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Deciphering the complexity of a ‘simple’ mesolithic phenomenon: Indicators for construction, use and taphonomy of pit hearths in Kampen (the Netherlands)

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ABSTRACT

Pit hearth features form a common phenomenon in the Mesolithic of North-West Europe, and the Netherlands and adjacent parts of Germany and Belgium in particular. Using soil micromorphology, we investigated the genesis and taphonomy of several pit hearth features, embedded in sandy podzolic soils from Kampen (the Netherlands). This is one of the first studies to investigate one of such pits in its entirety, instead of only the lower, charcoal-rich fill. Our results show that the upper fill of these pits contains considerable amounts of non-charred degraded organic matter. The lower fill typically contains fragments of charcoal and some wood tar, but also black coatings around sand grains, that is interpreted as charred humus from a podzol B-horizon. These coatings indicate that material from the upper horizons of a podzol profile – e.g. in the form of turves – was used to control a fire on the floor of the pit.

Fine charred material postdepositionally leached from the pit feature into the underlying deposits, associated with increased formation of limped clay coatings. This indicates that ash-induced alkaline charcoal degradation and associated clay translocation played a role in this process. The Kampen case provides strong evidence that fine charred organic material may contaminate underlying archaeological or sedimentary units.

1. Introduction

1.1. Research aim

Pits with a lower fill that is rich in charred organic material are the most common soil features in specific areas in the Mesolithic of northwest Europe. They are colloquial known as “hearth pits” or “pit hearths”. The majority (> 100 sites) is known from the sandy soils of the Netherlands and adjacent parts of Belgium and Germany (Peeters and Niekus, 2017), although several sites have been reported recently from France (Achard-Corompt et al., 2017) (see Fig. 2). They seem to be unknown, however, from Scandinavia and the British Isles. An overwhelming majority of sites with pit hearths occurs north of the River Rhine (Fig. 1). Pits occur as isolated features, in pairs or triplets and in larger concentrations of tens to hundreds. (Niekus, 2006, 2011; Peeters and Niekus, 2017; Peeters et al., 2017). Despite the fact that these features are known for decades and much research has been carried out since the pioneering work of Groenendijk (1987), the debate on their

formation is continuing (e.g. Crombé et al., 2015; Peeters et al., 2017). In the present study, we use soil micromorphology to derive information on the formation, use and taphonomy of pit hearths, contributing to discussion on their (intended) use.

1.2. Characteristics and use of mesolithic hearth pits

Pit hearths are generally described as typically U-shaped in cross section, more or less circular in plane view and a diameter between 60 and 110 cm at the top. The depth ranges from 50 to 90 cm. Their fill is rich in charred material, which can include large fragments of carbonized wood – sometimes even tree logs arranged in a centripetal pattern on the pit floor – and fragments of wood tar. Other materials, such as flint (microliths in particular), cooking stones or ‘potboilers’, charred hazelnut shell fragments, or bone are sometimes encountered (Peeters and Niekus, 2017).

A traditional view is that these pit hearths had some function in food preparation (e.g. Groenendijk, 1987). Although Perry (1999) did

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Fig. 1. Known sites with Mesolithic pit hearth features (site locations from Peeters et al., 2017, supplemented with Crombé et al., 2015).

recover plant remains, recent targeted research, was unable to identify a significant presence of botanical food indicators, apart from slightly higher numbers of charred hazelnut shells in some cases (Peeters and Niekus, 2017). More recently, researchers have argued that pits could have been used for the production of charcoal or wood tar. Macroscopical observations of wood tar fragments, as well as physico-chemical analyses that identified wood tar in several pit fills from the Netherlands have supported their use for tar production (see Peeters et al., 2017 for an overview). Here, however, a serious caveat is that wood tar may be a non-intentional by-product of another use in which oxygen-starved fires were needed - e.g. for (slow) cooking of plant or animal foodstuffs or smoking. It is also important to keep in mind that different pits may have been used for a range of activities.

Most recently, a hypothesis has been put forward that these features are in fact of natural origin, being the burnt remains of ant nests. It is proposed that wildfires would cause these nests to burn and leave behind a burrow filled with charred vegetative remains and sand due to subsequent sedimentation processes. The authors support this with interpretations of chemical analyses and ^{14}C dates and several contextual arguments (Crombé et al., 2015; Crombé, 2015).

This theory is not broadly accepted, and is still under discussion. Peeters et al. (2017) have provided ample arguments for an anthropogenic origin of the majority of the pits, which include evidence for digging activities, observations of straight pit walls, presence of charred logs, non-random artefact ensembles, and evidence for in-situ fire. In the present study, we support an anthropogenic origin of the pits, but do not intend to extensively discuss the ant nest theory at this point.

1.3. Challenges in pit hearth research

One major challenge in pit hearth research is that their upper fill is commonly hard or impossible to discern. The charred remains are

Fig. 2. Plan of the excavation, showing the distribution of pit hearth features as well as a dwelling structure. The sampled features are indicated. Note that some of the features are affected by sub-recent damage of linear North-South oriented drainage channels.

Fig. 3. Profile with pit feature 75 and samples. The natural profile shows the normal horizon sequence of a podzol, i.e. from base to top: C (base of section and parent material), Bh (altered parent material with illuviated humus), AE (eluviation horizon and topsoil). The feature is U-shaped, with a very dark, charcoal-rich base layer and a dark brown upper fill that is similar in colour to the Bh-horizon. Tree root casts that disturbed the profile are indicated. Thin illuviation bands (fibres) are shown with broken lines. In the C-horizon, the fibres underneath the pit feature are thicker and contain thin black lines. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

usually concentrated in the lower part of the fill, and contrast well with the surrounding clean yellowish-white sandy sediment. The top fill, however, coincides with the light podzol-E and dark B horizons, common in the poor sandy soils. Consequently, the pit features are hardly visible in the B horizon, if at all, and are only recognized once

Fig. 4. Drawings and field impressions of the sampling of features 22, 26 and 27 (pit 515). Broken line is the surface of the excavation pit.

the B or BC horizon is removed after mechanical stripping. As a result, the upper part of features (and the Mesolithic soil surface with, if any, associated artefacts) are usually removed with the overburden. What we know about these features is therefore almost exclusively based on the lower fills.

Many pits show evidence for bioturbation, which may have obscured feature edges (Huisman and Deeben, 2009), and fragmented the charred remains in the pits (Huisman et al., 2013). In addition, fragmentation of charcoal may in theory also have occurred if charred material became buried in the pits together with ashes, because the alkalinity of ashes may cause disintegration processes in charred material (Huisman et al., 2012, 2013). Fragmentation may further be due to mechanical disturbance – resulting in mixing and compressing mixtures of sand and charcoal – during extraction of some kind of matter by humans or clearing out pits for re-use.

In order to get a better grip on the nature of these enigmatic pits hearth features, it is therefore necessary to study complete profiles in undisturbed sections. Multi-proxy approaches are needed to develop deeper insight into the processes that led to initial formation of these features (a *chaîne opératoire* of pit hearths), as well as subsequent post-use processes of transformation, be it natural or anthropogenic.

As a first step towards a better understanding of the characteristics of these features, we sampled and analysed four “pit hearths” that were discovered during the excavation of a Mesolithic site complex at Kampen-Reevediep (The Netherlands; Geerts et al., 2018). Positioned on the slope of a Late Glacial coversand dune, the surface became buried by peat – probably during the Bronze Age or Iron Age – and later by medieval fluvial sediments.

A long section cutting through the soil and sediment sequence permitted to investigate one pit (feature 511.75) in its entirety, as here the upper part had not been removed with the overburden. We took a series of samples to characterise the various components of the pit and the surrounding parent material in order to (1) characterise the charred material, (2) study relationships between initial pit formation and soil processes and (3) identify evidence for human and/or biological activity. In addition, we took a series of samples right next to the pit feature to characterise soil formation processes outside and at some distance of this particular pit. The lower fill of three additional pits was sampled in order to assess to some extent the variability between the pits, and to evaluate the representativity of the pit in the long section.

2. Materials and methods

2.1. Feature characteristics

In the long section, the buried “natural” soil profile next to the pit

Table 1
Sample list.

Sample code	Feature	Description feature	Field observations
4062	515.27	Lower fill	Black sand with charcoal fragments
4063	515.27	Transition upper to lower fill	Grey sand overlying black sand
4065	515.26	Lower fill	Black sand with charcoal fragments
4066	Natural	C horizon below pit 26	Mottled sand with fibres
4263	515.22	BC next to pit 22	Light grey to light brown mottled sand
4264	515.22	Lower fill	Black sand with charcoal fragments
4265	Natural	AE horizon in top feature 75	Grey and with black mottles
4266	511.75	Transition AE horizon to upper fill	Grey sand, overlying dark brown sand
4267	511.75	Upper fill	Dark brown sand
4268	511.75	Upper fill	Dark brown sand
4269	511.75	Transition dark-brown to black fill	Dark brown sand overlying black sand
4270	511.75	Lower fill	Black sand with charcoal fragments
4271	511.75	Transition lower fill to C horizon	Black sand overlying very light brown sand
4272	Natural	C horizon with dark root fill	Very light brown sand with brown and black fibres
4273	Natural	C horizon	Very light brown sand with brown and black fibres
4274	Natural	C horizon	Very light brown sand with brown and black fibres
4275-B	Natural	AE horizon	Light grey mottled sand
4275-M	Natural	B1 horizon	Brown mottled sand with black fibres
4275 -O	Natural	B2 horizon	Brown mottled sand
4276-B	Natural	B2 horizon	Light brown sand
4276-M	Natural	C horizon	Light brown mottled sand with brown fibres
4276 -O	Natural	C horizon	Very light brown sand with brown fibres

Table 2
¹⁴C dating results on charcoal from the investigated pit features.

Pit feature	Wood species	Labcode	Uncalibrated 14C	Calibrated 14C date (95,4%) cal yr. BP
515.22	Pine	Poz-93498	7650 ± 50 BP	6595–6430
515.26	Pine	Poz-93495	7720 ± 50 BP	6641–6467
515.27	Pine	Poz-93496	7730 ± 50 BP	6644–6470
511.75	Oak	Poz-93493	6080 ± 40 BP	5206–4847

Feature 511.75 (Fig. 3) can be classified as a typical humus podzol. A sequence of A, AE, Bh (divided in darker upper Bh1 and lighter lower Bh2), BC and C horizons were distinguished in the field. Few fibres are present in the Bh2-and C-horizons. Multiple tree root remains could be recognized in the lower part of the C-horizon. The Mesolithic pit, measuring c. 150 cm (diameter) by c. 50 cm (depth) in the cross-section has a bowl-shaped bottom. The lower c. 20 cm of the pit fill consists of black, charcoal-rich material. The upper fill consists of deep brown fine sand, with a few thick, extremely dark illuviation bands (“fibres”). An E-horizon has developed in the upper part of the feature, contingent to the same horizon in the natural soil profile. The E-horizon seems to sink at both edges of the pit feature, but it is unclear whether this is accidental – a result of the wavy boundary between E- and Bh1-horizons – or related to the actual pit feature. The C-horizon below the pit is lighter in colour than in the adjacent soil profile, giving the sand a

bleached appearance. The dark brown fibres in the C-horizon below the pit, however, are thicker than in the surrounding soil material, and incorporate thin black lines which are absent in the natural soil profile.

Features 515.22, 515.26 and 515.27 (Fig. 4) are among the large group of pit features uncovered after the mechanical removal of the Bh-horizon during excavation, and are thus “decapitated”. The remnant lower parts of these features include a charcoal-rich layer on the bowl-shaped pit bottom.

2.2. Sampling

Pit 511.75 was sampled extensively in order to characterise the various subzones within a completely preserved profile and the associated soil characteristics, as well as the “natural” soil profile next to this pit feature (see Table 1 for an overview of samples). This allows for a thorough study of pit formation and its interaction with soil properties and soil forming processes. The pit fills were targeted to assess the variability in properties, especially where it concerns the charcoal-rich bottom fill, and the parent material. From pit features 515.22, 515.26 and 515.27, one sample was taken from the lower fill or, in the case of feature 515.27, of the transition from upper to lower fill. Samples were taken in 6 × 9 × 2.5 cm aluminium boxes (“Kubiena tins”) that were pushed into the profiles. The natural profile next to pit feature 511.75 was sampled using two 10 × 50 × 10 cm soil monolith tins. They were subsequently subsampled in the lab, using Kubiena tins as well.

Fig. 5. Plot of the ¹⁴C dating results, calibrated with OxCal version 4.3.2 (Bronk Ramsey, 2017) with the IntCal13 curve (Reimer et al., 2013).

Table 3
Summary of key micromorphological observations. -: not present; (+): single or sporadic presence; +: present - common; ++ dominant - abundant. Pyr. = pyrite; Feox. = iron oxides.

Sample code	Unit	Feature	Field identification	Micro-features	Non-carbonized organic material				Carbonized remains				Distributions	Remarks
					Roths				Fungal				Charred	
					Polymorphic organic matter				Humus coatings				humus coatings	
					Fungal hyphae				Sclerotia				Other charred materials	
					Fungal tissue				Organic tissue				Wood charcoal	
					Wood tar				Fragmented charcoal					
4275-B	Upper part	Natural	AE horizon		+	+	+	+	+	+	+	+	+	Gradual transition to lower part
	Lower part	Natural	AE horizon			+	+	+	+	+	+	+	+	Gradual transition to upper part
4275-M		Natural	Bh1 horizon	Pyr.	(+)									Humus coatings form band
4275-O		Natural	Bh2 horizon	Pyr., Fe ox	+				+					
4276-B		Natural	Bh2 horizon	Pyr., Fe ox	+				(+)					
4276-M		Natural	C horizon	Pyr., Fe ox	+				(+)					
4276-O		Natural	C horizon	Pyr., Fe ox	+				(+)					
4265	Upper part	Natural?	AE horizon in top feature	Pyr., Fe ox		+	+							(+)
	Lower part	Natural?		Pyr.		+	+		(+)	(+)	(+)			
4266	Upper part	75	Transition AE horizon to upper fill			+	+							
	Lower part	75	Upper fill	Fe ox	+	+	+		(+)	(+)	(+)			
4267		75	Upper fill	Fe ox	+	+	+		+	+	+	+	+	Charred humus distribution heterogeneous humus coatings in top; charred humus irregularly distributed
4268		75	Upper fill	Fe ox	+	+	+		+	+	+	+	+	4 with humus fill
4269		75	Transition dark-brown to black fill						(+)	(+)	(+)	1	1	Sclerotia2 fine
4270	Upper part	75	Lower fill		(+)									1 Sclerotia
4271	Lower part	75	Lower part fill											Lower boundary feature mottled
4272		Natural	C horizon											
		Natural	C horizon with dark root fill											
4273		Natural	C horizon	Clay coatings					(+)					Charred material most common in top of sample
4274		Natural	C horizon	Clay coatings					(+)					Powdered charcoal forms band on clay coatings
4062		27	Lower fill	Clay coatings	(+)				(+)					Powdered charcoal heterogeneously distributed

(continued on next page)

Table 3 (continued)

Sample code	Unit	Feature	Field identification	Micro-features	Non-carbonized organic material	Carbonized remains	Distributions	Remarks
4063		27	Transition upper to lower fill	Humus-iron-clay comp-lexes	+	+	+	Carbonized remains heterogeneously distributed
4066	Top and right side	26	Lower fill		(+)	+	+	
	Lower side	Natural	C horizon below feature					
4065	Left side	26	C horizon below feature		(+)	(+)		
4263		22	BC next to pit	Pyr., Fe ox	(+)			
4264		22	Lower fill			+	+	

2.3. Sample preparation

All samples were dried at 40 °C/104 °F and impregnated with acetone-diluted polyester resin, and gamma irradiated to harden the resin after evaporation of the acetone. Thin sections were made by mounting a sample on a glass base plate, lapping and polishing it to 25–30 µm thickness and attaching a cover slip. Thin sections were scanned using a flatbed slide scanner for the purpose of general description, and studied in detail using a Zeiss Axioskop 40 polarizing microscope with magnifications of 25–1000x and mounted MRC5 digital camera.

2.4. Radiocarbon dating

All four pits were sampled for ¹⁴C dating. Single charcoal lumps were selected and macroscopically studied for tree species identification prior to submission. The samples have been dated at the radiocarbon facility at Poznan.

3. Results

¹⁴C dating on charcoal from the four sampled pits are presented in Table 2 (Geerts et al., 2018) and Fig. 5. Pit features 515.22, 515.26 and 515.27 have age ranges, mostly overlapping, between 6595 and 6430 cal BC. However, with dates between 5206 and 4847 cal BC, pit feature 511.75 is significantly younger, and is among the youngest known pit features at this site, as well as in general for this type of feature.

An overview of the key micromorphological observations is given in Table 3. The parent material of the natural soils and features consists of Late Glacial (and Early Holocene?) coversands. The presence of framboidal pyrite and its oxidation products in some samples could be attributed to Medieval or later marine influence in the area.

3.1. Natural soil profile

The C horizon – corresponding to the base of the soil profile, and forming the parent material - contains very thin discontinuous yellowish coatings of organic material and clay on the sand grains (Fig. 6A). The horizontal fibres that were observed macroscopically in the deeper deposits at the level of sample 4276O could not be discerned microscopically. Apparently, the macroscopically visible slight increase in the thickness of the fibres is too limited to be discerned microscopically in the thin sections. Humus coatings are present on sand grains in the lower part of the AE horizon, and in the Bh1, Bh2, BC and C horizons. In the Bh1 horizon (sample 4275M) these coatings are particularly thick especially at the transition towards the AE horizon. In some cases they are present in recognizable horizontal bands. In the other horizons, the coatings are thin and discontinuous, except in the Bh2 horizon where some domains occur with slightly thicker and continuous humus coatings. They sometimes contain small fragments of degraded organic matter in the pore space (Fig. 6B and C). Fungal hyphae and *sclerotia* (fungal fruiting bodies) are also locally present, e.g. in sample 4275O. The AE horizon contains considerable amounts of strongly degraded organic matter (“raw humus”) with some less degraded tissue fragments, as well as humus coatings (sample 4275B, upper part; see Fig. 6D and E) which we classified as polymorphic organic matter *sensu* Buurman and Jongmans (2005); see also discussion in section 4.1. These samples also contain ample evidence for fungal activity.

3.2. Pit feature 511.75

The samples from pit feature 511.75 can be divided into three groups: lower fill, upper fill, underneath pit feature.

Fig. 6. Micrographs from the “natural” soil profile next to pit feature 511.75 from base to top. A: Sand grains with few, discontinuous humus coatings (some examples circled) on some of the grains in the C-horizon (sample 4276 M). B: Thin, continuous humus coatings in B2-horizon (sample 4275 O). C: Discontinuous light brown humus coatings (arrows point to examples) and scattered dark brown to black degraded organic fragments (examples circled) in B2-horizon (sample 4275 O). D: Polymorphic organic matter, containing continuous humus coatings, dark degraded organic material (e.g. D) and some tissue fragments (e.g. T) in transition from B1- to AE-horizon (sample 4275 B). E: Dark degraded organic matter with little or no humus coatings in AE-horizon. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.2.1. Lower fill (samples 4269–4271)

The samples contain large amounts of charred remains. The larger fragments are oak charcoal. Some fragments are large and well-preserved (Fig. 7A), but others appear degraded after they were charred: some fragments have sharp, irregular outer edges whereas other fragments are rounded and have an opaque outer rim (Fig. 7B). A few charred fungal *sclerotia* were also identified in samples 4269 and 4270 (e.g. Fig. 7C). The overlarge majority of charred material, however, has a morphology very similar to humus coatings (Fig. 7D), raw humus, or polymorphic organic matter (Fig. 7E). This material is therefore interpreted as carbonized soil organic matter, that formed due to heating of material from soil horizons – e.g. fragments of Bh-horizon.

3.2.2. Upper fill (samples 4265–4268)

These samples contain considerable amounts of non-charred degraded organic matter comparable to the polymorphic organic material in the upper part of sample 4275B (Fig. 8 A, B). Humus coatings occur in most samples; in sample 4267 they are particularly thick. The top samples 4265 and 4266 are almost devoid of any carbonized remains, but in samples 4267 and 4268 wood charcoal fragments – often small and rounded – are common. Moreover, some humus coatings in these samples contain scattered fine charred fragments (Fig. 8C), but domains with completely charred humus coatings occur as well (Fig. 8D). A few charcoal fragments have humus illuviated into their cells.

Fig. 7. Micrographs from the lower fill of feature 511.75. A: Oak charcoal (sample 4269). B: Small charcoal fragment with recognizable cell structure, combined with thick opaque outer rim (sample 4270). C: Charred sclerotium (sample 4269). D: Charred humus coatings (sample 4268). E: Charred polymorphic humus (sample 4270).

3.2.3. Underneath the pit feature (samples 4271, 4273, 4274)

Samples from the deposits underneath the pit feature do not show the thin coatings present in the natural soil profile. They do, however, contain small fragments of charred material that are scattered throughout the groundmass. This is mostly powdery material (Fig. 9A), but some slightly larger charcoal fragments are present as well (Fig. 9B). Sample 4272 contains higher amounts and larger charcoal fragments, but they have probably been displaced by tree roots. The fibres that were observed macroscopically are also clearly visible in the samples: they consist of bands with limpid coatings of illuviated clay that gradually change into bands of fine black (presumably charred) material upwards (Fig. 9C and D,E). It is remarkable that apparently continuous fibres can grade laterally from hardly detectable humus coatings in the natural profile to thick bands of illuviated clay and charred remains in deposits underneath an anthropogenic pit feature.

3.3. Characteristics of the “decapitated” pit features

The samples from the other three pit features (samples 4062, 4063, 4065, 4066 4263, 4264 from pits 515.22, 515.26 and 515.27) cover mostly the lower, dark, charred-material rich deposits and the transition to the natural soil profile. In one case (sample 4063, feature 515.27) the sample contains the transition from upper to lower pit fill, but from the other pits only the lower fill is available in thin sections. The samples from the pit fills contain a combination of charred material similar to the samples from pit feature 511.75 (wood, humus). The main difference is that the wood charcoal fragments are of pine instead of oak (in pit feature 511.75). In addition, the samples from pit 515.27 – especially 4062 – contain in some cases larger fragments of fragmented but articulated charcoal, suggesting *in situ* fragmentation (Fig. 10 A, B). These contain, or are fused or associated with black opaque vesicular

Fig. 8. Micrographs from the upper fill of feature 511.75. A: Polymorphic organic matter, with humus coatings and darkened modern-like material (sample 4266). B: Fungal hyphae among degraded organic matter (sample 4266). C: Humus coatings with (black) charred fragments (sample 4267). D: Fragment of wood charcoal with illuviated humus in the cells (sample 4267).

masses, which are interpreted as fragments of wood tar (Fig. 10B and C,D).

The samples from the natural soil profile around pit features 515.22, 515.26 and 515.27 can be directly compared to the samples from the “natural profile” described above (i.e. next to pit feature 75) the 4275 and 4275 samples. Humus coatings are found in the upper fill of pit feature 515.27 (sample 4063), as well as – combined with some fungal indicators – in the soil next to pit feature 515.22 (sample 4263). The soil horizon beneath pit feature 515.26 (samples 4065, 4066) contains low amounts of minute charcoal fragments, similar to those found in the horizons under pit 511.75.

4. Discussion

4.1. The natural soil profile

Podzols, like the one encountered at Kampen, typically belong to environments with poor nutrient status and limited soil fauna activity. Traditionally, the formation of podzol profiles was thought to entail the eluviation of dissolved organic matter, together with Al, Fe –humus complexes and Al silicates, forming an ash-coloured bleached E-horizon, and their precipitation below it, forming a Bh-horizon. In this model, Bh-horizon organic matter is typically dominated by illuviated organic matter. Adaptation of this theory, based on soil micro-morphology and organic matter dynamics, indicate that well-drained podzols typically have dominantly root-derived “polymorphic” organic matter in their Bh-horizons, i.e. organic matter in various stages of decomposition from tissue to amorphous humus. Complexation with Al and Fe stabilizes the various organic matter forms. Eluviation of Al and Fe from the E-horizon would remove this stabilization and promote the biological breakdown of the organic matter, resulting in the bleached appearance of the E-horizon. Only very poor and hydromorphic podzols have B-horizons that are dominated by illuviated humus (“monomorphic” organic matter) in the form of (cracked) humus-coatings around sand grains. Most podzol profiles lie between the extremes, and show combinations of polymorphic and monomorphic organic matter (Buurman and Jongmans, 2005).

The Kampen profile combines polymorphic and monomorphic organic matter. The thin humus coatings in the deeper part of the natural

profile are probably the remains of decayed root organic matter, complexed with Al, Fe and – possibly – minor amounts of clay. The top of the Bh1 horizon and the transition to AE are dominated by monomorphic humus coatings, indicating a predominance of illuviated amorphous organic matter. Some polymorphic organic matter is still present throughout the profile, indicating that contribution of root organic matter to the organic matter in the Bh horizons cannot be neglected. The top of the AE horizon shows polymorphic matter that probably has to be interpreted as remnants of a buried litter layer.

4.2. Pit feature characteristics

Two of the results of the analyses on the pit features are remarkable and significant. The first is that the upper part of the pit, in contrast to the natural profile, contains considerable amounts of non-carbonized degraded organic material. This material is comparable in composition to the top of the AE horizon in the natural profile, but it occurs on the depth of the B-horizons. The ubiquitous presence of fungal hyphae and sclerotia point to decay processes, which continued after burial of this organic material, whereas humus coatings are related to (continuing) podzolisation processes after burial. It is possible that the organic material became buried as fresh tissue, and only degraded after deposition. However, it is also possible that the material was already in an advanced state of decay when buried, e.g. consisting of topsoil litter from the surroundings.

The heterogeneity of the soil material in the upper part of the pit could in theory have several causes. Bioturbation, caused by tree roots or macrofauna in particular, may produce heterogeneous ground masses. However, this would also have resulted in mixing of the upper and lower pit fill, or at least in clear disturbances in the boundary between these two fills. Natural sedimentation in the pit would have resulted in sedimentary layering of sand and organic material – which is absent in this profile. Destruction of layering by bioturbation would also have obliterated the pit feature boundaries. If sedimentation would take so long that layering did not form, the lower pit fill would have been much more affected by soil forming processes. Therefore, the most likely explanation is that the pit was actively filled in by humans.

The second significant observation concerns the fact that the charred remains in the lower pit fill for the most part consist of

Fig. 9. Micrograph from the profile underneath feature 511.75. A: Small illuviated charred fragments (sample 4271). B: Illuviated wood charcoal fragment (sample 4272). C-E: sequence through fine illuviated band (sample 4273): yellow ovals indicate birefringent clay coatings in XPL image: C: Clay coatings at the base. D: Clay coatings, with superimposed dark-grey to black fine charred material, in the centre. E: Dark-grey to black fine charred material without clay coating at the top. F: Close-up of dark-grey fine charred material. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

carbonized humus-coated sand and humus, rather than charred wood or non-woody plant tissue. The black cracked coatings (Fig. 7 D) are similar in morphology to the non-carbonized humus coatings in the natural profile (Fig. 6C), whereas the morphology of the intergranular charred material (Fig. 7E) is similar to that of the degraded material in the AE horizon (Fig. 6 D,E) and in upper pit fill (Fig. 8A). Together with the charred sclerotia (Fig. 7C), they form indications that this material was already partially decomposed - by saprophytic fungi and other soil life - when it became carbonized.

The presence of charred humus – and sclerotia – indicate that the lower pit fill mostly consists of charred topsoil material, especially from the AE and Bh1 horizons. Apparently topsoil material was put on purpose on the bottom of the pit once dug, and subsequently got charred

when a fire was lit. The homogeneity of the distribution of charred coatings in the lower fills – especially in pit 511.75 – is not in line with digging and partial backfilling: this should have resulted in heterogeneous soil masses, with aggregates from A, AE, Bh1 and Bh2 horizons. It rather indicates that the pit bottom was lined with soil material from the upper soil horizons only. We hypothesize that the Mesolithic users collected topsoil turves as part of the pit hearth technology. Such turves might e.g. have been used to control (“bank”) the fire to produce smoke, charcoal or tar, or to cover food that was slow-cooked beneath a fire or ash layer.

It is remarkable that all sampled pits show evidence for humus carbonization, despite 1500 years of age difference between the oldest and the youngest pit. Spek et al. (1997, 1999) also found charred

Fig. 10. Charcoal and wood tar from the lower fill of pit feature 515.27 (sample 4062). A: Pine charcoal. The yellow oval indicates a fragment of dense tar with a cracked surface. B: Pine charcoal, fragmented *in situ*. The yellow oval indicates an area where the relatively large charcoal is broken into sub-mm fragments. C: Extremely vesicular wood tar. Note remnants of the pine cell structure on the left side of the fragment. D: Moderately vesicular wood tar sandwiched between charcoal with recognizable pine structure. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

humus coatings in thin sections from Mesolithic pits at the site of Hoge Vaart-A27. Humus carbonization may be a common characteristic in Mesolithic pit features. Further research is needed to establish to what extent charred humus is ubiquitous in Mesolithic hearth pits, and to further investigate the potential applications of topsoil material for pyrotechnological goals.

4.3. Taphonomic processes

Previous research has shown that charcoal is susceptible to disintegration in the alkaline environment that is formed when ashes are buried in the soil (Braadbaart et al., 2009). Field studies by Huisman et al. (2012, 2013); Slager and van de Wetering (1977) in loess have demonstrated that this alkaline charcoal degradation can be associated with clay translocation, which produces reddish limpid clay coatings. In the Kampen pit-fill thin sections, some of the charred remains appear to have been affected similarly, especially in view of the frayed edges of some fragments, and accumulations of fine charcoal powder on the outside of other fragments (see Fig. 7). The horizons underneath the pits are also clearly affected by these processes: macroscopically, the Bh2 horizon underneath the pit is of a much lighter colour than in the natural profile, and it has a bleached appearance. In the thin sections,

we see that the thin coatings on the sand grains, which were present in the natural profile, are absent underneath the pit. Deeper down in the profile, limpid, reddish clay coatings have formed underneath the pit as well. Moreover, fine black charred material occurs throughout the bleached Bh2 horizon, to form a typical powdery, concentration in the top of the clay fibres. Fine, eluviated charred material and clay coatings with fine powdery charcoal were also observed underneath a Mesolithic pit feature by Louwagie and Langohr (s.d.). All these effects concur with a process wherein ash-derived alkalinity causes disintegration of charred material which is subsequently translocated together with the little clay that is present in the soil material.

4.4. Implications

Our micromorphological observations on the Kampen pit hearths have several important implications. Firstly, the results indicate that the fire in the pits may have been controlled by using topsoil material, probably turves. The fires may have been intended e.g. to produce tar, or for food preparation – or a combination of these. Secondly, the results from hearth pit 511.75 stress the importance of the upper fill in pit hearths – a fill that is often less visible and (maybe therefore) largely neglected. In this case, the pit seems to have been intentionally filled

with material that was rich in non-charred organic material. At present, we can only guess at the reason. More detailed investigation and recording of the distribution of the various types of charred remains within a pit would be needed to determine e.g. whether pits were usually re-opened to extract products (e.g. tar, food products) and how the turves were placed into the pits and relative to the fire. Finally, our results, and those of Louwagie and Langohr (s.d.) show that ash-induced alkaline disintegration and eluviation of fine charcoal fragments can lead to contamination of pristine deposits by fine charred material. These fragments seem to be too small to appear in anthracological samples or be used for ^{14}C dating. However, they could still give false indications of (anthropogenic) vegetation burning based on micro-charcoal occurrences.

5. Conclusions

Micromorphological research on four Mesolithic pit hearths have indicated that:

- Use of these pits involved a fire that was controlled by using topsoil material, most likely in the form of turves.
- The fires were systematically oxygen-starved, probably at least partially due to the application of turves, and therefore may have been used for the production of wood tar or for smoking foodstuffs or other materials. Other forms of food processing or preparation, however, or a combination of uses cannot be excluded.
- After use, the pits were filled with an organic-rich material. This may have consisted of litter – which may imply that topsoil material was dumped into the pit - or it may have contained fresh organic matter that decayed into humus afterwards.
- Ash-induced alkalinity caused disintegration of charcoal, eluviation of clay and fine charred organics into the underlying deposits, and the formation of reddish limpid clay with fine charred organic material. This indicates that the presence of fine charred remains in a deposit may be intrusive in some contexts.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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