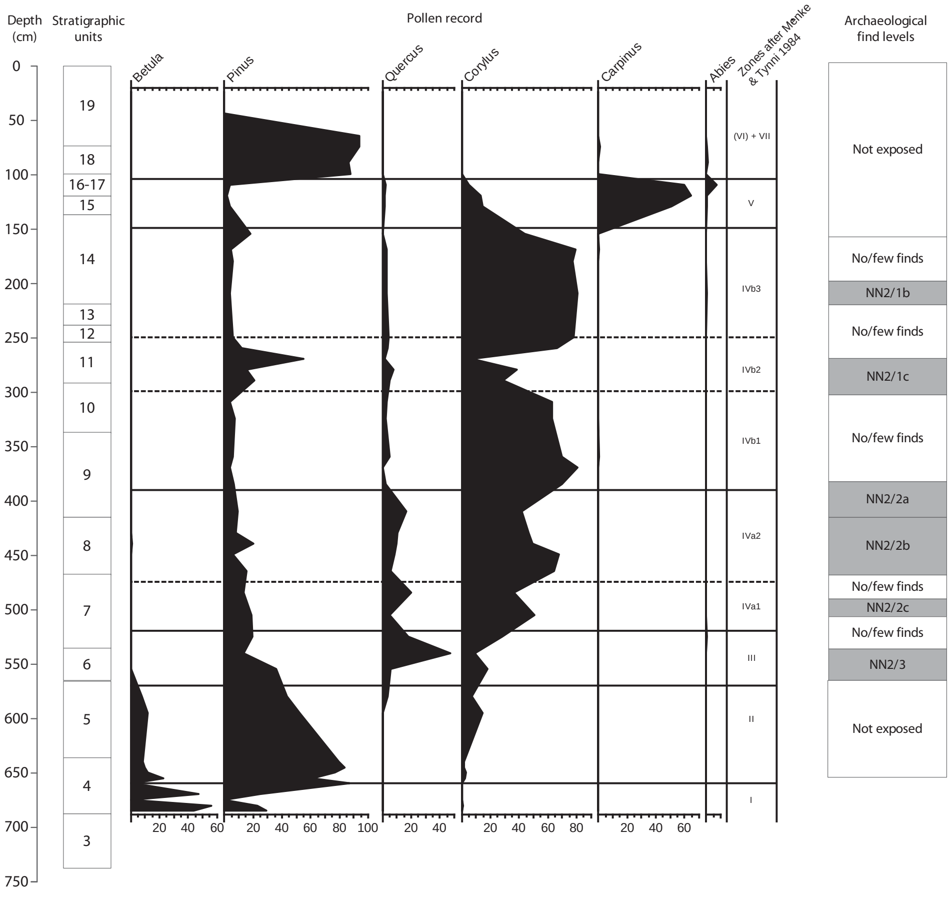

Figure 7: Stratigraphy of HP7 showing the lithostartigraphical units, the Neumark-Nord arboreal pollen record and associated pollen assemblage zones (Sier et al., 2011) and the position of the find levels relative to HP7.

fell dry completely during these phases (Mücher, 2014), but never for long periods of time as indicated by a continuous presence of the fresh water algae of *Spirogyra* (Bakels, 2012). Associated fluctuations of the waterbody are also indicated by occasional gley phenomena. The interglacial sequence is covered by ca. 6 meters of Weichselian loess.

At *Hauptprofil* 7, the silt loams situated between the till and the loess have been extensively sampled for pollen analysis. The well-preserved pollen show a typical Eemian vegetational succession (figure 7) of first *Betula* (PAZ I) followed by *Pinus/Betula* (PAZ II) and *Quercetum mixtum* (PAZ III). The largest part (ca. 4 m) of the sequence correlates with the *Corylus* phase (PAZ IV). The sequence ends with first *Carpinus* (PAZ V) phase, followed with the coniferous species of PAZ VI/VII (for a detailed description see: Sier et al., 2011; Bakels, 2014). At the same location and interval, samples were also taken to retrieve macrobotanical remains, molluscs and ostracods. Together with the palynological record, these remains inform us on the environmental conditions within and surrounding the basin locality through time.

The archaeological finds have been recovered from several find levels at the northern margin of the basin. As exposures were also made between the basin centre and the basin margin, the Eemian find levels can be correlated with units in *Hauptprofil* 7 (figure 7), as well as the pollen assemblage zones (Hesse and Kindler, 2014). The three excavated Eemian find levels yielded large amounts of faunal remains as well as lithic artefacts, which have been three dimensionally documented in the field. The uppermost Eemian find level, Neumark-Nord 2/1, has been excavated over 191 m2 and yielded ca. 9000 lithic artefacts and faunal remains (figure 7). This find level is correlated to unit 11 and lower unit 14 of *Hauptprofil* 7 (HP7) and to PAZ IVb. Neumark-Nord 2/2 is positioned further down in the sequence, correlating with mid unit 7 to lower unit 9 (HP7) and PAZ IVa (figure 7). This find level has been excavated over 491 m2 and yielded a very large archaeological assemblage including ca. 125.000 faunal remains as well as 20.000 lithic artefacts. Moving from the outer margin into the basin, this find level splits into several sublevels, which all contain various amounts of faunal remains and lithic artefacts. The lowermost and therefore oldest find level of the basin, Neumark-Nord 2/3, was discovered through a 4 m2 test-pit exposed in the NN2/1 excavation area and yielded ca. 300 finds including faunal remains and lithic artefacts. This find level correlates to unit 6 at HP7 which corresponds to PAZ III of the Eemian vegetational succession (figure 7). Due to its exceptionally large lithic and faunal assemblage, the Neumark-Nord 2/2 find level has been the focus of the lithic and faunal analyses following the excavations.

The 120.000 mammalian remains from Neumark-Nord 2/2 show excellent preservation, which is most likely the result of the calcareous soil as well as of quick burial through high sedimentation rates. The assemblage is dominated by herbivores like fallow deer (*Dama dama*), red deer (*Cervus elaphus*), bovids (*Bos primigenius*, *Bison Priscus*), and horse (*Equus* sp.) (Kindler et al., 2014). Megaherbivores, like rhinoceros (*Stephanorhinus* sp.) and straight tusked elephant (*Palaeoloxodon antiquus*) are present in low numbers. Carnivores were found in low numbers as well and include wolf, lion and bear. Other finds include birds, reptiles and fishes (Gaudzinski-Windheuser et al., 2014; Kindler et al., 2014). Most of the faunal remains are disarticulated and fragmented. The fragmentation can be (partially) attributed to marrow exploitation and/or the production of bone flakes. Some of the bones even show evidence for use as tools, for example bone percussors and simple scrapers. Also suggestive of hominin involvement are the large quantity of cut-marks on the bones, which are characteristic of butchery (Kindler et al., 2014). The lack of carnivore marks and high incidence of cut marks on the faunal assemblage has been explained as a “hominin dominance” at the locale during Neandertal presence there (Gaudzinski-Windheuser et al., 2014). Bovid and equid remains from find level NN2/2 have also been subjected to isotope analysis, providing evidence for inter-specific differences between bovids and equids, which can be explained as niche separation between these two species (Britton et al., 2012).

The lithic assemblage contains both flint artefacts as well as larger, non-flint gravel-sized rocks that were in the field described as “manuports”. As these non-flint rocks were found within the fine grained sediments of the basin infill, it is likely that they reflect hominin transport to the site. Functional analysis shows that many of these “manuports” bear evidence of use as hammerstones and anvils (Langejans et al. in prep). The 20.000 well-preserved (“fresh”) lithic artefacts, which are discussed in detail in chapter 3, are mostly produced from till-derived flint nodules of Baltic origin.

1.4 Outline of thesis chapters

The four following chapters (submitted for publication as separate papers elsewhere) address the issue of Neandertal adaptations to Eemian Interglacial environments, by focusing on several aspects of the case study site Neumark-Nord 2:

Chapter 2 (Paper 1) – site formation processes – linking high resolution environmental data from basins to archaeological records

A study of the basin context of the site and associated post-depositional processes is required to understand the structure of the archaeological record. This is important as the archaeological record of Neumark-Nord 2 seems to deviate from other Eemian localities in its well stratified deposits. Are these differences merely the product of research bias associated with excavations taking place during lignite mining? The results of this analysis may not only be of importance for a better understanding of the Neumark-Nord 2 basin, but also for the interpretation of several newly discovered Eemian localities. The relationship between the dynamics of the basin (water influx, standing water within the basin) and the archaeological record does not only involve post-depositional processes, but also includes behavioural processes: are phases of hominin presence associated with specific basin conditions (water levels)? What role did basin localities play in the Eemian landscape? The scope of this chapter is limited to the basin conditions, while the discussion of the interaction between the full Eemian environment and Neandertals is further addressed in chapter 5.

Chapter 3 (Paper 2) – lithic raw material acquisition and technology: Neandertal activities at the lake shore

In chapters 3 and 4 the focus is shifted towards the evidence for activities carried out by Neandertals at the margin of the Neumark-Nord 2 basin. The lithic assemblage has been subjected to a detailed typo- and technological analysis. The aim was to identify the stages of the reduction sequence carried out at the basin margin. Does the assemblage reflect, like many other known Eemian localities, predominantly the use of lithic implements for tasks like butchery, or does it also include splitting raw material nodules, decortication, flake production, and resharpening, i.e. tool production and -maintenance? Another point of inquiry is raw material acquisition: what was the source, size and quality of the raw material nodules used? This ties in with the challenge of acquiring raw materials in densely vegetated Eemian environments, which decreases the visibility/accessibility of this resource. Raw material availability and quality also place constraints on the techniques for working the flint material, like the size of flake products, the possibility of applying more complex reduction techniques (e.g. Levallois) and the potential reduction intensity of tools. Furthermore, raw material scarcity may also promote a conservative use of raw material, including working cores to exhaustion and intensive resharpening of tools. Most sites dating to the Eemian yield small and relatively simple flakes and tools, of which some have been attributed to the "Taubachian" (Valoch, 1988, 1984). Does Neumark-Nord 2 yield a similar lithic assemblage and to what extent can characteristics be attributed to raw material constraints? These issues will be addressed in chapter 3.

Chapter 4 (Paper 3) – fire proxies, evidence for fire use

Another behavioural component that seems to characterize the basin margin occupation at Neumark-Nord 2 is the (recurrent) use of fire. As only a limited number of Eemian sites are known, Eemian sites with evidence for fire use are very rare. Despite the more favourable climatic conditions that characterize the Eemian Interglacial, Neandertals may still have relied on fire; not only for heating, but possible also for the preparation of food, as well as keeping away large predators from killed prey and/or occupational sites. The more forested environments would have provided the necessary fuel for building fires, decreasing energetic investments in the use of this technology, while its potential use for cooking may have increased the nutritional value of the kills made by Neandertals. But before the function of fire can be discussed, the scale, proximity and nature of the fire proxies recovered at Neumark-Nord 2 need to be identified. Are these fire proxies indicative of Neandertal fire use or can they also be the product of natural fires? These fire-related questions will be addressed in chapter 4.

Chapter 5 (Paper 4) – Environmental conditions of Neanderthal occupations at Neumark-Nord 2

The question whether Neandertals were able to maintain themselves in interglacial environments is already partly answered by several Eemian localities dating to this time period. Less known, are however the character of these environments (were they densely forested or semi-open and diverse?) and the way in which Neandertals exploited them. Chapter 5 tries to answer these questions by studying the environmental conditions of the basin environment, including the basin conditions as well as the vegetation in the surrounding landscape, during phases of hominin presence. How open was the environment surrounding the basin, which factors play a role in the vegetation openness, and what resources did the environment offer during phases of hominin presence? What role did basins like Neumark-Nord 2 play in the survival of Neandertals in Eemian Interglacial environments?

Chapter 6 – Conclusion

The last chapter will provide a recapitulation of the conclusions of this study, feeding back to the research questions outlined in the introduction.

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