The Neanderthal Occupations at Veldwezelt-Hezerwater (Belgium) and the Challenge of the Eemian Forest in Northwest Europe

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ABSTRACT

The loess-paleosol sequences in the provinces of Belgian and Dutch Limburg (Northeastern Belgium and Southern Netherlands, respectively) reveal a continuous record of paleo-climatic variations during the late Middle and Upper Pleistocene. These abrupt impacts of climate change will alter the intricate ecological balances that let specific plants and animals grow and thrive and must have deeply altered the nature of the successive ecosystems. The climatic challenges Neanderthals had to face, as new ecological communities formed, must have been colossal. The data from Veldwezelt-Hezerwater show that the Neanderthals in Northwest Europe preferred interstadial, open mosaic or even steppe-like environments (e.g., the 'Mammoth Steppe'). When there was a major change in their preferred habitat, Neanderthals could either move and track their favored habitat or they could adapt to the new situation. Otherwise, they would become extinct locally. One of the strategies with which Neanderthals responded to rapid changes in habitat was the adaptation of their stone tool kits. The observed variation in the frequency and diversity of lithic tool types derived from presumed environmental factors was clearly separated in space and time. The study of the loess-paleosol sequences at Kesselt-Op-de-Schans (Belgium), Maastricht-Belvédère (The Netherlands) and Veldwezelt-Hezerwater (Belgium) yielded at least 17 different Middle Paleolithic levels. The lithic assemblages of most of these archaeological levels are mainly characterized by Levallois technology and Mousterian tools. So-called 'Quina tools' were only excavated in the early Middle Weichselian horizons (first half of Marine Isotope Stage [MIS] 3) at Veldwezelt-Hezerwater. Crude laminar lithic assemblages were found in horizons dating most probably to MIS 6.01 at Veldwezelt-Hezerwater. Neanderthals were also moderately specialized to hunt large, cold environment animals. However, being specialized became a problem when changes in climate passed certain limits and when some of those cold environment animals went extinct. The data from the loess-paleosol sequences at Veldwezelt-Hezerwater show that not only cold, glacial and stadial 'harsh' environments—but also wet, full interglacial 'climax' environments—were extremely stressful for Neanderthals. Notwithstanding these observations, some researchers still make the assertion that Neanderthals did, for instance, occupy the Eemian climax forests, but at the same time fail to explain why the Neanderthal signal during the Eemian is so weak. It is known that climate in Northwest Europe is strongly affected by sea-air exchanges of heat and moisture. The raised temperature and increased evaporation and precipitation allowed the rapid expansion of moisture-requiring vegetation. The 'oceanic effect' in Northwest Europe during the Eemian interglacial period must have led to dense climax forests that were largely uninhabitable for Neanderthals. On the other hand, the extreme cold climatic conditions in Northwest Europe during glacial periods must have affected the distribution and viability of the Neanderthal populations as well. In Northwest Europe, the weakness or total absence of the Neanderthal signal in the archaeological record during certain time periods can neither be explained by research bias nor by taphonomic issues. The data suggest that during extreme cold and dry, and during extreme warm and

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wet periods of time, the Neanderthals in Northwest Europe went through a deep demographic crisis. We further argue that (1) during the climatic optimum of the Eemian (MIS 5e), (2) during the cold second half of MIS 4, and (3) during the cool and unstable second half of MIS 3, the Neanderthal population in Northwest Europe must have collapsed. In conclusion, supportive evidence was found for the presumption that three major population bottlenecks hit the Neanderthal population in Northwest Europe during the Eemian interglacial (around 125 thousand years ago ('ka')), during the cold second half of MIS 4 (around 68 ka), and finally during the second half of the Middle Weichselian (around 47 ka). These population bottlenecks severely reduced their numbers, leaving Northwest Europe largely empty of Neanderthals.

INTRODUCTION

The deposits from the Quaternary, starting ca. 2.58 Ma (million years ago) (Gibbard et al. 2010), are characterized by dramatic changes in climate. Oxygen isotope variations (Johnsen et al. 2001; Martinson et al. 1987) spanning the Last Glacial cycle and the Holocene, derived from ice-core records, show strong similarities, while the atmospheric and climate properties in the later phases of the Pleistocene seem to oscillate between stable boundaries (Petit et al. 1999). In Northwest Europe, wind-blown mineral dust—loess—is one of the key components of the Quaternary deposits. Loess (Ložek 1965) is a sediment that is dominated by silt-sized particles that can be readily identified in the field. Extensive loess deposits were formed during the Ice Ages, while paleosols (Retallack 2001) represent periods of landscape stability when loess deposition ceased altogether. Many loess records (Muhs 2013) span much of the Quaternary, and thus represent a terrestrial analogue to the deep-sea sediment record (Cohen and Gibbard 2011; Railsback et al. 2015; Wohlfarth 2013). In this study we will focus on Neanderthal occupation and the climatic and environmental changes in the late Middle and Upper Pleistocene in Northwest Europe, roughly between 133,000 and 28,000 years ago.

During the past 35 years, several Middle Paleolithic sites (Figure 1) have been discovered within the loess-paleosol sequences in the Loess Belt in the southern Netherlands and in northeastern Belgium (Bringmans 2006). These prehistoric sites were discovered in the active brickyard quarries of the region. Within these loess-paleosol sequences, potential *in situ* lithic artifacts can only be found in the fossil soils, never in the pure, aeolian loess (Bringmans 2006). The geomorphology of the study area, located between Riemst in Belgium and Maastricht in The Netherlands, is mainly characterized by the presence of a Pleistocene fossil meander of the River Maas/Meuse, which curves around the so-called Dousberg in Maastricht (Meijs 2002). Within this fossil meander, two ancient Maas/Meuse terrace levels (Rothem 1 and 2) have been preserved (Meijs 2002; Meijs et al. 2012). When the meander was subsequently abandoned by the River Maas/Meuse, this geomorphological incision acted as a sediment trap, preserving a sequence of late Middle and Upper Pleistocene loess deposits, paleosols, and their embedded archaeological levels. The thickness of the loess strata in the study area can be as much as 20 meters.

CHRONOSTRATIGRAPHY OF THE LOCAL LOESS-PALEOSOL SEQUENCES

In the sediment trap environment (Meijs 2002) of the study area between Riemst and Maastricht, the terrace of the River Maas/Meuse is overlain by a thick loess-paleosol sequence. The loess sections consist of deposits of mostly unaltered sediment with intercalated paleosol complexes. A paleosol complex consists of two or more fossil soils that are so intricately interwoven that they cannot be considered separate soils. The loess-paleosol sequence in the study area consists of at most five separate interglacial and interstadial soil complexes with interbedded loess. Loess-paleosol sequences were attested at Kesselt-Op de Schans (Bringmans et al. 2005, 2014; De Warrimont 2007; Meijs 2012; Van Baelen 2017; Vroomans et al. 2006), Maastricht-Belvédère (De Loecker 2006; De Warrimont 2007; Roebroeks 1988; Roebroeks et al. 1983) and Veldwezelt-Hezerwater (Bringmans 2006). When these different datasets are put together, a uniform picture (Meijs 2002, 2011; Meijs et al. 2012) emerges, with aggradation of river gravels and sands, and accumulation of loess occurring during glacial and stadial periods, and with soil formation and deposition of fine-grained river sediment ('overbank loam') during interglacial and interstadial periods. The detailed loess-paleosol sequences in the study area provide an excellent high-resolution terrestrial archive of climate forcing, showing cycles of landscape stabilization with soil formation, followed by erosion, cryogenic activity, and deposition of loess and slope-derived sediments (Meijs 2002). Sometimes, the interglacial and interstadial 'soil-complexes' are intercalated with relatively thin loess deposits (ca. 1m), which exhibit no signs of cryogenic activity, and are thus part of the same interglacial double 'soil-complex' (Schirmer 2002a, b).

The loess-paleosol sequences in the study area (Figure 2) provide an important set of distinct chrono-stratigraphic markers (Meijs 2002; Meijs et al. 2012). On the one hand, there is the characteristic MIS 2 deflation horizon, the so-called 'Patina-Discordance' (Meijs 2002) and, on the other hand, there is the so-called 'Rocourt-Tephra' signature (Meijs 2002)—a widespread 90–74 ka stratigraphic marker in Belgium (Pouclet et al. 2008)—from the MIS 5–4 Transition. The so-called A-loess is the terrestrial equivalent of MIS 2–4, while the 'Rocourt Pedocomplex' (Gullentops and Meijs 2002) was formed during MIS 5. Next comes the B-loess, which represents MIS 6. The 'Hees Pedocomplex'

Figure 1. Location of the Neanderthal sites at Kesselt-Op de Schans (Belgium), Maastricht-Belvédère (The Netherlands) and Veldwezelt-Hezerwater (Belgium), next to the present-day Albert Canal in the valley of the River Maas/Meuse, near the city of Maastricht.

is the equivalent of MIS 7. The C-loess can be correlated with MIS 8, while the 'Montenaken Pedocomplex' is the equivalent of MIS 9. The D-loess equates to MIS 10, and the extraordinary well-developed, purplish-red and marbled 'Pottenberg Pedocomplex' was formed during MIS 11. Finally comes the E-loess, which represents MIS 12, and then the 'Dousberg Pedocomplex', which is the equivalent of MIS 13.

On top of the so-called 'Rocourt Pedocomplex' (MIS 5) at Veldwezelt-Hezerwater (Gullentops and Meijs 2002), rests a complex Weichselian loess-paleosol sequence (MIS 4-2), which, apart from traces of minor oscillations, also contains paleosols of more prolonged 'interstadial' warmings. However, most of the warmer oscillations during the Middle Weichselian (MIS 3), which led to the development of several brown paleosols (Gullentops and Meijs 2002) that sometimes contain Middle Paleolithic artifacts (Bringmans et al. 2006), were short-lived, of the order of ca. 1000–2000 years. Indeed, these paleosols are always weakly developed and interrupted by progressing sedimentation (Meijs 2002, 2011; Meijs et al. 2012). The Middle Weichselian loess-paleosol sequence is separated from the Holocene Soil-complex by thick loess stacks (MIS 2), which clearly show traces of severe frost action (Gullentops and Meijs 2002). The most characteristic feature of the late Middle and Upper Pleistocene loess-paleosol sequence at Veldwezelt-Hezerwater is the recurrent alternation of different sorts of sedimentation, pedogenesis, and erosion, which were the result of climate forcing (Gullentops and Meijs 2002).

HUMAN PRESENCE DURING THE LATE MIDDLE PLEISTOCENE

In 1980, the first Middle Paleolithic artifact was found at Maastricht-Belvédère (Roebroeks 1988), which was at that time a loess and gravel pit just north of the city of Maastricht (The Netherlands), about 2km north of Veldwezelt-Hezerwater (Belgium). This first archaeological find was followed by a systematic survey of the brickyard quarry. One of the main objectives of the excavations at Maastricht-Belvédère (De Warrimont 2007) was to determine the age of the different archaeological find horizons (Huijzer and Mücher 1993; van Kolfschoten and Roebroeks 1985). The conclusion was that the interglacial paleosols of the so-called 'Belvédère Interglacial' (De Warrimont 2002) should be regarded as an interglacial within the Saalian (MIS 8-6). The so-called 'Belvédère Interglacial' was thus correlated with the intra-Saalian warm-temperate stage MIS 7, dated to ca. 250 ka. Although micro-morphological studies (Huijzer and Mücher 1993) had shown that the 'Belvédère Interglacial' consisted of two distinct interglacial luvisols (K1s and K2s), this fact did not receive the attention it deserved (De Warrimont 2007). Based on additional research, it was suggested that the oldest find horizon d3, within the sites B, C, and G, represents the terrestrial equivalent of the MIS

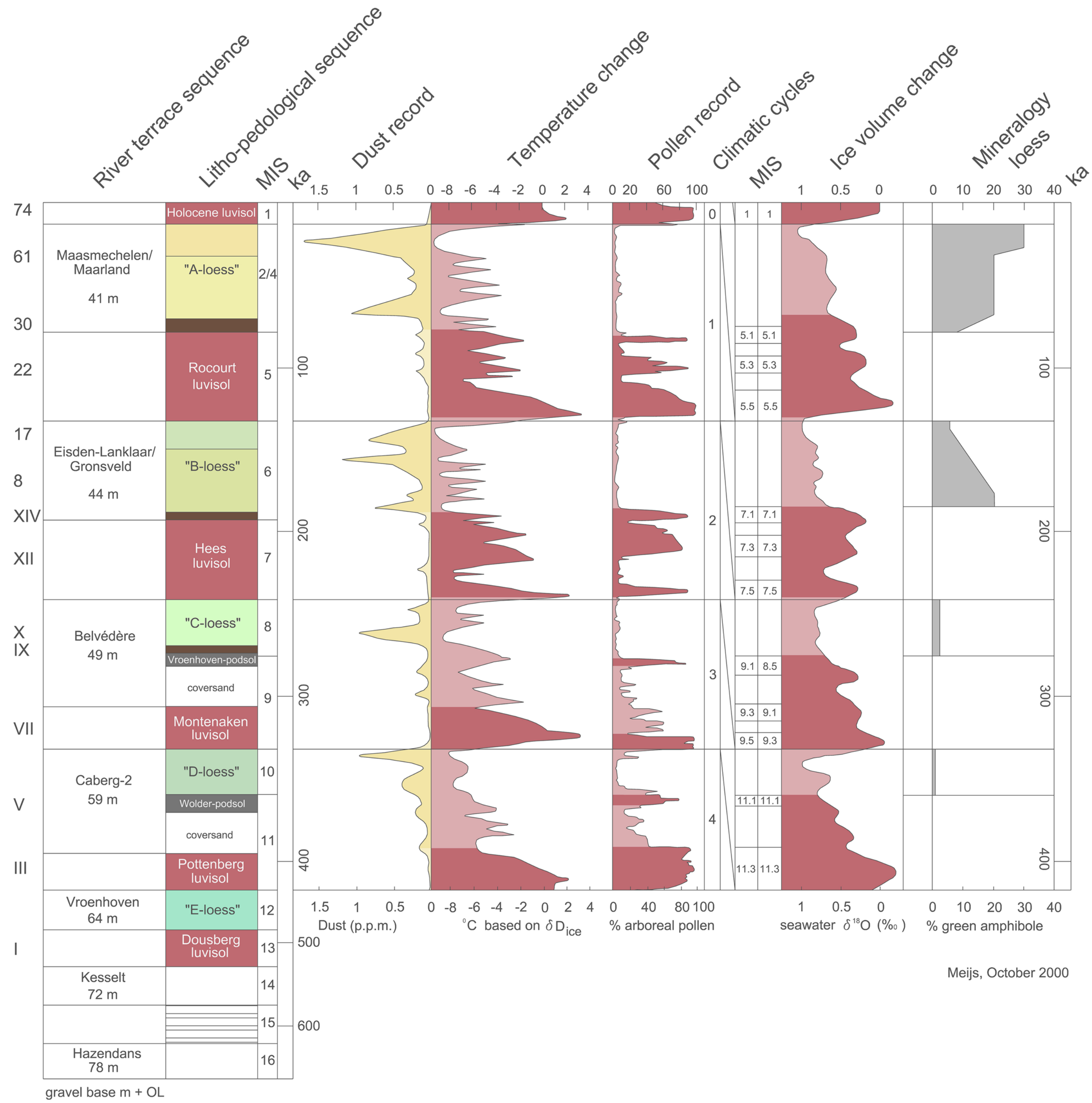

Figure 2. Chronostratigraphical framework for the study area between Riemst and Maastricht (Meijs 2002; Meijs 2011; Meijs et al. 2012), including river terraces, loess deposits, paleo-pedology, climate change, pollen, climatic cycles, MIS, ice volume, and loess mineralogy. The dust, temperature and ice volume records are adopted from Petit et al. (1999).

7.5 interglacial (De Warrimont 2007; Vandenberghe et al. 1993) or MIS 9, based on amino acid racemization (Meijer and Cleveringa 2009), while the archaeological find horizon e5/e5', within the sites A, D, F, H, K, and N, is the terrestrial equivalent of the younger MIS 7.3 interglacial (De Warrimont 2007; Vandenberghe et al. 1993). The younger Site J belongs to the MIS 5–4 transition (De Warrimont 2007). At Maastricht-Belvédère, thousands of flint artifacts were found (De Loecker 2006; Roebroeks 1988). As a general characterization, it can be said that, to a large extent, the different flint industries are the result of the prepared-core technique, including several classical Levallois products.

The site of Kesselt-Op de Schans (Bringmans et al. 2005), about 1.6km south of Veldwezelt-Hezerwater, was discovered in 2005. The first *in situ* Levallois artifacts of 'Level 1' were found in the topsoil (VBLB-Soil) of the 'Ro-

Figure 3. Aerial view of the Veldwezelt-Hezerwater Neanderthal Heritage Site (Community of Lanaken, Belgium).

court Pedocomplex' (MIS 5) and can be dated around 85 ka (MIS 5a). In 2007, another Middle Paleolithic level was discovered in the eastern trench of the brickyard quarry (Bringmans et al. 2014, 2015; De Warrimont 2007; Van Baelen 2014). In Level 5, a large bifacial side-scraper and an atypical biface were found in disturbed sediments of the brickyard quarry. Level 3 contained four discrete knapping spots (ODS 1, 2, 3, and 4) located 10m below the present surface. Based on stratigraphic arguments, Level 3 was dated to the transition from MIS 9 to MIS 8 (Meijs 2002, 2011; Meijs et al. 2012; Van Baelen 2014, 2017; Van Baelen et al. 2007; Vroomans et al. 2006). Each flint scatter (ODS 1, 2, 3, and 4) yielded between 100 and 1,037 artifacts (Van Baelen 2014) and had a maximal diameter of ca. 5m, whereas the distance between these lithic scatters varied between 20m and 90m. These lithic concentrations represent four knapping spots where a limited amount of flint nodules was reduced. From a technological point of view (Van Baelen 2014), discoidal and Levallois strategies, alongside simple prepared cores, are represented. In addition to the flint knapping taking place on site, a limited number of finished products (e.g., scrapers and Levallois flakes) were present as well. The Level 5 sediments were probably deposited at the beginning of MIS 10. Based on the chronostratigraphic model (Meijs 2002, 2011; Meijs et al. 2012) developed for this region, the sediments in which the oldest artifacts from the Kesselt-Op de Schans pit were found, were deposited around 390 ka.

HUMAN PRESENCE DURING THE UPPER PLEISTOCENE

CONTEXT

At the Vandersanden brickyard quarry (Lanaken, Province of Limburg, Belgium), the 'Veldwezelt-Hezerwater Middle Paleolithic Project' took place under the overall supervision of Prof. Dr. Pierre M. Vermeersch (Catholic University of Leuven) and Dr. Patrick M.M.A. Bringmans (Catholic University of Leuven). For several years, the Vandersanden company exploited the loamy fill of the asymmetrical Hezerwater valley. The industrial exploitation started in 1995 and came to an end in 2002. At Veldwezelt-Hezerwater, high sedimentation rates resulted in a very detailed lithostratigraphic record, because of the presence of an ancient Maas/Meuse terrace, which acted as a sediment trap. The final western quarry wall (Bringmans 2016) has been preserved and is still accessible (Figure 3). This final wall is slightly oblique to the Hezerwater valley. The surveyed area comprized approximately 75,000m².

The archaeological survey was undertaken in close collaboration with the owner of the brickyard quarry, the Vandersanden company. The sediments in the brickyard quarry were dug, moved, and disposed with a wheeled or a crawler excavator. This commercial work continued every day of the week. A team of three collaborators from the Laboratory of Prehistory from the University of Leuven, Belgium, visited the quarry every week in search of lithic artifacts. The survey methodology used here was to record the different geological sections—especially the paleosols—in the brickyard quarry over hundreds of meters. This meant that the new vertical quarry walls or the sections of the newly excavated zones were manually scraped with the help of sharpened Wolf-Garten metal hacks (blade: 15cm), which have proven to be ideal for this type of work. The geological sections were photographed and drawn to scale. Lithic artifacts are easily recognized in the sediment when tapped by a metal hack. In this region, primary context, Middle Paleolithic artifacts can usually be found at a depth of about 5m to 15m below ground level. Over time, the paleosols in which artifacts could be expected, were easily recognized. By moving the profiles vertically to the rear, more artifacts could be found. However, in many cases only a single artifact was found, but sometimes, when more artifacts were present, a horizontal surface was created well above the relevant horizon with the wheeled or crawler excavator. From that level, test pits were dug manually. These archaeological test pits were small 1m by 1m trenches dug in a series of horizons to a depth of approximately 1m. The test pits were dug using trowels, hand shovels and Wolf-Garten hacks. Typically, the sediment of a luvisol—especially the Bt-horizon—is quite hard and had to be gently loosened. The test pits were then dug in a series of 10cm thick spits and recorded. The archaeological materials collected from the soil horizons tell us something about the density and the number of artifacts in the different horizons. If it became clear that we were dealing with a 'potential site in a primary context,' a formal archaeological excavation was started.

Except for the presence of pieces of charcoal (n=835) and animal bones (n=613), the Middle Paleolithic finds at Veldwezelt-Hezerwater were exclusively lithic artifacts. More than 2,500 flint artifacts were excavated at 24 different spots where isolated or concentrated artifacts were found. However, most of the artifacts were found at seven Neanderthal occupations, of which ultimately 1000m² were excavated.

STRATIGRAPHY

The loess-paleosol sequence at Veldwezelt-Hezerwater (Figure 4) overlies the fluvial Maas/Meuse terrace (Middle Pleistocene) and layers of Hezerwater gravel, sands, and silts (probably late Middle Pleistocene). Then follow several loam and loess layers, within which several late Middle Pleistocene paleosols were attested. The Upper Pleistocene starts with a complex of paleosols, which has been labelled the 'Basal Soil-complex' (Gullentops and Meijs 2002). The Last Interglacial 'Basal Soil-complex' starts with the formation of a sequence of soils (SRB-VLL-VLB / Units 18, 19, and 20). The SRB-VLL-VLB sequence (Bringmans 2006, 2007) was originally dated to the end of MIS 6—around 133 ka—although some researchers (Meijs 2011: 90; Pirson and Di Modica 2011: 130 – VLL-VLB / Units 19 and 20) later suggested that an attribution to MIS 5d could not be ruled out entirely. In order to shed some light on this situation, we should recall the 2004 study by Wolfgang Schirmer (Department of Geology, Heinrich Heine University of Düsseldorf, Germany) who examined the section at Veldwezelt-Hezerwater in great detail, and who concluded that the SRB-VLL-VLB sequence represents a loess-paleosol succession "prior to the Rocourt Soil (Unit 22 – MIS 5e)" (Schirmer 2004: 2).

In this interpretation, the SRB-VLL-VLB sequence represents an older soil-complex beneath the Rocourt Soil (Gullentops 1954), starting with a separate truncated Bt-horizon (SRB / Unit 18) in which the pedological 'tail' of the Rocourt Soil is present (Unit 18/22), followed by a thin layer of loess with the formation of a stagnic soil (VLL / Unit 19) and a steppe soil (VLB / Unit 20). The SRB-horizon (Unit 18) is only preserved locally on the right bank of the gully, but not on the latter's left bank. On the left bank of the gully, the VLL-VLB sequence is situated directly on the Late Saalian loess (Units 11–17 – MIS 6). The SRB-horizon is completely missing there, which proves that the SRB horizon cannot be the Rocourt Soil.

Nevertheless, the attribution of these stratigraphic levels to the Late Saalian has been questioned by Meijs (2011: 90). One of the arguments claims that the main loess stratigraphical frameworks of Northern France, Central and Southern Belgium, and Western Germany attest that the first luvisol developed in Saalian sediments should be of Eemian MIS 5e age (Antoine et al. 1998, 2003; Haesaerts et al. 1999; Haesaerts and Mestdagh 2000; Schirmer 2000, 2002). Obviously, we do not want to dispute that this is generally the case, but in this particular case, it seems to be a false argument, because it is a simplistic generalization that does not take into account the local stratigraphic situation. Furthermore, it is quite possible that weaker soils, such as the SRB-VLL-VLB sequence, may be obliterated by more vigorous stages of soil formation, such as the Rocourt Soil (MIS 5e), which represents one of the most developed soils of the Pleistocene. Finally, it is quite possible that in depressions or in gullies, the 'known' or 'presumed' stratigraphy was stretched like an accordion and can be studied in much greater detail, even macroscopically.

Another problem is that the established loess stratigraphical frameworks of Northern France, Central and Southern Belgium, and Western Germany lack detail, and are therefore not complete or exhaustive. However, we need to highlight the fact that Schirmer (2010) and Schirmer and Kels (2006), in their stratigraphical framework for Western Germany, indicate a Late Saalian soil beneath the Rocourt Soil. In Schirmer and Kels (2006: Fig. 5), they even name the Veldwezelt-Fundkomplex and indicate artifacts in the Late Saalian levels. In principle, this interpretation (Schirmer and Kels 2006; Schirmer 2010) agrees well with the original hypothesis (Bringmans 2006, 2007) that the

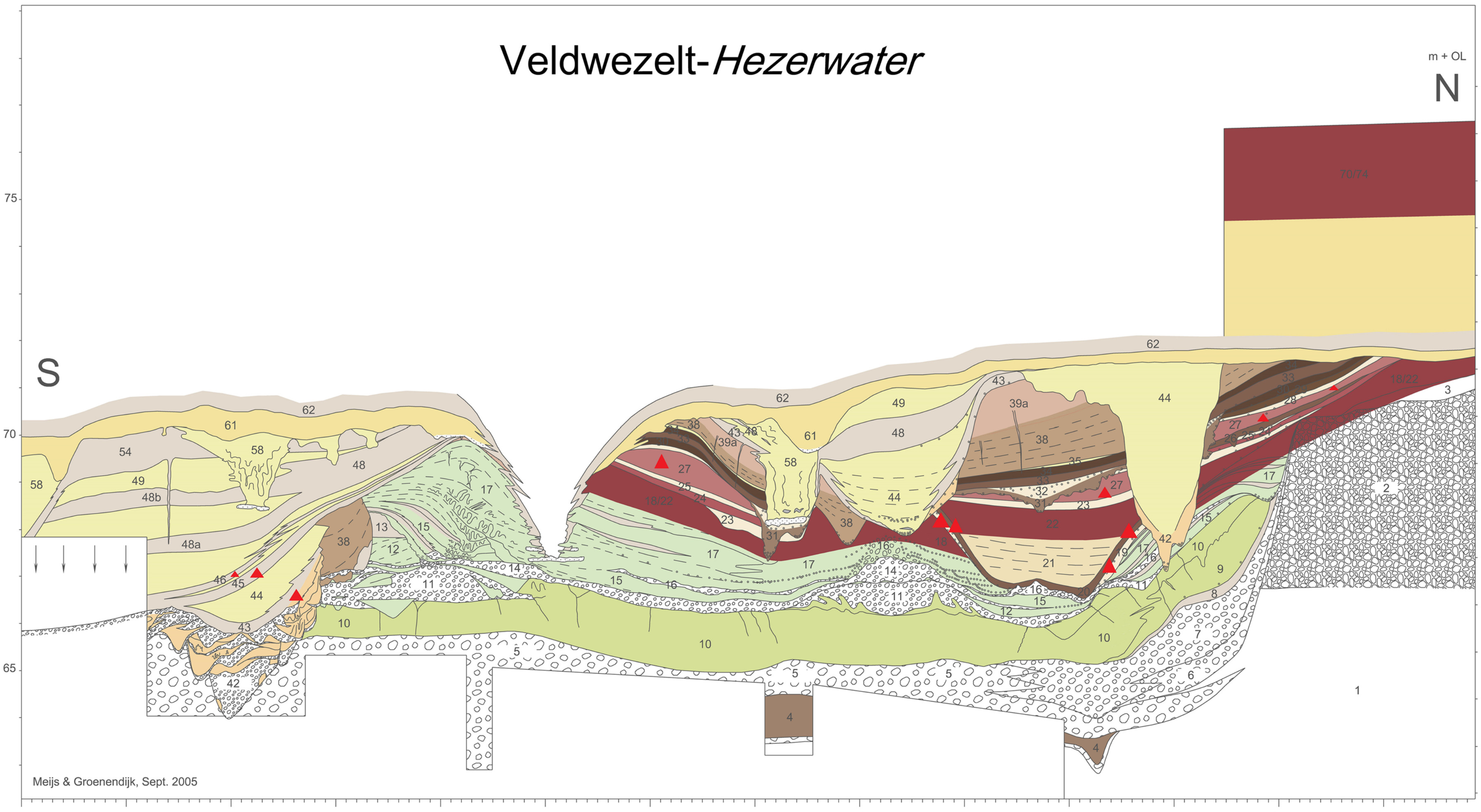

Figure 4. The main North-South Profile at the Veldwezelt-Hezerwater Site (Meijs 2002; Meijs 2011; Meijs 2012). The red triangles indicate the different archaeological levels. The numbers indicate the different paleosols, which have been identified at Veldwezelt-Hezerwater: 1 = OZ (Tertiary Sand); 2 = MG (Meuse Gravel); 3 = FS (Fluvial Sand); 4 = GC; 5 = HWG1; 6 = HG1; 7 = HG28; 8 = OLB/N5; 9 = OL1; 10 = OL2/HSS/ZZ; 11 = WV1/BDA; 12 = OL3; 13 = HSB; 14 = WV2/TDA/GRA0; 15 = ZNB; 16 = GRA1; 17 = OL4A/B; 18 = SRB; 19 = ***VLL SITE*** *(Reduced: OVL); 20 =* ***VLB SITE;*** *21 = GSL (Top GSL: OMVL); 22 = PGB; 23 = OBHB; 24 = RB; 25 = RBHB; 26 = RHZB; 27 =* ***VBLB SITE;*** *28 = BHB; 29 = OHZB1; 30 = OHZB2; 31 = M; 32 = MB; 33 = MHZB; 34 = BHZB; 38 = SL/GBL/MRW; 39a = SLB; 42 = W-G/HWG2; 43 =* ***TL SITES****; 44 = ML; 45 =* ***WFL SITE****; 46 =* ***MLMB SITE****; 48a = MLB3; 48b = MLB4; 54 = LLBB; 58 = ZL; 61 = PL; 62 = THB; 70/74 = Holocene Soil.*

SRB-VLL-VLB-sequence is the pedostratigraphic equivalent of a 'Younger Dryas-type' climate oscillation just prior to the MIS 6–MIS 5e boundary.

The existence of a 'Younger Dryas-type' climate oscillation just prior to the MIS 6–MIS 5e boundary has been demonstrated earlier based on biostratigraphic, pedostratigraphic and speleothem studies, as well as on analyses of stable isotope compositions of marine records and ice cores (Seidenkrantz 1993; Seidenkrantz et al. 1996). This climate oscillation (MIS 6.01) is named after the warm Zeifen interstadial and the cold Kattegat stadial (Seidenkrantz 1993; Seidenkrantz et al. 1996), which was later also recognized by other researchers (e.g., Gibbard 2003; Sánchez Goñi et al. 1999, 2000).

It is interesting to note that the lower cryptotephra layer—THP-TII5—which was found in Theopetra Cave, Greece, was correlated with the P-11 Pantellerian eruption, which is dated to ~128–131 ka (Karkanas et al. 2015). Ash clouds created from large volcanic eruptions are known to cause temporary climate cooling effects. The pollen profiles at the Wola Starogrodzka site in central Poland (Kupryjanowicz et al. 2021) also show a stadial-interstadial-stadial succession at the end of the Late Saalian (late MIS 6), just prior to the Eemian. The recorded interstadial was correlated with the Zeifen interstadial, while the following stadial was correlated with the Kattegat stadial (Kupryjanowicz et al. 2021).

Pedostratigraphical records from all over Europe also provide direct evidence of a distinct cold Kattegat stadial between the Eemian soil (MIS 5e) and the development of an earlier Late Saalian Zeifen interstadial '*limon-à-doublet-soil*' (Seidenkrantz et al. 1996). These pedostratigraphical records include the sections at Nantois and Tournemine from the St. Brieuc Bay, France (Loyer et al. 1995; Monnier and van Vliet-Lanoë 1986), at Jersey, U.K. (Keen et al. 1996), and at Caen and Corbie in the Somme Valley, France (Van Vliet-Lanoë 1988). According to these researchers, the '*limon-à-doublet-soil*', which is attested at these sites, is the terrestrial equivalent of the Zeifen climate oscillation. This '*limon-à-doublet-soil*', which developed in Late Saalian soliflucted loess deposits, clearly shows evidence of clay illuviation. The soil was mostly truncated before being buried by reworked loam, within which the Eemian soil developed. The '*limon-à-doublet-soil*' seems to have marked an 'early' phase of pedogenesis under Late Saalian and still boreal conditions, with evidence of a shrub tundra environment (Van Vliet-Lanoë and Guillocheau 1995). After the development of the soil, a short cooling phase resulted in vegetation degradation, soil erosion with loess reworking, and finally the genesis of a weakly developed fragipan. Only after these developments was the biological stability of the Eemian finally reached (Van Vliet-Lanoë and Guillocheau 1995).

In the Czech Republic and Slovakia, the same phenomena prior to the MIS 6–5e boundary have been observed earlier (Kukla et al. 1961; Kukla 1977; Rousseau et al. 1998). Generally, the genesis of the 'interglacial' soil-complex in the Czech Republic and Slovakia begins with a layer of redeposited, washed, but unweathered, loessic sediments within which a 'gleyic cambisol' was formed under a 'pre-interglacial-climax' climate. Later, newly redeposited sediments capped the initial 'gleyic cambisol', and then followed the genesis of a humic soil of 'rendsina' or 'regosol' type. This rendsina is preserved, but sporadically, for example, at Nové Mesto on the Váh, now in Slovakia (Kukla et al. 1961; Kukla 1977). However, in most cases, these loams with initial soil formation, which were situated just below the basal zone of the Eemian soil, were usually 'secondarily' altered (obliterated) under the influence of the development of the later Eemian soil.

The most striking horizon of the 'Basal Soil-complex' at Veldwezelt-Hezerwater is a luvisol (PGB / Unit 22), which shows macroscopically distinguishable traces of movement of clay, with the presence of so-called 'clay-coatings'. This massive luvisol, which has been identified as the so-called 'Rocourt Soil' (Gullentops 1954) and is dated to MIS 5e, was capped by a bleached horizon. Then followed two other luvisols (RB and VBLB / Units 24 and 27), which were each capped by a bleached (Units 23, 25 and 28) and a humic (Units 26 and 29) horizon. The 'Rocourt Soil-complex' (Gullentops and Meijs 2002), which represents the terrestrial equivalent of MIS 5, is covered by a series of distinct humic soils, which have been labelled the 'Warneton Soil-complex' (Units 30, 33 and 34) and should be dated in the first half of MIS 4. The Last Interglacial 'Basal Soil-complex' at Veldwezelt-Hezerwater is overlain by relatively thick and differentiated Last Glacial loess and loam layers, which were further characterized by periods of interstadial pedogenesis (e.g., TLB soil / Unit 43 and WFL soil / Unit 45). At the beginning of the Last Glacial cycle, the formation of soils exceeds the sedimentation of loess, whereas towards the end of the Last Glacial cycle, the deposition of pure loess prevailed.

CORE AND TOOL REDUCTION STRATEGIES AT VELDWEZELT-HEZERWATER

In the Vandersanden loam quarry at Veldwezelt-Hezerwater, 24 archaeological loci [= particular spots where lithic artifacts were situated] have been discovered (Bringmans 2006). Only 7 of the 24 discovered *loci* seemed to represent relatively well-preserved Middle Paleolithic occupation sites [= any kind of place, large or small, where traces of human occupation or activity are present in a primary context], which thus required further excavation. These 7 occupation sites—(1) VLL / Unit 19 (n of artifacts = 795); (2) VLB / Unit 20 (n of artifacts = 687); (3) VBLB / Unit 27 (n of artifacts = 350); (4) TL-R / Unit 43 (n of artifacts = 57); (5) TL-GF / Unit 43 (n of artifacts = 27); (6) TL-W / Unit 43 (n of artifacts = 29; (7) WFL / Unit 45 (n of artifacts = 133) (Table 1)—provided enough evidence to support the hypothesis that Neanderthals were present at Veldwezelt-Hezerwater at different times during the late Middle and Upper Pleistocene (Bringmans 2006). On the basis of the chronology described above, the lithic assemblages at Veldwezelt-Hezerwater can be characterized as follows: (1) the VLL and VLB sites (late MIS 6 – around 133 ka) were characterized

TABLE 1. ARTIFACTS EXCAVATED AT VELDWEZELT-HEZERWATER.

Cores	**VLL Site**	**VLB Site**	**VBLB Site**	**TL Site**	**WFL Site**
Levallois Cores	-	2	2	1	3
Parallel Cores	7	3	-	1	1
Opportunistic Cores	9	2	-	1	-
Total Cores	**16**	**7**	**2**	**3**	**4**
Tools	**VLL Site**	**VLB Site**	**VBLB Site**	**TL Site**	**WFL Site**
Tools with Ordinary Retouch	5	-	2	1	-
Tools with Quina Retouch	-	-	-	3	2
Tools with Bifacial Retouch	-	-	-	-	-
Notched and Denticulated Tools	1	2	-	-	1
Combination Tools	3	1	-	-	-
Bifacial Tools	-	-	2	-	-
Handaxes	-	-	-	-	-
Total Tools	**9**	**3**	**4**	**4**	**3**
Total Artifacts	**VLL Site**	**VLB Site**	**VBLB Site**	**TL Site**	**WFL Site**
Total Cores	16	7	2	3	4
Primary Decortication Flakes	25	15	6	1	7
Partially Cortical Flakes	160	119	53	19	10
Flakes	277	215	184	61	73
Blades	30	11	4	-	1
Crested Blades	3	-	1	-	-
Points	-	-	-	-	-
Levallois Flakes	-	2	17	-	2
Levallois Blades	-	-	-	-	-
Levallois Points	-	-	-	1	-
Total Tools	9	3	4	4	3
Hammer-stones	9	7	4	3	4
Chips (<1cm)	251	301	70	21	29
Debris	15	7	5	-	-
Total Artifacts	**795**	**687**	**350**	**113**	**133**

by crude laminar products (blades) and small tools, (2) the VBLB site (MIS 5a – around 85 ka) was characterized by medium-sized Levallois flakes and a few bifacial tools, and (3) the TL-R, TL-GF, TL-W sites (MIS 3 – around 58 ka) and the WFL site (MIS 3 – around 50 ka) were all characterized by big Levallois flakes and a few big Quina tools.

Overall, the lithic assemblages (Table 1) contain relatively large numbers of chips and flakes. Cortical flakes (10–90% cortex) are also abundantly present. Primary decortication flakes (> 90% cortex), on the other hand, seem to be quite rare. Core types include 'centripetal/Levallois,' 'parallel/prismatic,' and 'opportunistic' cores, with single, opposed, and multiple platforms. Centripetal core reduction (Tixier et al. 1980) involved striking flakes from around the perimeter of a relatively flat, round flint nodule, gradually spiraling towards the center by rotating the core with each new blow. At Veldwezelt-Hezerwater, Levallois cores and flakes—made from the same raw material units—were present in most lithic assemblages. Refitting efforts were successful in various cases. On the other hand, the 'parallel' core-reduction strategy (Tixier et al. 1980) includes pieces that were removed parallel to the long axis of a core from the striking platform, or from two opposed platforms located at both ends. Parallel cores were only present in the VLL and VLB assemblages, which overall show a high degree of laminarity. Finally, lithic artifacts that cannot be assigned to any of these two core-reduction strategies were labelled 'opportunistic' pieces. Most of the cores excavated at Veldwezelt-Hezerwater were relatively small (4–8cm), and it is difficult to escape the impression that the cores were discarded.

Levallois products were usually made of 'exotic' [= naturally absent from the region], fine-grained lithic raw materials (e.g., VLB, TL, and WFL sites). The main stone-knapping technique used was direct hard-hammer percussion. It has been noticed that at Veldwezelt-Hezerwater, Levallois core-reduction strategies tended to produce relatively large, broad flakes that were comparatively thin and light for their size. Levallois products thus usually tend to maximize the length of the cutting edge per unit weight. At the VLL and VLB sites at Veldwezelt-Hezerwater (Bringmans et al. 2004), blades were clearly made of locally available raw materials, which were not really fine-grained lithic raw materials. However, it seems that at the VLL and VLB sites, the crucial factor was the elongated morphology of the initial flint nodules, rather than the quality of the nodules. Indeed, the Veldwezelt-Hezerwater blades were produced in an opportunistic fashion. Nevertheless, these blades were made by typical parallel/prismatic core-reduction strategies, and the flint nodules were probably intentionally selected.

In the case of Veldwezelt-Hezerwater, it is hypothesized (Bringmans 2006) that the proliferation of certain tool types and the specific composition of the lithic assemblages at the different sites were functional responses to changing climatic conditions and variable lithic raw material availability. If the spread of different tool types were a response to various environmental stresses, it would be logical to observe different tool types in different environmental niches, which seems to be the case at Veldwezelt-Hezerwater.

At Veldwezelt-Hezerwater, the shape and quality of the initial flint nodules and the availability of local raw materials seem to have had an important impact on the final morphology of the cores and tools. It seems that the Neanderthals who inhabited the VLL and VLB sites relied heavily on raw materials that were derived from very local sources. The only sources of workable stone of consistent quality available at the Veldwezelt-Hezerwater were the Maas/Meuse terrace and the Hezerwater gravel beds. Although some larger flint nodules may be present, they are in general quite small. They seldom exceed 15cm in maximum diameter, but the great majority are considerably smaller. Some fine-grained materials were found in these gravel deposits, but the overall quality of flint is highly variable. Today, the gravel beds in the Veldwezelt-Hezerwater area are buried by Upper Pleistocene sediments. These gravel beds would, of course, have been less deeply buried or even exposed during the Upper Pleistocene, but their availability may have varied markedly from time to time. Indeed, these gravel beds were comparatively ephemeral geological entities that may have been repeatedly covered with sediments or exposed over the course of a few millennia.

Besides the availability of local raw materials, it seems that the core and tool reduction strategies at the Veldwezelt-Hezerwater sites constituted a whole range of technological options, which were invoked differently according to context. The 'cyclic' appearance or reappearance of prismatic or Levallois core-reduction strategies, the presence or absence of unifacial, bifacial, notched, denticulated, Quina, or 'small' tools in the different lithic assemblages excavated at the Veldwezelt-Hezerwater open-air sites should not be seen as extraordinary events, but simply as the natural outcome of the dynamics of flint knapping. Not the cyclic 'reinvention' of some sort of core or tool reduction strategy, but the recognition of it as being more useful for certain kinds of activities in specific climato-environmental contexts was the crucial element in this fluctuating technological system. Technological change is thus not the result of a linear 'evolution,' but the outcome of isolated creative human actions. Indeed, frequently doing the 'same' thing, but with minor dissimilarities in the original knapping strategy/*chaîne opératoire*, can bring about diverging results. Various elements (Clark 2002a, b) must come together before triggering a technological shift, such as the element of restricted access to certain resources, climato-environmental conditions, the element of group mobility, socio-economic dynamics, etc.

Based on the presence of 'informal' or 'expedient' toolkits, local, poor-quality raw materials must have been abundant at the VLL and VLB sites. However, when raw material availability was scarce, Quina tools were produced from high-quality, imported lithic raw materials. Quina tools were only excavated at the early Middle Weichselian TL and WFL sites. The Quina tools (up to 10cm long) that were excavated at these sites represented the biggest tools discovered at Veldwezelt-Hezerwater. These observations

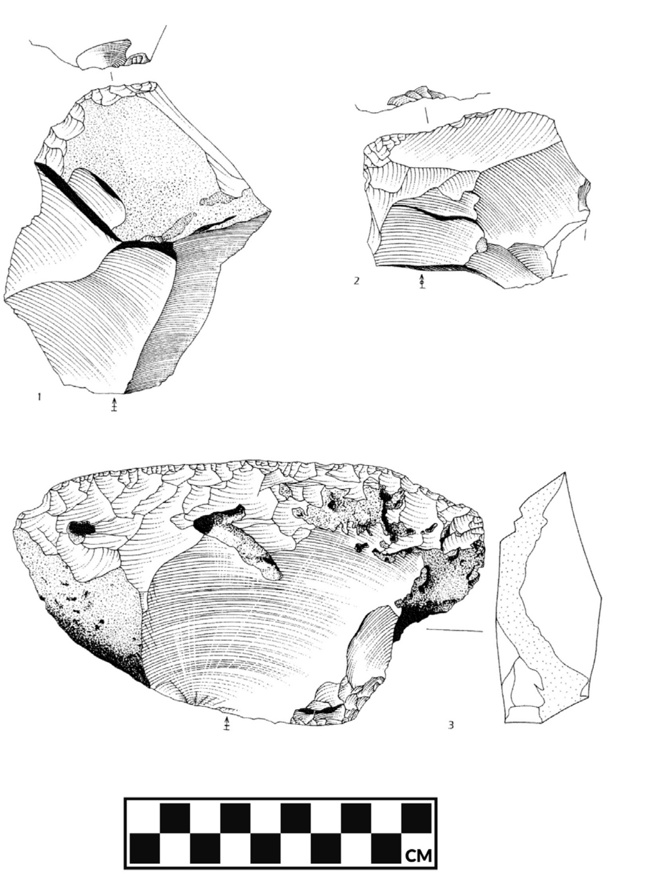

Figure 5. Veldwezelt-Hezerwater, TL Site: 1) retouched flake; 2) retouched flake; 3) Quina transverse side-scraper (drawings M. Van Meenen - I.A.P.).

seem to support the hypothesis (Andrefsky 1994) that attributes of availability, such as abundance and quality of lithic raw materials, condition the production of formal tool vs. informal tool types. It seems that in most cases poor-quality raw materials tended to be transformed into informal tool designs, while high-quality lithic raw materials tended to be transformed into formal tool designs when such materials occur in low abundance.

The forms of the early Middle Weichselian over-sized and over-designed Quina tools, which were excavated at the TL and WFL sites, were made of fresh, imported, high-quality flint. The classical Quina Mousterian is often associated with the acquisition of almost solely local raw materials, even if they were of poor quality (Geneste 1989). However, the Veldwezelt-Hezerwater data show that the Neanderthals had the capacity to anticipate future needs, resulting in the transport of specialized toolkits. These Quina tools were transported over longer distances and were typically made of high-quality flint. The careful selection of high-quality Quina tools to be transported and maintained has also been observed in the Dordogne, France (Hiscock et al. 2009).

The over-sized and over-designed Quina tools at the TL and WFL sites were probably influenced by the fact that they were used under 'high-risk' cool climatic conditions.

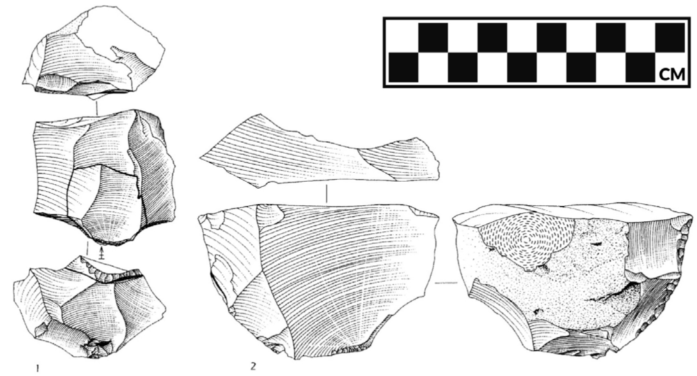

Figure 6. Veldwezelt-Hezerwater, WFL Site: 1). small bipolar recurrent Levallois core with a refitted broken blade; 2) unipolar lineal Levallois core (drawings M. Van Meenen - I.A.P.).

Indeed, lithic technologies that were employed in high-risk environments can be expected to be 'over-designed', because flint knappers usually wanted to maximize core or tool use-life in dangerous circumstances. So, big and thick 'over-designed' Quina tools guard against tool breakage (Bringmans 2006). This may be explained as a technological risk-reducing response to relatively cool and 'hostile' environments. At the TL and WFL sites at Veldwezelt-Hezerwater, the presence of Quina tools (Figures 5 and 6) coincides with the warmest phases of the interstadial climatic fluctuations during the first half of the Middle Weichselian (first half of MIS 3), from ca. 58 ka to ca. 47 ka.

In more temperate environments, most toolkits are casual and display little effort to extend tool use-life. This seems to be the case within the lithic assemblage of the VBLB site at Veldwezelt-Hezerwater, which has been dated to MIS 5a; the latter stage can be interpreted as a 'low sea-level interglacial' (Zagwijn 1989). Low sea-level interglacials are characterized by a more continental character, with a distinct North-South and East-West gradient in vegetation, and with less ecological homogeneity (Zagwijn 1989). This means that after about 115,000 years ago, there were several thousand years of summers cooler and moister than today, but with milder winters.

THE WFL FAUNAL ASSEMBLAGE

The lithic artifacts (n=133) and animal bones (n=225) from the WFL site (Unit 45) at Veldwezelt-Hezerwater (Bringmans 2006; Bringmans et al. 2004) were excavated in a sealed lithostratigraphical unit. The WFL soil formation phase seems to represent an important phase of Middle Weichselian pedogenesis, which could be dated around 50 ka. It is known that the interstadials of MIS 3 were characterized by high-frequency and high-amplitude oscillations of the order of 1000–2000 years duration. It is likely that Neanderthal occupation of Northwest Europe was sporadic and restricted to these relatively warm interstadials, because the environments were too unstable in phases of loessic deposition (dust storms and loess accumulation) for hominin occupation. The WFL site probably represents a very brief occupation by a Neanderthal task group, whose main technological activity appears to have been maintaining a heavily curated toolkit (Bringmans et al. 2004), suggesting high mobility and planning.

The mammalian fauna from the WFL site at Veldwezelt-Hezerwater (Bringmans 2006) has been identified as mammoth / *Mammuthus primigenius* (MNI=1), woolly rhinoceros / *Coelodonta antiquitatis* (MNI=2), horse / *Equus caballus* (MNI=5), European ass / *Equus hydruntinus* (MNI=1), steppe bison / *Bison priscus* (MNI=2), reindeer / *Rangifer tarandus* (MNI=1), arctic fox / *Alopex lagopus* (MNI=1), cave lion / *Panthera leo spelaea* (MNI=1), cave hyaena / *Crocuta crocuta spelaea* (MNI=2), badger / *Meles meles* (MNI=1), and hare / *Lepus* sp. (MNI=1). The WFL fauna thus shows a series of cold-adapted species. There is only one warm-adapted species present, and that is the badger. Overall, the character of the WFL fauna shows the existence of continental conditions, with fairly warm summers, but harsh winters. This would result in the dominance of rich open grasslands (i.e., the 'Mammoth Steppe' of Guthrie 1982). The WFL faunal assemblage corresponds in its composition to a typical steppe fauna. The development of large deforested spaces, characterized by the expansion of grasses during summer, allowed the development of herds of large herbivores.

The dominance of horse at the WFL site (Bringmans 2006) is a strong indication providing evidence for Neanderthal interaction with these faunal remains. There were no cut-marks observed on the bones due to the quality of preservation. On the other hand, there is clear evidence that points to carnivore interaction, probably after the Neanderthals had left the site. The WFL faunal assemblage seems to be an example of a so-called 'species-dominated' assemblage. In this case, a 'horse-dominated' faunal assemblage could be an indication of the anthropic origin of the assemblage. On the other hand, the presence of a 'hyaena den' (Bringmans 2006), in the immediate surroundings of the WFL site, is indicated by the simultaneous presence of corroded and/or partially digested bones, by the remains of a coprolite, and by the presence of some bones and teeth of the hyaena itself. In the latter case, it is significant to note that practically all the excavated remains belong to very young individuals, proven by the presence of unfused long bones and milk teeth. They were probably still-born individuals. These data imply that the place of parturition (i.e., the 'hyaena den') is very close. This would indicate that both Neanderthals and hyaenas were sympatric, thus existing in the same geographical area, around 50 ka (Bringmans 2006). It is easy to envisage how Neanderthals and hyaenas might co-exist. As hyaenas are active almost entirely at night and spend the day in dens, there would be little direct competition for resources with the Neanderthals.

DISCUSSION

NEANDERTHAL HABITAT SUITABILITY

The most commonly studied form of biological response to climate change is changes in species' geographical distributions, because the distribution of vegetation types depends largely on climate (e.g., Hoffman and Parsons 1997; Parmesan et al. 2000). Five major types of terrestrial biomes can be distinguished: (1) forest, (2) grassland, (3) tundra, (4) desert, and (5) ice sheet. Different hypotheses (e.g., Hoffman and Parsons 1997; Parmesan et al. 2000) have emerged linking climate changes with changes in the geographic distribution of the flora, fauna, and humans. A species range is the area where a particular species can be found during its lifetime (e.g., Hoffman and Parsons 1997), and is limited by climate and also by suitable resource availability (Parfitt et al. 2000). As the distance to the edge of the range for a species decreases, individuals often experience increasingly stressful climatological conditions resulting in fewer, smaller patches of suitable habitat (e.g., Hoffman and Parsons 1997; Parmesan et al. 2000). A species habitat can be seen as the physical manifestation of its ecological niche. Archives of pollen have long been a particularly useful tool for reconstructing past ecological niches and changes in terrestrial vegetation over time (e.g., Woillard 1978, 1979).

Obstacles (Nicholson 2017) to our understanding of Neanderthal habitat suitability during, for instance, the Eemian (MIS 5e) include not only the scarcity of sites in Northwest Europe, but also a lack of knowing what the landscape may have looked like during this time. Nevertheless, it seems that Neanderthals had a preference for site locations in temperate to cool climates (Nicholson 2017). Furthermore, Neanderthals have been commonly depicted as top predators who met their nutritional needs by focusing entirely on meat (Bocherens et al. 2001). This information mostly derives from faunal assemblage analyses and stable isotope studies. Unfortunately, these methods (Fiorenza et al. 2015) tend to underestimate plant consumption and overestimate the intake of animal proteins. Several studies (e.g., Fiorenza et al. 2015; Hockett 2012) in fact demonstrate that there is a physiological limit to the amount of animal proteins that can be consumed. Exceeding these values causes protein toxicity. Consequently, to avoid food poisoning from meat-based diets, Neanderthals must have incorporated alternative food sources in their daily diets, including plant materials as well (Fiorenza et al. 2015), e.g. the starch granules from teeth of the individuals from Grotte du Spy (Henry et al. 2011).

Benito et al. (2017) investigated the role of climate and topography in shaping the distribution of Neanderthals in Europe during the Eemian (MIS 5e). According to them, annual rainfall and winter temperatures were the most important abiotic drivers at the continental scale. On the other hand, we can observe the richness of the Middle Paleolithic record in the Maas/Meuse Basin in Belgium during MIS 3 (Di Modica et al. 2015), which is quite overwhelming. For instance, in 1829, the first Neanderthal skull ever found was discovered in Engis (Di Modica et al. 2015). In 1886, two nearly perfect skeletons were found at Spy (Di Modica et al. 2015) with numerous Mousterian-type implements. Unfortunately, the focus during the nineteenth century was entirely on the pluristratified sites in caves or rockshelters. Specialized and/or short-term Middle Paleolithic open-air sites at the time were not known, which led to an incomplete picture with regard to Neanderthal occupation in the

Maas/Meuse valley. This gap was filled in the second half of the twentieth century, thanks to the study of the loess-paleosol sequences and their embedded archaeological levels, which allow high-resolution, temporal and spatial correlations, as for instance is the case at Veldwezelt-Hezerwater (Figure 7).

THE MAMMOTH-STEPPE DURING MIS 3

Neanderthals were absent in Northwest Europe during the cold, harsh, full-glacial periods with loess deposition (e.g., second half of MIS 4), because dust storms must have created intolerable conditions during periods of heavy winds and also suppressed plant growth, affecting herbivore distributions. These cold, harsh glacial periods made Northwest Europe thus only marginally fit for human occupation. However, during MIS 3 these 'harsh' conditions are often exaggerated and assumed as the overall environmental background. This perception is false as has been discussed by van Andel and Tzedakis (1996), because the harsh glacial conditions apply only to a small fraction of Upper Pleistocene time. Between roughly 60,000 and 28,000 years ago, the glacial landscapes were for much of the time less barren than is generally assumed (van Andel and Davies 2003; van Andel and Tzedakis 1996), because numerous climate changes on a scale of several millennia are evident.

During MIS 3, sudden warm and moist phases occurred, often taking the climate in Northwest Europe from stadial conditions to a climate about as warm as at present (van Andel and Tzedakis 1996). The interstadials lasted for varying spans of time, usually a few centuries to about two millennia, before a rapid cooling returned conditions to their previous state. Interstadials show up in the Northwest European record as brief influxes of temperate climate species (van Andel and Tzedakis 1996). Forests or open woodlands of birch, pine, and other conifers also recolonized the steppe and forest-steppe in Germany, The Netherlands, Belgium, and Britain (van Andel and Tzedakis 1996). By adapting to the conditions of the open 'Mammoth Steppe' (Guthrie 1982, 1990), Neanderthals successfully occupied Northwest Europe, mainly during the first half of MIS 3. Steppe expansions (Guthrie 1982, 1990) are believed to be generally associated with human demographic increase, as a result of the increases in animal biomass. It seems that the Upper Pleistocene Neanderthals were hunting cold environment animals, such as horse, reindeer, and mammoth. It is in these interstadial environments that the TL and WFL sites at Veldwezelt-Hezerwater, which were inhabited during the first half of MIS 3, must be situated.

We believe that the curated Quina tools, which were excavated at the early Middle Weichselian TL and WFL sites at Veldwezelt-Hezerwater, represented a specialized technological risk-reducing strategy. This strategy was oriented towards the production of reliable tools (*sensu* Bleed 1986), which would never fail when they were needed. As has been observed before (Hiscock et al. 2009), Quina tools are most consistently associated with cool climate environmental conditions. In order to secure optimal tool performance under dangerous environmental circumstances at the TL and WFL sites, procurement of lithic raw materials, Quina tool manufacture, tool use, and repair were carefully scheduled so as not to conflict with the periods when the Quina tools were required. Indeed, these over-sized and over-designed Quina tools, which were used in stressful and high-risk cool environments, should mainly guard against tool breakage, which could have had serious consequences. Curation of Quina tools at the TL and WFL sites clearly was an important form of 'risk-averse behavior,' which according to Hiscock et al. (2009) formed the central strategy of the Quina strategy.

NEANDERTHAL LANDSCAPE USE DURING THE EEMIAN (MIS 5E)

Nowadays, the so-called 'Eemian,' which was defined at its type locality near Amersfoort (The Netherlands), covers only a restricted part of MIS 5 (e.g., Turner 2000). The Amersfoort Eemian *sensu stricto* is broadly the continental equivalent of MIS 5e. Two somewhat cooler 'interglacials' (MIS 5c and MIS 5a) come after the Eemian *sensu stricto* (van Andel and Tzedakis 1996). Marine Isotope Stage 5 in the broad sense thus includes the Eemian interglacial (MIS 5e) and the long and complex period of climatic deterioration—the so-called 'Early Glacial' (MIS 5d–5a) preceding the Weichselian Pleniglacial (MIS 4–2). The timing of the Eemian warm 'optimum' (MIS 5e) in Northwest Europe began about 130,000 years ago at the end of the Penultimate Glacial Period and ended about 115,000 years ago at the beginning of the Last Glacial Period (Lisiecki and Raymo 2005; van Andel and Tzedakis 1996). During the 'optimum' of the Eemian (MIS 5e) in Europe, temperate forest extended much farther North than at present.

However, the Eemian interglacial (MIS 5e) was quite exceptional, because just like the Holsteinian interglacial, it was a so-called 'high sea-level interglacial' (Zagwijn 1989). The Eemian climate was 'oceanic' in Northwest as well as Central Europe, and was significantly warmer than the present one. Mean temperatures, some 2–2.5 degrees Celsius above present values, are suggested for this 'optimum' phase (van Adel and Tzedakis 1996). The vegetation was rather uniform over large areas. It seems that there was a broad succession in forest composition during the early-to-mid Eemian (Zagwijn 1989, 1996), with an initial pine (*Pinus*) phase during deglaciation, followed by such species as deciduous oaks (*Quercus*), hazel (*Corylus*) and hornbeam (*Carpinus*).

Inspired by the work of Kelly (1983), who stated that most of the primary biomass in forested environments consists of plant leaves and stems that are difficult to access, Clive Gamble (1986, 1995, 1999) postulated that interglacial Northern Europe was actually a hostile environment for Neanderthals. According to Gamble (1986, 1995, 1999), the Eemian climax forests in Northern Europe must have functioned as so-called 'green human deserts.' These 'green human deserts' were spaces abandoned by hominins, due to the fact that the majority of the biomass was stored in non-edible form, like stems and leaves of trees (Sandgathe

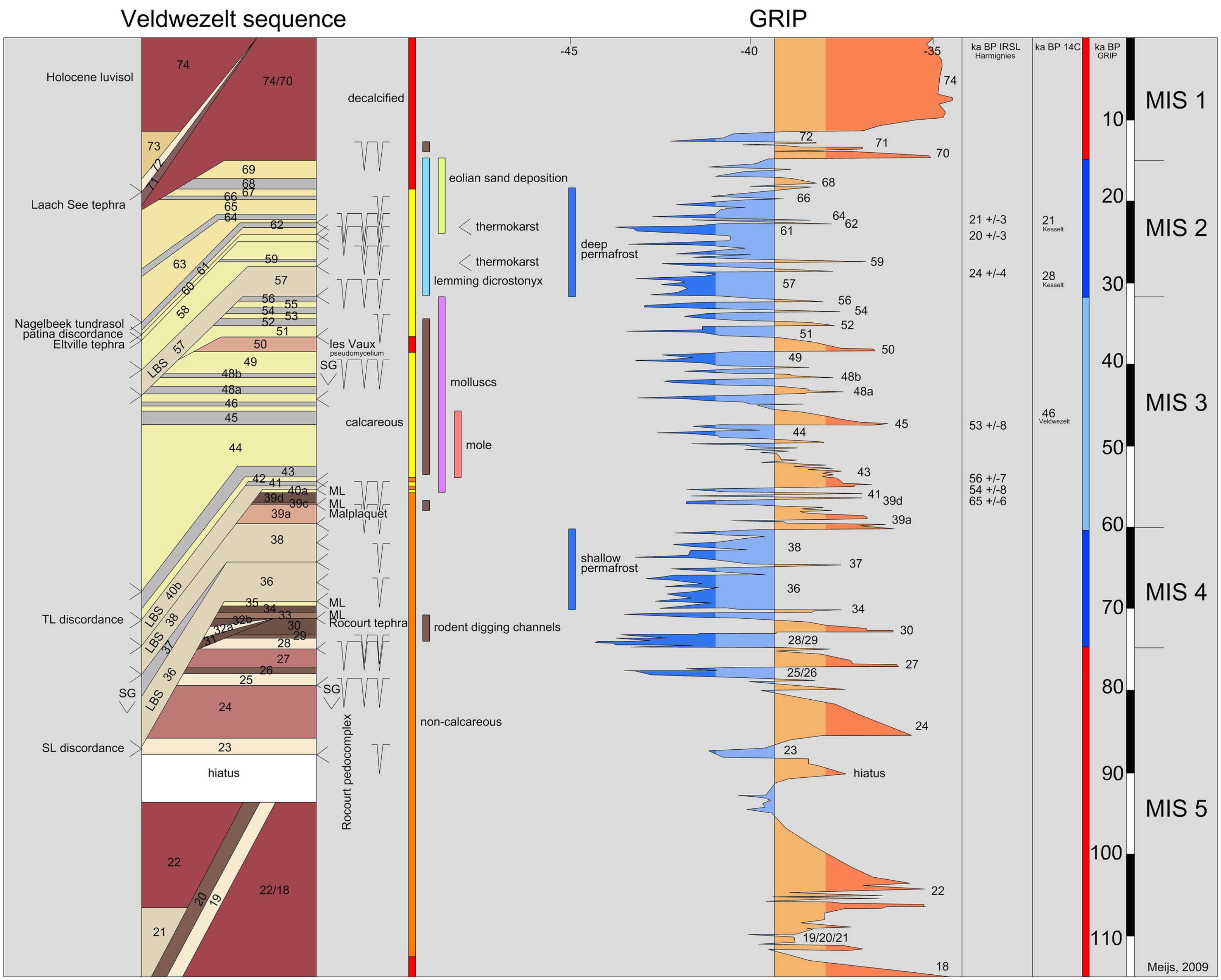

Figure 7. The Standard Veldwezelt-Hezerwater Loess-Paleosol Sequence (Meijs 2002; Meijs 2011; Meijs 2012): sedimentological, pedological, tephrochronological, faunal, and cryogenic characteristics and chrono-correlation with the Greenland Ice Curve (after Johnsen et al. 2001). Abbreviations: ML = Marker Loess; SG = Segregation-ice features; LBS = Lehmbrockelsande or pellet sands. The numbers indicate the different paleosols, which have been identified at Veldwezelt-Hezerwater (see Figure 4).

and Hayden 2003). Moreover, the dispersion and the small scale of the plant resources made them costly when measured by the time needed to collect and process them (Kelly 1995). The same is true for the animal food resources. Although a large variety of species roamed the forests, they were quite small and very scattered. The dense forest also posed hunting challenges such as an impeded mobility and a reduced ability to throw projectiles. The apparent lack of archaeological sites during the Eemian (MIS 5e) in Northern Europe gave support to Gamble's view.

The essence of what could be dubbed the 'Eemian Problem' (Bringmans 2006) concerns the dense interglacial, climax forests of Northwest and Central Europe during the Eemian (MIS 5e), which were 'hostile' to Neanderthals. These interglacial, climax forests are considered to have been less favorable habitats for Neanderthals than the grasslands or the Mammoth Steppe of interstadial Europe (MIS 3). Some researchers, such as Roebroeks et al. (1992), however claim to have refuted Gamble's hypothesis by presenting evidence that Neanderthals were present in Central Europe in full interglacial periods. Unfortunately, most of these sites were found in travertine deposits and lake basins in Northern Germany (e.g., Roebroeks and Speleers 2002; Roebroeks and Tuffreau 1999; Roebroeks et al. 1992; Speleers 2000; Wenzel 1998), which make solid long-distance correlations virtually impossible. It should thus come as no surprise that controversy exists concerning the ability of Neanderthals to exploit the Eemian climax forests (e.g., Bringmans 2006; Gamble 1986, 1995; Locht et al. 2016; Mellars 1996; Roebroeks et al. 1992; Speleers 2000; Weiss et al. 2022; Wenzel 2007).

One reason for this 'Eemian debate' is the patchy nature of the environmental data. Indeed, attributions and correlations were—and very often still are—highly problematic (Bringmans 2006). The fact of the matter is that several archaeological sites have previously been falsely attributed to the 'Eemian.' A notorious example is the Middle Paleolithic open-air site of Rheindahlen (Bosinski 1966) situated in the German Loess Belt, which was initially dated to MIS 5e (e.g., Frechen et al. 1992). Rheindahlen is arguably the most important open-air reference site in the west of present-day Germany. However, its chronostratigraphic position has long been hotly debated. Now, the interglacial soil-complex of Rheindahlen has been safely attributed to MIS 7 (Schirmer 2002a; Schirmer and Feldmann 1992).

Since the Middle Paleolithic period is mostly outside the range of radiocarbon, a temporal resolution on the millennial scale is usually only reserved for the loess regions, where highly-resolved loess-paleosol sequences occur. Beyond the Loess Belt, shallow sediment deposits in unison with frequent cryoturbation features often hamper the establishment of such a precise chronostratigraphic framework (Bringmans 2006, Hein et al. 2020, 2021; Wisniewski et al. 2019). Because of this situation, many of the so-called 'Eemian' archaeological sites were labelled as such just because the faunal remains associated with the lithics had an 'interglacial' character. At that time, older interglacials (e.g., MIS 7, MIS 9, MIS 11) were not known or not believed in, let alone the existence of the more modest interstadials (e.g., Wenzel 2007).

On the other hand, a number of scholars (e.g., Roebroeks and Speleers 2002; Roebroeks and Tuffreau 1999; Roebroeks et al. 1992; Speleers 2000; Wenzel 1998) still claim that on the North European Plain, a Neanderthal presence is well established during the Eemian (MIS 5e). They list Middle Paleolithic sites such as Taubach, Wallertheim (horizon A), Weimar Parktravertine, Neumark-Nord, Rabutz, Grabschütz, Gröbern, Lehringen, Veltheim-Steinmühle, and Stuttgart-Untertürkheim (e.g., Gaudzinski-Windheuser and Roebroeks 2014; Hein et al. 2020; Litt and Weber 1988; Nielsen et al. 2017; Richter 2016; Thieme and Veil 1985). These Middle Paleolithic sites form a remarkably dense cluster in the central part of the east of Germany, compared to the general rarity of Eemian sites in the rest of Northwest Europe, with the exception of a few sites in northwest France (Locht et al. 2016). This asymmetry in site cluster density cannot for sure be explained away by claiming variations in site preservation processes or differences in research intensity of the particular regions, as is proposed by Roebroeks (1996) and Speleers (2000).

We would like to stress once more that Britain, northern France, Belgium, Luxembourg, The Netherlands, and western Germany seem to have been totally deserted by Neanderthals during the Eemian (MIS 5e). It is important to keep in mind, that in the European Loess Belt, the accumulated sediment thicknesses are sometimes of the order of tens of meters. Because of this, a very detailed stratigraphy with a temporal resolution on the millennial scale could be established there. Since most of the Middle Paleolithic archaeological sites in Northwest Europe were actually excavated in the Loess Belt, the factual absence of Neanderthal occupations during the Eemian (MIS 5e) is almost inexplicable, unless the Neanderthals had actually left. It is an established fact (Bringmans 2006) that nowhere in Northwest Europe have Middle Paleolithic artifacts been found in or on the paleosurface of the so-called 'Rocourt Soil,' which is the terrestrial equivalent of MIS 5e. It is also interesting to note that during the Eemian not only humans, but also horses—typically cold environment animals—were certainly absent from Britain (Sutcliffe 1995). The same situation seems to be the case in Northwest Europe. It should not be forgotten that in Northwest Europe the oceanic effect—and the specific vegetation response to precipitation—must have led to dense climax forests that were largely uninhabitable for Neanderthals. This situation must have caused a sharp demographic contraction in Northwest Europe.

During the Eemian (MIS 5e), a broadleaf or 'summer green' deciduous forest was the native vegetation of Northwest and Central Europe. This part of Europe, which includes the United Kingdom, northern France, Belgium, Luxembourg, The Netherlands, and the northern part of present day Germany, shows little topographic variation, and hence a rather uniform vegetation. How could it be possible that in the Loess Belt, where most of the Neanderthal sites were excavated within a solid stratigraphic framework, not a single sign of Neanderthal activity has been found during the Eemian (MIS 5e)? How could it be possible that 'Eemian' Neanderthal habitation is seemingly 'omnipresent' in the more marginal areas of Northwest and Central Europe? Could it be that the chronology of most of these 'Eemian' sites is either poor or controversial (e.g., Jöris 2004; Mania 2002; Pastoors 2009; Veil et al. 1994), and that many of these alleged 'Eemian' sites are not well dated at all (Weiss et al. 2022)?

THE EEMIAN IN GERMANY

Currently, several researchers claim that Neanderthals were present in Northwest and Central Europe during the Eemian *sensu stricto* (e.g., Gaudzinski-Windheuser and Roebroeks 2014; Hein et al. 2020; Litt and Weber 1988; Nielsen et al. 2017; Richter 2016; Thieme and Veil 1985). In the east of present-day Germany these alleged 'Eemian' sites can be found in two different types of deposits: (1) lake basins and (2) travertine deposits. Several of the so-called 'Eemian' lake basins in northern Germany (e.g., Wenzel 2007) lie in an area that was only reached by ice in the Drenthe phase (MIS 8) of the Saalian glaciation (MIS 8 to MIS 6), but not during the Warthe phase (MIS 6). Discussions concerning the dating of those 'Eemian' lake basins overlying the Drenthe basal moraine are closely linked to the still heavily disputed question—in Germany—of the existence of an interglacial period (MIS 7) between the Drenthe and Warthe ice advances of the Saalian stage (Eissmann 2002; Lippstreu and Strackebrandt 2003; Wenzel 2007 and *contra*: Mania 2001; Nowel 2003). This means that for some of these lake basins, an MIS 7 age has in the past been ruled out *a priori*, which almost automatically leads to a MIS 5e age (cf. the discussion at Rheindahlen).

The same problems arise when dealing with the travertine deposits. Travertine owes its formation to mineral waters rich in calcium carbonate, which often flow out of the ground at the edge of floodplains (Adam and Berckhemer 1983). Reliable dating is essential in order to put paleoclimatological, paleoenvironmental, and archaeological information from continental travertines in the correct time-frame. Unfortunately, the dating problems associated with the travertine deposits of Stuttgart-Untertürkheim (Wenzel 2007) are exemplary for most other travertine sites. The Stuttgart-Untertürkheim travertine deposit (e.g., Geyh et al. 1999; Reiff 1994) consists of the 'lower travertine' and the travertine sand of the 'upper travertine.' These two fairly homogeneous deposits are separated by an 'intermediate layer' containing the remains of steppe rodents. The 'lower travertine' is traditionally assigned to MIS 5e, while the 'steppe rodent layer' is assigned to MIS 5d and the 'upper travertine' to MIS 5c (e.g., Geyh et al. 1999; Reiff 1994). However, an alternative chronological interpretation by Frank et al. (2000) places the major part of the lower travertine and all of the upper travertine in MIS 5c. This model was based on ^{230}Th/^{238}U mass spectrometry datings. Frank et al. (2000) found no evidence for travertine accumulation during MIS 5a, MIS 4, MIS 3, and MIS 2. However, it is obvious that travertine growth was not limited to MIS 5e, which poses major problems in terms of accurate and precise dating.

To complicate the situation even more, we have to discuss the so-called 'late Eemian aridity pulse' (Sirocko et al. 2005) in Central Europe during the Last Interglacial inception. This pulse was observed in an annually resolved, layer-counted record of varve thickness, quartz grain size, and pollen assemblages from a maar lake in the Eifel (Germany). This late Eemian aridity pulse (ca. 118,000 years ago) lasted 468 years and was characterized by dust storms, aridity, bushfires, and a decline of thermophilous trees at the time of glacial inception (Sirocko et al. 2005). The fact that this 'late Eemian aridity pulse' was driven by orbitally controlled insolation (Sirocko et al. 2005) immediately debunks, for instance, the hypothesis by Roebroeks et al. (2021: 7) that the distinct openness of the wider Neumark-Nord landscape (dated around 121±5 ka) was created by the Neanderthals who used fire to keep the landscape open. Roebroeks et al. (2021) are baffled by the 'openness' of the environment, as in their view, climatic conditions would have allowed closed forests. Weber (1920) had long ago suggested that the Neanderthals ignited fires to keep the landscape open. In our view, the open character of the Neumark-Nord vegetation can easily be explained in terms of climatic factors changes (e.g., gradual vegetation and faunal replacement, etc.), which allow us to conclude that the occupation of Neumark-Nord cannot be situated within the Eemian climax forests of MIS 5e, but fall most likely within the late Eemian aridity pulse (ca. 118,000 years ago).

The contradictory 'openness of the environment' has also been noticed by other researchers. Wenzel (2007) concluded that more than 80% of the datable deposits originated from the (relatively cool) first third of the Eemian *sensu stricto*. The chronological distribution of sites evincing the presence of Neanderthals—according to Wenzel (2007)—possibly reflects a deterioration of environmental conditions within MIS 5e. However, Wilcox et al. (2020) found that temperatures in the Swiss Alps were up to 4.3 °C warmer during the Eemian period than in our present-day reference period of 1971 to 1990. Climate instability, including an abrupt cooling event about 125,500 years ago, interrupted this thermal optimum, but temperatures remained up to 2.0 °C warmer than the present day (Wilcox et al. 2020). These findings are consistent with, for instance, Cheddadi et al. (1998), who claim that the estimated intra-Eemian temperature changes were certainly not as strong as those reconstructed for the MIS 6/MIS 5e termination or the MIS 5e–5d transition. These findings are again consistent with the constantly high ratio of tree pollen throughout the Eemian, indicative of a succession of temperate forest types. Cheddadi et al. (1998) claim that this gradual transition between different forest landscapes can be related to intrinsic competition between the species rather than to a drastic climatic change. Even Wenzel (2007) has to admit that the rarity of Neanderthal settlements in Germany dating to the last two-thirds of MIS 5e appears to be mirrored by an extremely weak Neanderthal signal in Northwest Europe.

Our current knowledge of the Eemian (MIS 5e) occupation of Northwest and Central Europe is based on only a few Middle Paleolithic sites that have been named above. The claim that travertine formation took place only during warm and humid 'interglacial' periods has been debunked many times (see, for instance, Frank et al. 2000). The correlation of these archaeological sites with the Eemian (MIS 5e) is mainly based on the composition of the associated faunal assemblages. However, the various Middle and Upper Pleistocene interglacial/interstadial periods are very difficult to distinguish from each other, based on the fauna alone (see, for instance, van Kolfschoten 1995). It is now becoming clear that the chronology of most of the so-called 'Eemian' sites is either poor or controversial (e.g., Jöris 2004; Mania 2002; Pastoors 2009; Veil et al. 1994), and that many of these alleged 'Eemian' sites are not well dated at all (Weiss et al. 2022).

We agree with Wenzel (2007) that more than 80% of the datable deposits originated from the (relatively cool) first third of the Eemian *sensu stricto*. We think that a Zeifen-age (MIS 6.01) deserves consideration, because many artifact bearing layers were found at the base of the travertine deposits. This is an important observation that was made earlier by Ložek (1961), who pointed out that as far as 'colder' type floral and faunal assemblages are found within Eemian sediments, they mostly seem to occur at the base of the travertine deposits.

We also would like to point to the specific problems concerning the chrono-stratigraphic position of the so-called 'Eemian' German lake sites: (1) Grabschütz, (2) Gröbern, (3) Lehringen, and (4) Rabutz. Indeed, Von Koenigswald and Heinrich (1999) excluded an Eemian age for the faunal assemblages from Grabschütz and Rabutz, because of the occurrence of *Apodemus maastrichtiensis*. This species of mouse is not unambiguously attested during the Eemian. As a result, an Eemian age seems not really possible. Mania (1999) has also pointed to the apparent differences between the floral composition and the mollusc associations from Rabutz and Grabschütz, and the floral assemblage and the mollusc associations from the more 'classical' Eemian sites like Taubach and Burgtonna. On the other hand, the stratigraphic setting of the Grabschütz and Rabutz sites is more or less identical, and quite similar to the one at Gröbern. The interglacial deposits of these sites were formed within a basin of Early Saalian glacial deposits (Mania 1999). Indeed, these glacial deposits seemed to refer to the Drenthe Glacial, which is the terrestrial equivalent of MIS 8. It is very likely that the sites of Steinmühle bei Veltheim, Grabschütz, Rabutz, and Gröbern should also be dated to the 'low sea-level' Intra-Saalian interglacial (MIS 7), which was apparently characterized in Central Europe by subcontinental, warm climatic conditions, in other words, less 'extreme' than the 'high sea-level' Eemian.

THE EEMIAN IN FRANCE

In Northwest France, only four archaeological sites have been attributed to the Eemian (Locht et al. 2016): (1) the site of Grossoeuvre (Lautridou and Cliquet 2006) has been found in a doline or sinkhole context; (2) the sites of Caours (Antoine et al. 2006) and (3) Waziers (Locht et al. 2014) were excavated in fine fluvial deposits; and, (4) the site of Montfarville en Anse de Quéry (Coutard and Cliquet 2005) was associated with a fossil beach. The distinctive feature of these different lithic industries (Locht et al. 2016) is the association of Levallois and discoidal debitage (e.g., Caours and Grossoeuvre).

Within the sinkhole at the site of Grossoeuvre (Lautridou and Cliquet 2006), two different occupation layers were present. The first occupation layer (Cliquet 2013) can be dated to MIS 7, and consists of heavily blunted artifacts in a secondary position. The second so-called 'Eemian' occupation layer (Cliquet 2013) was dated by thermoluminescence on heated flint to 130±8 ka. Furthermore, the Grossoeuvre lithic assemblage (Cliquet 2013) is characterized by an original production of micro-flakes (cf. VLL and VLB sites at Veldwezelt-Hezerwater) often obtained by the Levallois method. The retouched toolkit mainly comprises notches and scrapers.

The Middle Paleolithic site of Caours (Hauts-de-France) has traditionally been attributed to an Eemian age (Antoine et al. 2006). The site contains large numbers of Paleolithic flint artifacts and faunal remains. The Caours basal fluvial sequence (ca. 50cm thick) has been correlated to MIS 6 and MIS 5 (Antoine et al. 2006; Dabkowski et al. 2016). The tufa sequence is separated from the underlying periglacial alluvial gravels (MIS 6) by fluvial calcareous silts, overlain by a thin marshy soil and a thin peat layer. The lower part of the tufa includes several organic horizons that have yielded numerous large mammals and rodent remains. Within these horizons, several Middle Paleolithic layers have been discovered.

While Antoine et al. (2006) interpret the faunal remains of Caours as 'interglacial,' we would caution against drawing firm conclusions. The interpretation of Upper Pleistocene mammal assemblages is often hampered by taphonomic biases, and by the fact that mammals have the capacity to adapt to environments and tolerate circumstances other than those under which they live today, i.e., non-analogue communities/behaviors. The faunal remains at Caours (Antoine et al. 2006) are dominated by: (1) *Bos primigenius*; (2) *Cervus elaphus*; (3) *Dama cf. clactoniana*, and (4) *Dicerorhinus hemitoechus*. While *Bos primigenius* (van Kolfschoten 1995) originally inhabited the steppe, it later occupied meadows and open forests, which resulted in a more stationary behavior. *Cervus elaphus* (van Kolfschoten 1995) is also a highly adaptable species, and associated with many climatic (glacial and interglacial) and vegetational types. Moreover, its present-day restriction to deciduous and mixed woodlands is not typical at all. *Dama cf. clactoniana* (van Kolfschoten 1995) was characteristic of mature woodland, although it sometimes colonized coniferous plantations (provided these contain some open areas) as well. *Dicerorhinus hemitoechus* (van Kolfschoten 1995) inhabited the Mammoth Steppe, but they occurred in Northwest Europe in areas with an open vegetation during 'interglacial' phases as well.

While nobody disputes the Eemian age of the tufa above the archaeological layers at Caours, having a tighter age control on the four layers with Neanderthal artifacts underneath would help with its interpretation, and would help facilitate comparison to other sites in Northwest Europe. We would like to repeat the important observation made by Ložek (1961), who pointed out that as far as 'colder' type floral and faunal assemblages are found within Eemian sediments, they mostly seem to occur at the base of the deposits. This is also the case in Caours. The archaeological layers are situated at the base of the Eemian tufa. The old age of the archaeological levels at Caours is confirmed by the newly obtained ESR/U-series ages, which led to the calculation of a weighted mean age of 125±9 ka (Bahain et al. 2022).

The Neanderthal site at Waziers (Locht et al. 2014) was excavated in an area called Le Bas Terroir, located to the northeast of Douai in northwest France. The site is situated on a low-lying plain on the southeast border of the river Scarpe. Locally, fluvial deposits are present with peat and organic loam layers (ca. 1.2 m thick), at a depth of 3 meters below the current surface. Lithic artifacts and remains of aurochs were found in these peat layers. The site of Waziers was dated to the Eemian stage (MIS 5e), mainly because of the interglacial pollen present within the peat layers. The peat and organic loam layers are directly covered by aeolian loess, which can be dated to the Early Weichselian. Several bone pieces—mostly aurochs—that show evidence of butchering have been retrieved from the peat layers, scattered all over the excavated area (Hérisson 2016). Although aurochs (*Bos primigenius*) was often associated with a wooded habitat, it should be re-iterated that aurochs originally inhabited the steppe (van Kolfschoten 1995). The evidence of Waziers provides a very mixed picture, which makes it quite difficult to assign the site to a specific timeframe. The archaeological assemblages at Waziers may be accumulated and altered by multiple taphonomic agents through different processes. The newly established ESR/U-series chronology for teeth of Unit 4, with a mean age of 129±11 ka, represents the first numerical age estimate for these levels at Waziers (Bahain et al. 2022). We agree with Bahain et al. (2022) that this age confirms the attribution of Unit 4 to the Late Saalian glacial stage (MIS 6), but according to our interpretation, this age does not automatically allow the attribution of the overlying organic fluvial deposits and associated archaeological levels to the Eemian.

The Middle Paleolithic site of Montfarville en Anse de Quéry (Coutard and Cliquet 2005) was associated with a fossil beach. The artifacts were collected in the Eemian beach or in the gravel. The artifacts could only have an Eemian age on the condition that they were not eroded out of older formations. This makes the attribution to the Eemian quite questionable. Probably, these artifacts were not found in a primary context. We would like to draw attention to the fact that, in northwest France (Locht et al. 2016), virtually all Middle Paleolithic sites were discovered in loess-paleosol sequences. Why, then, were there no Eemian sites found in these loess-paleosol sequences?

AN EEMIAN NEANDERTHAL POPULATION COLLAPSE

One of the most important periods to understand the Neanderthal ecological niche in Northwest Europe is represented by the Eemian. Although clear evidence has emerged for the Late Pleistocene human occupation and use of the tropical rainforests of Southeast Asia by *Homo sapiens* from at least 50–45 ka (Roberts and Stewart 2018), it is nevertheless important to keep in mind that mid-to-high latitude full interglacial environments—such as in Northwest Europe—were probably only successfully exploited for the first time during the Holocene (Gamble 1986, 1995, 1999). It should come as no surprise that the Eemian climax forests in Northern Europe appear to have been 'green human deserts' (Gamble 1986), being less suitable places for food collecting as undergrowth vegetation would have been very sparse and diffuse. For now, we suppose that is safe to say that in Northwest Europe, interglacial broadleaf and moist climax forests were probably not really targeted by the Neanderthals, who may actually have preferred open, 'mosaic' environments.

It is clear that the Middle Paleolithic sites belonging to the Eemian (MIS 5e) are entirely absent from the Loess Belt in Northwest Europe. Still, there are a small number of sites in Northwest and Central Europe that some researchers have interpreted as 'Eemian.' However, these sites are found in localized stratigraphic contexts, which means that no stratigraphic control is possible over long distances. The small number of sites cannot be explained by a poor state of preservation (Speleers 2000; Tuffreau 2001). The main problem is that many of these so-called 'Eemian' sites are poorly defined stratigraphically, and are not well dated (Bringmans 2006; Weiss et al. 2022).

In our view, it is not sufficient to attribute a site to the 'Eemian' only on the basis of an alleged 'interglacial' fauna that may also be 'interstadial' (van Kolfschoten 1995). The fact that the pollen spectra indicate an Eemian age for the whole section does not automatically mean that the sites themselves, which very often seem to occur at the base of the deposits, must be dated to the 'Eemian'. The Eemian itself was not a monolithic block with a stable climate and a fixed vegetation. However, most archaeologists describe the vegetation over large areas only in generalized terms, which obscures the subtle differences between multiple climate zones in geographically confined areas (Nicholson 2017). But even in this situation, the majority of the floral and faunal remains excavated at these sites almost invariably point to the 'open character' of the landscape.

Rapid climate change altered ecosystems, causing a geographical redistribution of flora and fauna. Due to the scarcity of archaeological sites representing the Eemian, the effect of these events on the behavior of the Neanderthals in Northwest and Central Europe has been poorly understood. We believe that Neanderthal sites that can be safely dated to the Eemian are extremely rare, due to a drastic decline in the Neanderthal population. We further argue that on the European continent, during the Eemian (MIS 5e), the Neanderthal population largely collapsed, maintain-

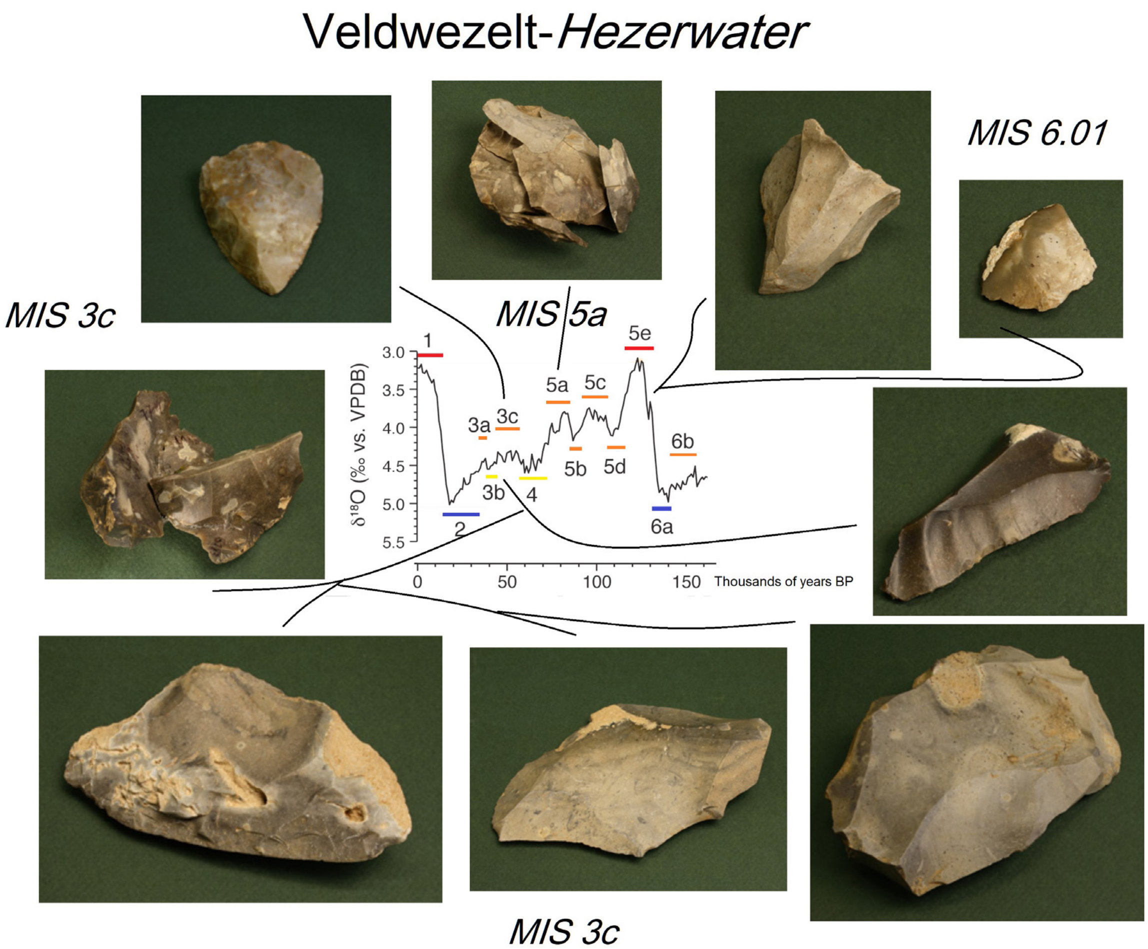

Figure 8. Sample tools and cores excavated at Veldwezelt-Hezerwater correlated with the Marine Isotope Stages. The inverted scale on the left puts higher temperatures and higher sea-level at the top, and lower temperatures and lower sea-level at the bottom. The central climate curve is derived from Figure 3 of Railsback et al. (2015).

ing itself only in a few regions. These results suggest that the Neanderthals in Northwest and Central Europe during the Eemian (MIS 5e) went through a genuine demographic crisis—a population bottleneck that severely reduced their numbers—leaving Northwest and Central Europe largely empty of Neanderthals until the onset of the Early Weichselian. It is also interesting to note that the inventory of the Middle Paleolithic sites attributed to MIS 5e in the southern half of France (Defleur and Desclaux 2019) also shows a population collapse during the Eemian period of global warming.

THE MAMMOTH-STEPPE AND MIDDLE PALEOLITHIC TOOLS

The Veldwezelt-Hezerwater evidence (Figure 8) shows that this part of Northwest Europe would probably have represented a very unfavorable territory during full glacial and full stadial periods. However, by adapting to the cool interstadial conditions of the open Mammoth Steppe (Guthrie 1982, 1990), Neanderthals successfully occupied Northwest Europe during the first half of the Middle Weichselian (MIS 3). Some of the longer interstadials were indeed sufficiently warm enough for Middle Paleolithic groups to repopulate and to survive at these more northern latitudes (e.g., TL and WFL sites). We assume that these interstadial occupation phases represent successful adaptations by Neanderthals to milder interstadial environments. Most of these sites could be interpreted as specialized and/or short-term camps of highly mobile foraging groups.

At Veldwezelt-Hezerwater, just as across the rest of Northwest Europe, narrow windows of opportunity for hunting terrestrial game during the relatively warm Middle Weichselian interstadials would make optimal tool performance really indispensable. Optimal tool performance was achieved primarily through the use of over-sized, highly specialized heavy-duty tools (Bousman 1993). Predictability and abundance of resources was key to the spatio-temporal and social organization of hunter-gatherer groups (Davies 2020). Risk-reduction strategies were, of course, the most useful (Torrence 1989). Risk is made up of both the probability of not meeting dietary requirements and the costs of such failure (Torrence 1989). Tools are usually the most effective objects for coping with risks that must be overcome in a short time-scale. Tools were chosen by Neanderthal hunters as a function of their ability to capture prey that was only accessible for short periods of time. Failure costs, and therefore the level of risk, increase toward the poles, because the availability of food decreases with longer winters (Bleed 1986; Davies 2020; Torrence 1989).

Peopling high latitudes and cold continental regions required overcoming significant climatic barriers (Whiting et al. 1982), which depended on technological means (e.g., the mastery of fire; adequate lithic toolkits). There seems to exist a significant linkage between Middle Paleolithic occurrences all over North Eurasia and the Upper Pleistocene Mammoth-Steppe (Bosinski 1963; Rolland 2010). It seems that the Upper Pleistocene Neanderthals in Northwest Europe were living in an open landscape, the so-called Mammoth Steppe (Guthrie 1982, 1990), where they were hunting cold environment animals, such as horse, reindeer, and mammoth. This hypothesis predicts an increase in the diversity of lithic tools during colder periods (Bocquet-Appel and Tuffreau 2009), in order to maintain carrying capacity. During the Upper Pleistocene, we see the full development, not only with the presence of Levallois technology, but especially with the presence of a panoply of Mousterian tools. Virtually all Neanderthal sites belonging to the Weichselian glacial period contain Mousterian tools.

Finally, there appears to exist a strange dichotomy (Di Modica et al. 2015) between open-air sites and cave sites in the Maas/Meuse Basin in Belgium. The last-known Neanderthal open-air site in the Maas/Meuse Basin—the MLMB site at Veldwezelt-Hezerwater—was occupied ca. 47 ka (Bringmans 2006). The cave sites in the Maas/Meuse Basin were inhabited by Neanderthals only between ca. 50 and 35 ka (Di Modica et al. 2015). If it is assumed that the frequency of Middle Paleolithic artifacts is an indicator of the intensity of human activity, the apparent 'shift' from open-air sites to caves in the Maas/Meuse Basin from 50 ka onwards could signal a much colder climate and a lower population density. In these circumstances, Neanderthals would prefer to stick to caves as much as possible (Bringmans 2015), because of the more stable temperatures of caves, which provided a relatively warmer and dryer shelter especially in winters. Karst landscapes are quite rare in Northwest Europe and are special parts of the natural environment because the micro-climate of the more sheltered valleys with cave sites could probably act as micro-refuges for food resources.

An extremely small Neanderthal population size during the second half of MIS 3 could be attributed to these harsh climatic conditions. During glacial periods (Astakhov 2008), the formation of ice caps/sheets requires both prolonged cold and precipitation in the form of snow. Despite having temperatures similar to those of glaciated areas in Europe, Asia remained largely unglaciated during the Weichselian, except at higher elevations. The asymmetry of the glacial history (Astakhov 2008) suggests a progressive aridification of the Eurasian North, with the result that during the first half of MIS 2 significant ice volumes could only accumulate along the Atlantic seaboard. The Neanderthals in Northwest Europe would have to survive in ever-smaller groups, becoming largely confined to caves. This would explain the near-absence of the Neanderthal signal in the archaeological record during the second half of MIS 3, just before they would leave Northwest Europe around 35 ka for good. We argue that during the cool and unstable second half of MIS 3, the Neanderthal population in Northwest Europe completely collapsed. The climatic oscillations in Northwest Europe altered the existing ecosystems causing major geographical redistributions of flora and fauna. This must have affected a vulnerable Neanderthal population, which was sensitive to climate change impacts, leading to periodic demographic collapses, as successive bottleneck events led to genetic weakness (e.g., Dalén et al. 2012; Hajdinjak et al. 2018).

CONCLUSION

The rapid changes in climate during the late Middle and Upper Pleistocene have deeply altered the successive ecosystems, causing major geographical redistributions of the flora and the fauna in Northwest Europe. The climatic challenges the Neanderthals had to face as new ecosystems and ecological communities formed, must have been colossal. One of the strategies with which the Neanderthals responded to these rapid changes in climate was the adaptation of their lithic toolkits according to local circumstances. Contextual factors (e.g., availability, size and quality of raw materials, mobility, anticipated tasks, flexibility, versatility, portability, reliability, etc.) seem to have constrained choice among lithic reduction options. Notwithstanding this, our approach considers Neanderthals—within certain limits—as flexible agents, rather than passive recipients of optimized environmental conditions. However, this does not mean that the Neanderthals in Northwest Europe did not have clear habitat preferences.

The data from Veldwezelt-Hezerwater show that the Neanderthals preferred interstadial, open mosaic or even steppe-like environments. The loess-paleosol sequences show that the Neanderthals shunned not only extremely cold and dry environments, but also extremely warm and wet environments. In Northwest Europe the oceanic effect—and the specific vegetation response to precipitation—must have led to dense climax forests during the Eemian that were largely uninhabitable for Neanderthals. The study of the Northwest European Loess-Soil Sequences has demonstrated that the most prominent paleosol in the Loess Belt is the so-called 'Rocourt Soil.' It is a massive soil, which represents the terrestrial equivalent of MIS 5e. It is an established fact that nowhere in Northwest Europe were Middle Paleolithic artifacts found in or on the paleosurface of the 'Rocourt soil'.

The interglacial deciduous forests in Northwest Europe during MIS 5e exhibited a high primary biomass predominantly represented by trees, vegetation, invertebrates, and non-mammalian vertebrates. The medium-sized ungulate biomass during the Eemian was much lower and more dispersed in contrast to the Middle Weichselian open steppe landscapes during the first half of MIS 3 where a rich pasturage favored cold environment animals, mammoth being the most typical representative. This open steppe biotope in the north is opposed in the south by the hot and dry

Mediterranean climate, which resulted in the typical Mediterranean vegetation types, that can range from forests to woodlands, and from shrublands to grasslands, but where also 'mosaic landscapes' were quite common.

It seems that the Neanderthals in Northwest Europe always tried to avoid the high-risk, cold glacial environments as well as the full interglacial environments as much as possible. This last statement may seem a little strange, but heavily forested high-risk environments were not the Neanderthals' favorite biotopes, because they depended for a great deal on big game at higher latitudes, which was not available in great numbers in dense interglacial forests. Nevertheless, use of a broader spectrum of animals in the Mediterranean, including marine resources and plant foods, indicates dietary breadth.

However, in Northwest and Central Europe, the weakness or total absence of the Neanderthal signal in the archaeological record during certain time periods can neither be explained by research bias nor by taphonomic issues. On the contrary, supportive evidence was found for several presumed environmental determinants. We believe that it is safe to say that (1) during the climatic optimum of the Eemian (MIS 5e), but also (2) during the cold second half of MIS 4 and (3) during the cool and unstable second half of MIS 3, the Neanderthal population in Northwest Europe completely collapsed. The data suggest that during the Late Pleistocene in Northwest Europe, the Neanderthals went through a series of acute demographic crises. These population bottlenecks severely reduced Neanderthal numbers—leaving Northwest Europe largely empty of Neanderthals.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in LIRIAS at https://lirias.kuleuven.be/handle/1979/270, reference number LIRIAS1736443.

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