BIOTURBATION AND THE FORMATION OF LATENT STRATIGRAPHIES ON PREHISTORIC SITES

Two case studies from the Belgian-Dutch coversand area

Ph. Crombé[1]
L. Messiaen[1]
D. Teetaert[1]
J. Sergant[1]
E. Meylemans[2]
Y. Perdaen[2]
J. Verhegge[1]

[1] Department of Archaeology, Ghent University, Belgium
[2] Flemish Heritage Agency, Belgium

Corresponding author
Ph. Crombé, philippe.crombe@ugent.be

"Soil is not a static body; it is a dynamic, open system, in which a variety of processes may act to move not only soil matter, but objects (including artifacts), from one position to another. It must therefore be included as one of the major natural features we must contend with in interpreting the archaeological record."

— Wood and Johnson, 1978, p. 316

ABSTRACT
This paper discusses the vertical distribution of artefacts of two Mesolithic-Neolithic sites within the sand belt of Belgium and the southern Netherlands. Contrary to prevailing theories claiming that sites from these archaeological stages are generally no more than mixed surface sites, the present study demonstrates the existence of a latent stratigraphy, which can be traced in the vertical distribution of the different categories of archaeological finds (lithic artefacts, pottery sherds, carbonized plant remains, calcined bones). Furthermore it is suggested that the formation of these latent stratigraphies is due to long-term faunalturbation occurring in non-podzolic soils.

KEYWORDS
sand belt, vertical migration, faunalturbation, prehistory, latent stratigraphy, podzol soil

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ORCID
Ph. Crombé: 0000-0002-4198-8057

1. Introduction

Within the extensive sand belt of NW Europe, remains of prehistoric occupation sites, such as stone artefacts and ecofacts (carbonized hazelnut shells, calcined bones, charcoal) are found but incidentally in the original stratigraphic position, i.e. in a well-defined stratum corresponding to a former living-floor. On most prehistoric sites, particularly those dating to the Final Palaeolithic and Mesolithic, finds occur vertically distributed over depths varying from a few decimeters to more than a meter within the top of the Pleistocene sands. Although a wide range of post-depositional processes, such as floralturbation, cryoturbation and trampling among others (Wood and Johnson, 1978; Villa and Courtin, 1983) can be responsible for this vertical displacement, it is generally assumed that faunalturbation, i.e. soil mixing by burrowing animals, was the principal mechanism (Barton, 1987; Collcutt, 1992; Vermeersch and Bubel, 1997; Crombé, 1998; Crombé et al., 2015a). Several studies and experiments have demonstrated the impact of particularly small animals, such as ants, beetles and earthworms, on the vertical displacement of prehistoric artefacts and ecofacts. Depending on the size and weight, archaeological finds descent either through individual vertical galleries, collapsing galleries and/or the deposition of worm castings at the surface (Darwin, 1896; Atkinson, 1957; Wood and Johnson, 1978). If long lasting, on sites with multiple occupation events this process potentially leads to a mixing of artefacts and ecofacts of different ages (Wood and Johnson, 1978). This creates sites with uncertain stratigraphic associations as artefacts and ecofacts found in the same level are not guaranteed synchronic. The latter is demonstrated by the large number of aberrant radiocarbon dates on charcoal from Final Palaeolithic and Mesolithic sites within the NW-European sand-belt (Crombé et al., 1999; Crombé et al., 2013b; Lanting and

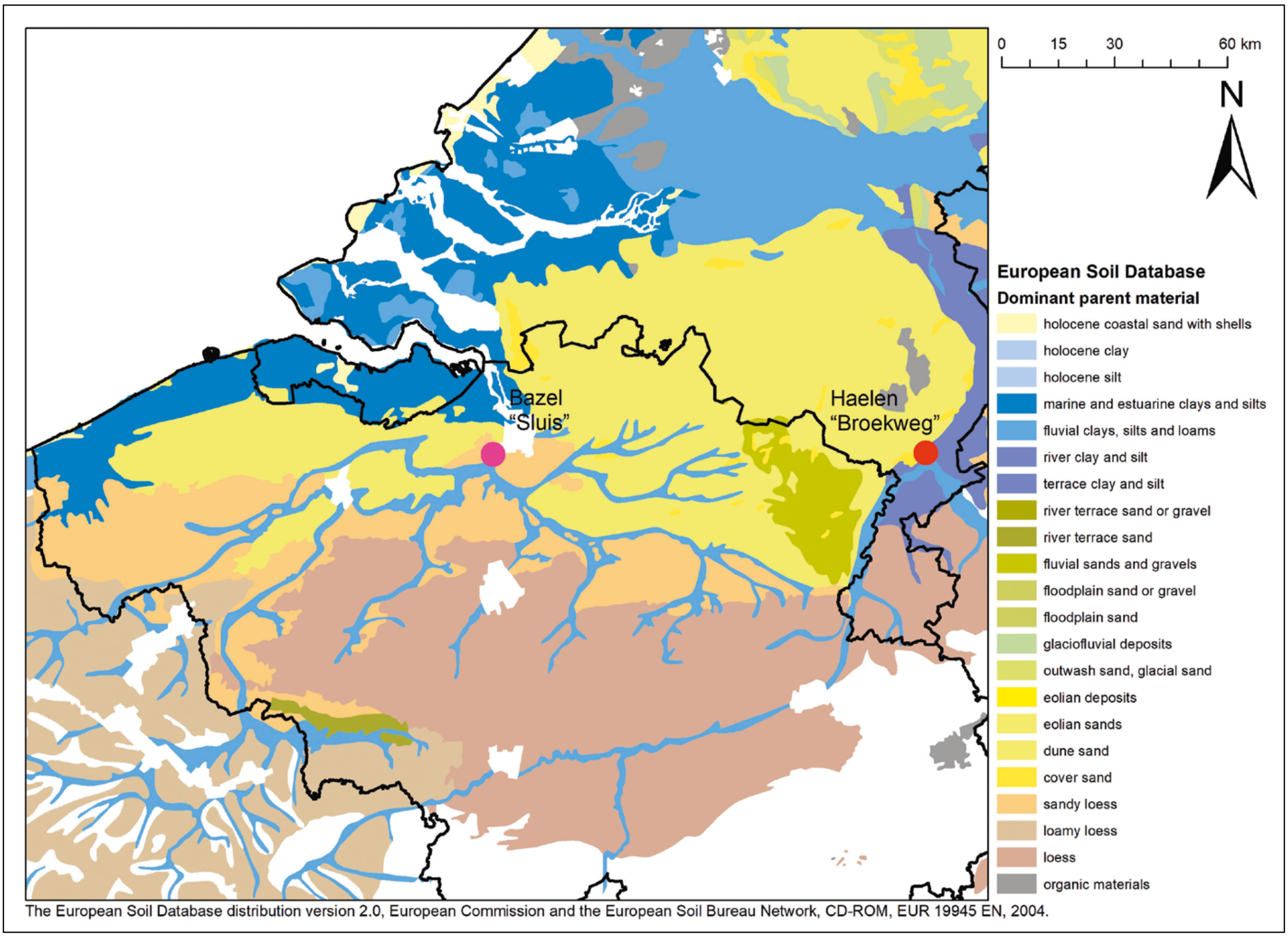

Figure 1. Map of parent materials in Belgium and the southern Netherlands, with the position of the two studied sites.

van der Plicht, 1995/1996; 1997/1998). These observations have led some archaeologists to the conclusion that bioturbated multi-occupation sites need to be considered as purely surface-sites with all the uncertainties specific for such sites (Vermeersch and Bubel, 1997). According to these scholars, even very precise excavation methods cannot resolve these problems. In this paper, we will demonstrate through two case-studies from the Belgian-Dutch sand belt – Bazel 'Sluis' and Haelen 'Broekweg' – that in some cases, bioturbation can form a latent stratigraphy which allows the disentanglement of different diachronic occupations on a same location to a certain degree.

2. The site of Bazel 'Sluis'

2.1. GENERAL PRESENTATION

The floodplain site of Bazel 'Sluis' is situated on an elongated elevation, probably a scroll-bar or a levee, on the left bank of an abandoned channel of the Scheldt river in NW-Belgium (province of East Flanders) (Fig. 1). The substrate of this elevation, the top situated ca. 2.0 to 2.5 m below actual surface, consists of rather homogeneous beige-greyish fine sand, the upper ca. 30 cm of which is very humiferous. The base of this humiferous layer is irregular due to a high degree of bioturbation recognizable by traces of roots, uprooted trees and bio-galleries. Except for the channel bank, there is no indication of erosion of the sandy elevation, which was covered with peat from ca. 3500-3105 cal BC onwards (Deforce et al., 2014). Later peri-marine clayey sediments were deposited on top of the peat through alluviation.

In 2011, excavations revealed a large amount of prehistoric settlement waste, including lithic artefacts, pottery fragments, charred hazelnut shells, calcined bone fragments, charcoal and unburnt bones (mainly teeth) (Meylemans et al., 2016). The vast majority was found on the top of the sandy elevation, in small clusters corresponding to former activity and/or dwelling areas (Fig. 2). Remains of waste depositions from the different occupation events consisting of mainly animal bones, were discovered along the channel bank. Based on diagnostic artefacts, pottery and a large set of radiocarbon dates, it can be concluded that the site was occupied over a very long time span, starting from the Early Mesolithic till the Middle Neolithic, from ca. 8000/7600 to 3600/3400 cal BC, albeit probably in a discontinuous way (Crombé et al., 2015b; Meylemans et al., 2018).

The vertical distribution analysis focuses on the largest trench WP1, covering ca. 260 m^2 (Fig. 2). The zones disturbed by windthrow features, mainly situated in the eastern sector of WP1, are excluded. The vertical analysis follows artificial, 5 cm thick sampling horizons, which were excavated and sieved through 2 mm meshes.

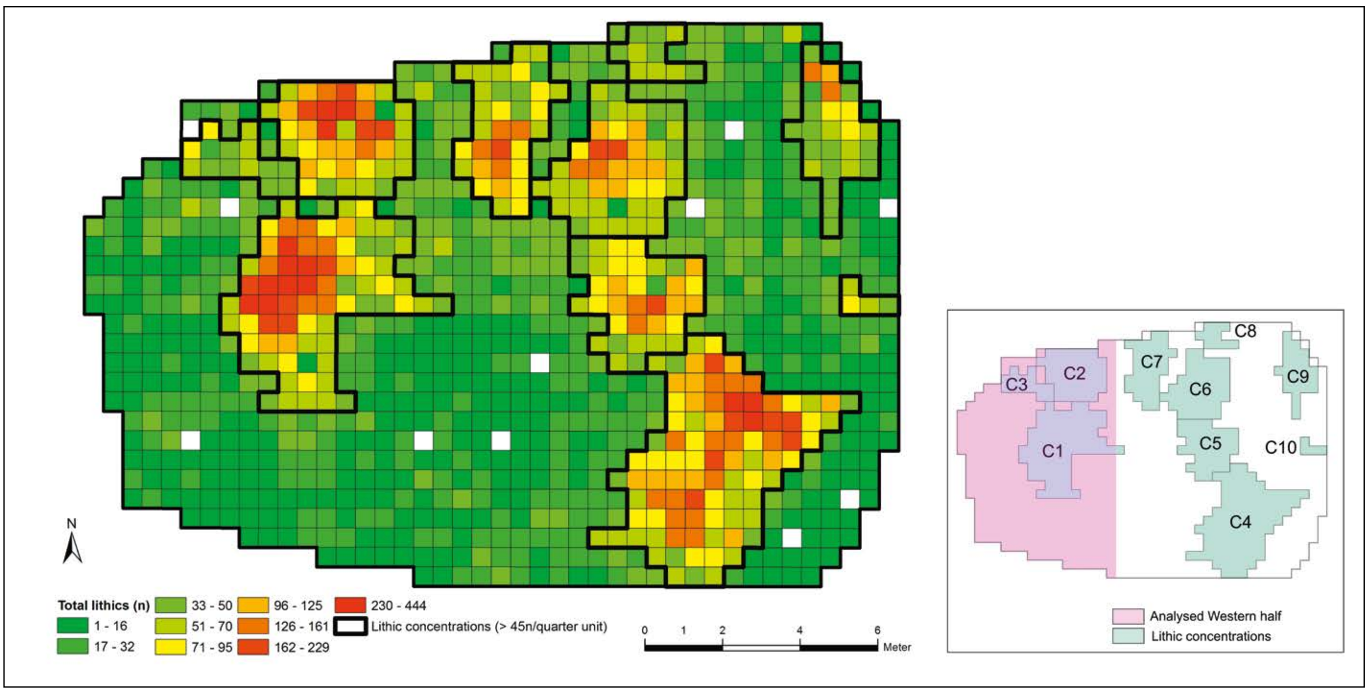

Figure 2. Distribution map of the lithic artefacts within WP1 at Bazel. Small inset map: numbering of the individual artefact clusters.

-cm	total	> 1 cm	< 1cm	total
0-5	1.482	10%	8%	9%
5-10	4.023	25%	23%	23%
10-15	4.852	26%	29%	28%
15-20	2.890	16%	17%	17%
20-25	1.686	10%	10%	10%
25-30	858	5%	5%	5%
30-35	687	4%	4%	4%
35-40	436	2%	3%	3%
40-45	291	1%	2%	2%
45-50	90	0%	1%	1%
50-55	23	0%	0%	0%
55-60	4		0%	0%
60-65	8	0%	0%	0%
65-70	1		0%	0%
70-75	5		0%	0%

Figure 3. Vertical distribution of the lithic industry from WP1 at Bazel.

-cm	EM (n=25)	MM (n=6)	LM (n=27)	MN (n=46)
0-5				20%
5-10	8%	17%	22%	48%
10-15	16%	33%	33%	24%
15-20	12%	17%	30%	7%
20-25	16%	17%	11%	2%
25-30	12%			
30-35	20%	17%	4%	
35-40	12%			
40-45	4%			

Figure 4. Vertical distribution of the lithic guide fossils from WP1 at Bazel.

-cm	EM (n=15)	MM (n=1)	LM (n=7)	MN (n=16)
0-5				
5-10			29%	50%
10-15	7%		43%	31%
15-20	7%		14%	13%
20-25	27%	100%	14%	6%
25-30	20%			
30-35	27%			
35-40	13%			
40-45				
45-50				

Figure 5. Vertical distribution of the lithic guide fossils from the Early Mesolithic cluster C2 at Bazel.

2.2. VERTICAL DISTRIBUTION ANALYSIS

2.2.1. Lithic artefacts

The overall vertical distribution of the lithic industry from WP1 (n = 17,492), mainly consisting of flint artefacts and a small amount of artefacts in Wommersom quartzite (ca. 1 %) and Tienen quartzite (ca. 0.1 %), presents a unimodal trend, with the highest concentration (ca. 68 %) between -5 and -20 cm (Fig. 3). The maximum depth of migration is -70/75 cm, but below -50/55 cm the amount of artefacts drops drastically to just a few specimens (<10). There is no marked difference in the dispersion of artefacts > or < than 1 cm, except for the fact that below -55 cm, only chips have migrated deeper.

As the palimpsest character of the lithic assemblage is known (cf. 2.1), the vertical distribution should be interpreted in a diachronic way. However, this approach is hampered by the difficulty of associating the vast majority of artefacts, mainly the unretouched waste products (blades, bladelets, flakes, cores, chips, ...) but also undiagnostic tools (scrapers, retouched flakes and blades, ...), with a specific sub-phase of the Mesolithic and Neolithic. Hence, the analysis must be limited to the vertical distribution of the most diagnostic artefacts, such as projectile implements (microliths and arrowheads), axe fragments and long blades in mined flint (total n = 104 tools). These are divided over the Early Mesolithic (n = 25), Middle Mesolithic (n = 6), Late Mesolithic/Early Neolithic (n = 27) and Middle Neolithic period (n = 46).

Despite the low numbers, some clear patterning is observed in the vertical distribution of the lithic implements (Fig. 4). The Early Mesolithic finds clearly have the largest vertical dispersal. These are found in the upper -40/45 cm of the soil, without presenting a clear peak at a certain level. A different pattern emerges when restricting the analysis to the Early Mesolithic artefact cluster C2 (Fig. 2, 5). Here, nearly all Early Mesolithic diagnostic artefacts (13 out of 15 artefacts) are situated between -20 and -40 cm. This contrasts sharply with the vertical distribution of the Late Mesolithic/Early Neolithic and the Middle Neolithic artefacts (Fig. 4, 5), which are bound to the upper 15 to 20 cm. Nearly half of the latter are situated between -5 and -10 cm depth, while the peak of Late Mesolithic trapezes (ca. 85 %) is situated between -5 and -20 cm. The distribution of the Middle Mesolithic armatures is difficult to interpret due to the small sample size.

2.2.2. Pottery

The pottery assemblage of WP1 (n = 5970 >1 cm²) comprises at least five different technological groups based on the dominant temper material. Combined with morpho-decorative features, these can be attributed to different cultural groups (Crombé et al., 2015b). The oldest pottery is mainly bone-tempered (n = 354) and is linked to Early Neolithic cultures, such as the (late) *Linearbandkeramik* (LBK) and Limburg-pottery groups, dated roughly between ca. 5300 and 4900 cal BC. However, most potsherds have only a grog temper (n = 2908), making the cultural attribution less clear. Based on other technological and morphological characteristics, this pottery category can be linked with the Swifterbant and partly with the Epi-Rössen/Bischheim tradition of the second half of the 5^{th} millennium cal BC. Also the moss-tempered pottery (n = 826) mainly belongs to the Swifterbant and partly to the Michelsberg/Spiere group tradition. The cultural attribution of the crushed flint/quartz-tempered pottery (n = 1765) is more straightforward, as it can be linked with the Michelsberg/Spiere group tradition, dated between ca. 4300 and 3800 cal BC.

The overall vertical distribution (Fig. 6) clearly indicates that pottery fragments are bound to the upper 20/25 cm of the soil, as the number of finds drops drastically (<1 to 2 % per level) below this level. Despite this limited vertical dispersal, a differential spread is observable between the five types of pottery. Clearly, the oldest bone-tempered pottery has the deepest stratigraphic position, concentrating between -10 and -25 cm (ca. 66 %). By contrast, the youngest pottery with crushed flint/quartz temper has the highest stratigraphic position and cumulates between 0 and -15 cm (ca. 89 %). The grog and moss-tempered pottery has a transitional vertical position with the bulk (ca. 50-55 %) situated between -5 and -15 cm.

-cm	Bone (n=354)	Grog (n=2901)	Moss (n=825)	Flint/Quartz (n=1744)
0-5	10%	12%	21%	25%
5-10	16%	28%	27%	45%
10-15	24%	27%	27%	19%
15-20	27%	18%	14%	4%
20-25	16%	8%	5%	1%
25-30	4%	5%	4%	3%
30-35	2%	2%	2%	2%
35-40	1%	1%	0%	1%
40-45	0%	0%	0%	0%
45-50	0%	0%	0%	0%

Figure. 6 Vertical distribution of the different pottery types from WP1 at Bazel. The crushed flint and quartz pottery has been grouped in one type.

2.2.3. Radiocarbon dates

Two multi-period clusters of lithic and ceramic artefacts (C1 and C2; Fig. 2) were selected for extensive radiocarbon dating. Dating was conducted on three types of samples: 1° charred hazelnut shells; 2° carbonized cereal grains; 3° charcoal fragments.

The obtained dates were calibrated and Bayesian modelled using Oxal 4.3 software (Bronk Ramsey, 2009) and the IntCal 13 calibration curve (Reimer et al., 2013). Bayesian chronological modelling allows the integration of *a-priori* relative chronological knowledge (e.g. stratigraphy, depth, typochronology, …) and probability distributions of the standardized likelihoods of (radiocarbon) dates to recalculate modeled posterior beliefs preferably resulting in a higher precision (Bayliss et al., 2007). Detailed information on the modelling methodology is given in the Appendix.

The modelling results show a chronological model with a sufficient model and overall agreement index (Appendix; Table 1), while the individual dates agree within the model as well, suggesting an appropriate prior. However, some modelled *sigma boundaries* cover too wide time-spans and are therefore dismissed. The vertical distribution of the radiocarbon dates on hazelnut shells within C1 (n = 8; Fig. 7) presents a marked chronological hiatus between the upper 25 cm and the lower levels. The three dates from the upper 25 cm all situate within the 5^{th} millennium cal BC, while from -30 cm onwards the chronology shifts to the 8^{th} millennium cal BC. The latter coincides perfectly with the exclusively Early Mesolithic age of the diagnostic lithic artefacts and the near-absence of pottery fragments in the lowest levels (cf. 2.2.1). However, the upper three dates fit perfectly with the age of the 'associated' Late Mesolithic/Early Neolithic ceramics and lithics (trapezes). The same vertical pattern is observed within C2 (n = 8; Fig. 8). With exception of the RICH-26075-date, all hazelnut dates in the upper levels are much younger than those below -25 cm and display the same chronological hiatus between the 8^{th} and 5^{th} millennium cal BC.

The vertical distribution of the radiocarbon dates obtained on carbonized cereal grains also shows a clear chronological trend (Fig. 9). Of the oldest grains, dated to the first half of the 5^{th} millennium cal BC (n = 7), all except one (RICH-22107) situate between -15 and -30 cm. Between -10 and -15 cm dates situate in the second half of the 5^{th} millennium cal BC, while in the upper 10 cm they belong to the first half of the 4^{th} millennium cal BC. This pattern is also visible in the vertical distribution of the four ^{14}C-dates obtained on charcoal fragments from C1 (Fig. 10).

2.2.4. Interpretation

Combining the evidence from all three vertical distribution analyses, a clear spatio-temporal correlation becomes noticeable between the lithic artefacts, pottery and dated ecofacts of the different occupation periods of the site. Clearly, the -20/25 cm level is important as it represents the limit between the Early Mesolithic finds (8^{th} millennium cal BC) and those from the Late Mesolithic to the Middle Neolithic (late 6^{th} to mid-4^{th} millennium cal BC). In addition, even midst the latter, a further 'stratification' can be observed. Indeed, there is a marked vertical coincidence between the lithic finds, potsherds and radiocarbon dates both for the Late Mesolithic/Early Neolithic and the Middle Neolithic. The latter peak in the top of the soil (-5/10 cm), while the former have an intermediate position (-5 to -20/25 cm) between the Middle Neolithic finds and the Early Mesolithic finds. In sum, the upper 10 cm of the soil contains settlement waste, mostly belonging to the late 5th to the mid-4th millennium cal BC, while the level of -10 to -20/25 cm is attributed to the late 6th and 5th millennium cal BC. Finally, the levels below 25/30 cm date to the 8th millennium cal BC. Hence, an important occupation hiatus can be defined during the 7th and most of the 6th millennium cal BC, which stratigraphically probably correlates with the levels around -20/25 cm.

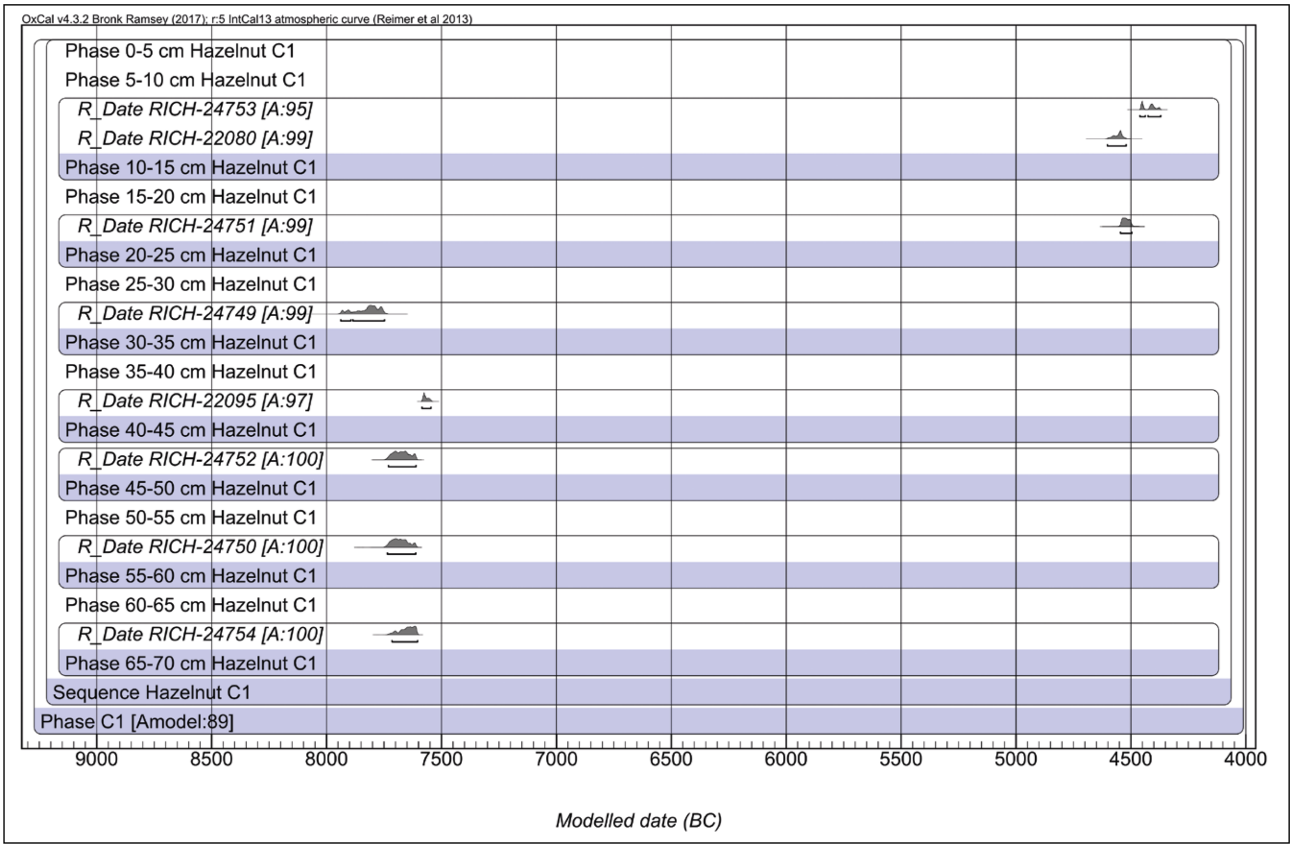

Figure 7. Bayesian model of the dates on charred hazelnut shell from artefact cluster C1.

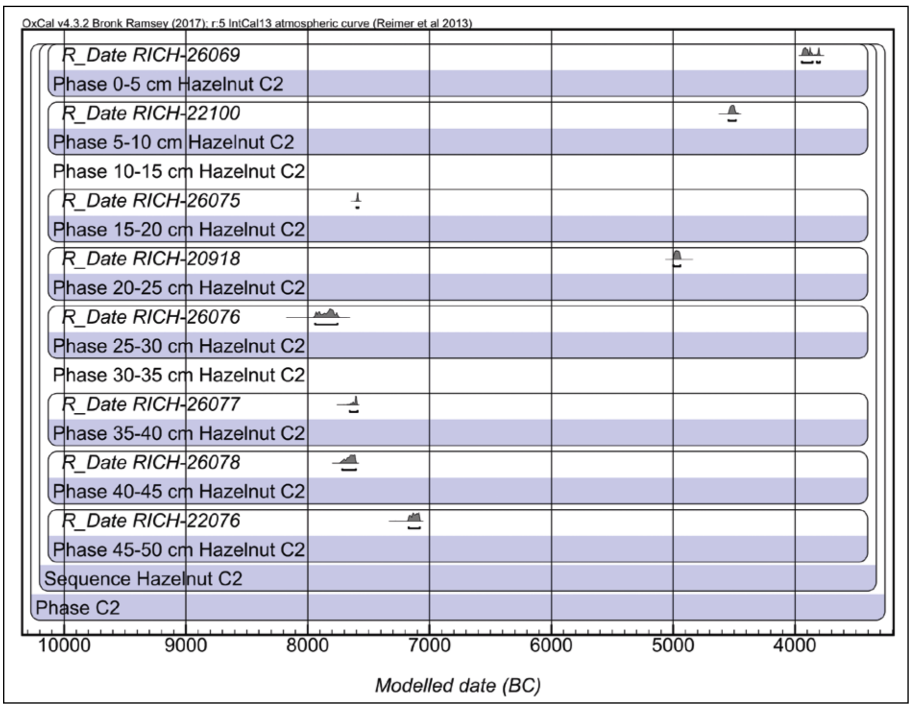

Figure 8. Bayesian model of the dates on charred hazelnut shell from artefact cluster C2.

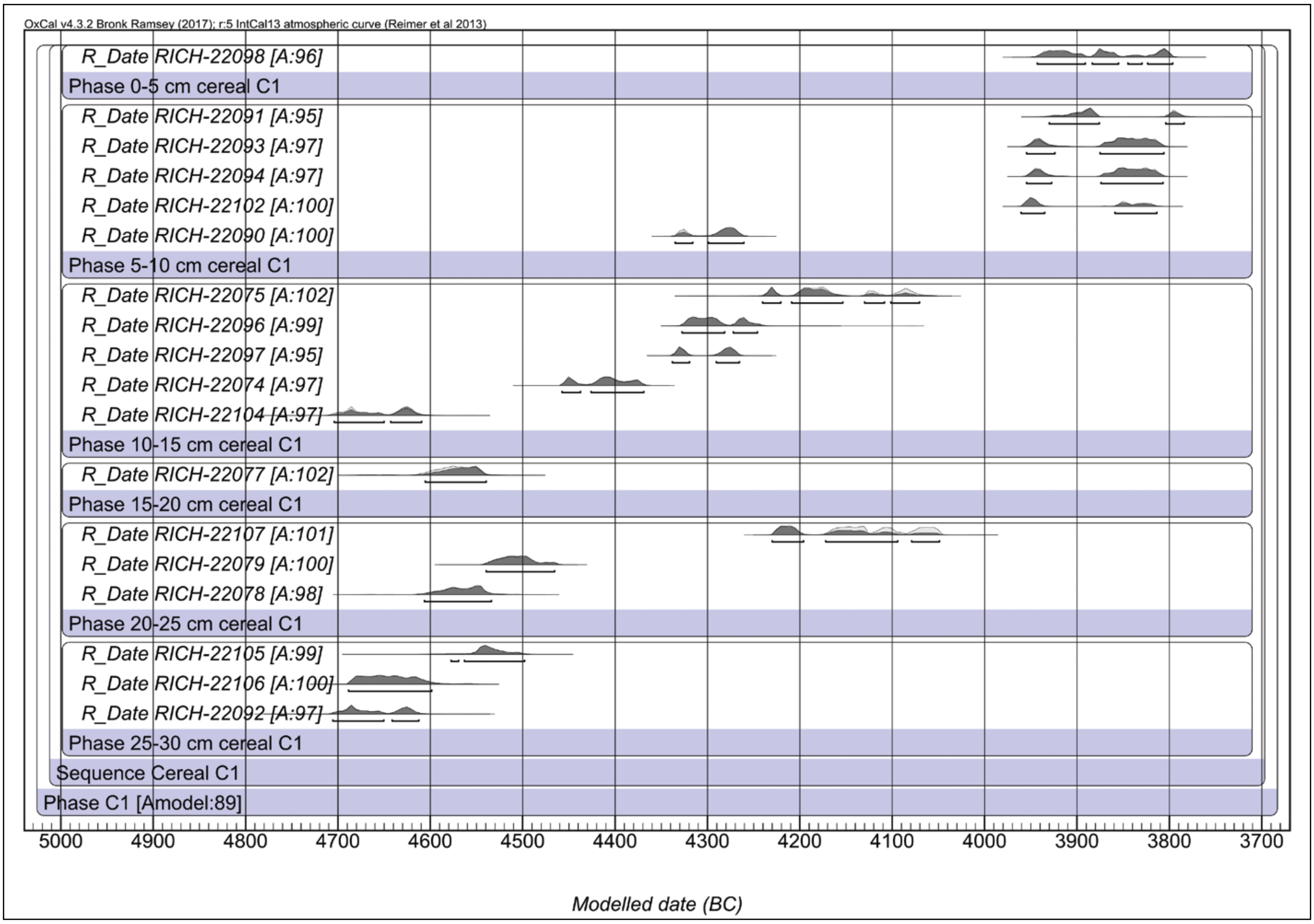

Figure 9. Bayesian model of the dates on carbonized cereal grains from artefact cluster C1.

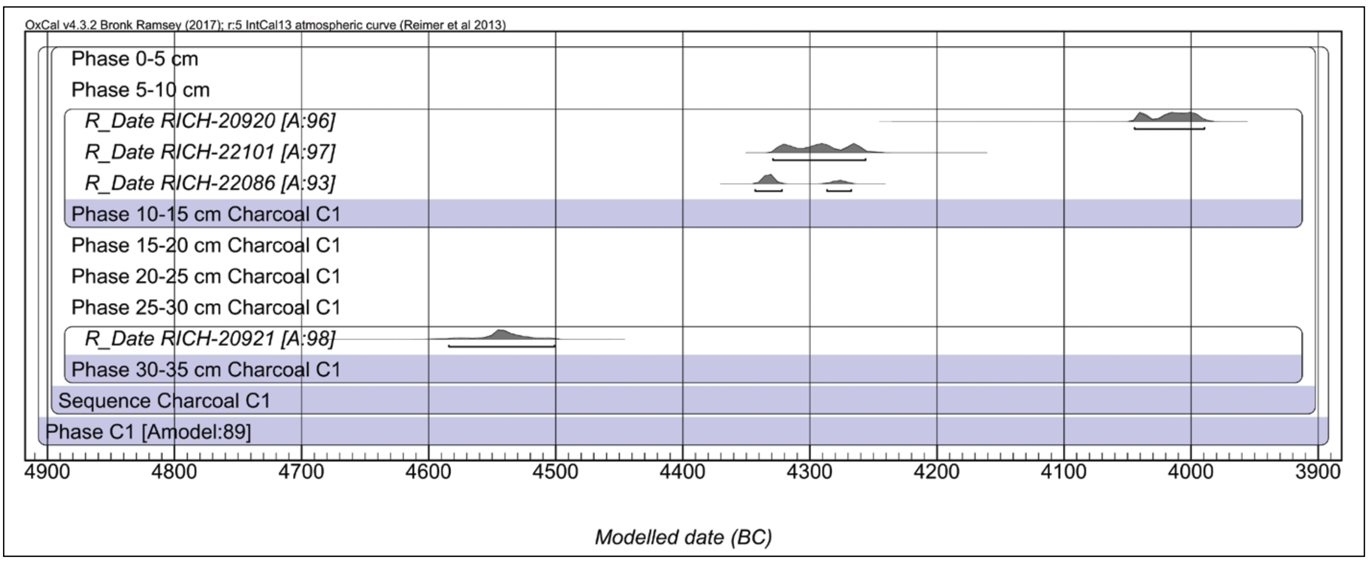

Figure 10. Bayesian model of the dates on charcoal from artefact cluster C1.

3. Haelen 'Broekweg'

3.1. GENERAL PRESENTATION

The site of Haelen is situated on a sandy elevation on the left bank of the Meuse river in the southeast of The Netherlands (province of Limburg) (Fig. 1). The site-stratigraphy consists of a well-developed color B-horizon (H4) separated from the underlying C-horizon (compact sands with local thin Bt-bands; H6) by a relatively thick transitional layer (H5) (Bats et al., 2010) (Fig. 11).

Evidence of human occupation and activity dating to different archaeological periods was collected during excavations in 2001 and 2002. The oldest occupation remains consist of an assemblage of 14,634 stone artefacts and a small amount of carbonized hazelnut shell (5.21 g) and calcined bone (30.23 g), dated to the Early Mesolithic (ca. 8290-8210 cal BC). A series of 76 decorated pottery fragments, belonging to the so-called *La Hoguette/Begleitkeramik,* point to limited human activity during the Late Mesolithic/Early Neolithic (ca. 5500-5000 cal BC). Furthermore, pottery from the Middle Bronze Age (n=242), Late Bronze Age/Iron Age (n=1026), Roman period (n=26) and (post-) Medieval period (n=672) were collected.

The vertical distribution analysis was applied on a selection of the excavated area, i.e. the zones which were not perturbed by tree planting pits. In total, it concerns a surface area of 61.5 m² including 5327 lithic and 561 ceramic finds, retrieved from a 3 mm-mesh sieve. The analysis uses the 10 cm artificial layers from the excavation.

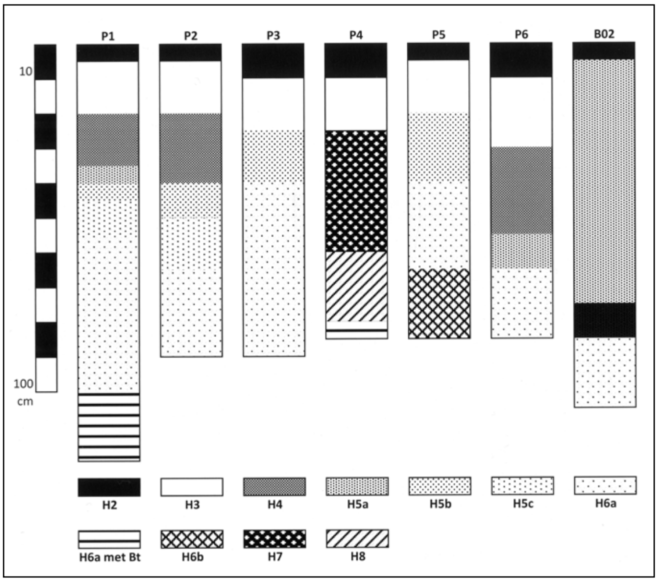

Figure 11. Schematic representation of the soil stratigraphy at Haelen; P1 to P4 profiles are situated within the limits of the archaeological site; P5-P6 and B02 are profiles from the surrounding area (from Bats et al., 2010, fig. 19). H1: topsoil; H2: dark grey-brownish A-horizon; H3: humiferous AE-horizon with numerous roots; H4: color B-horizon (Bw) with numerous roots; H5: transitional horizon with numerous roots; H6: C-horizon with few roots (compact sands).

3.2. VERTICAL DISTRIBUTION ANALYSIS

3.2.1. Mesolithic assemblage

The vertical distribution (Fig. 12) indicates that most lithic finds, dating to the Early Mesolithic, are situated deeper than -30 cm. The largest proportion of flint artefacts (ca. 65 %) occurs between -30 cm and -60 cm, below which the amount decreases rapidly. Apparently, there is no differentiation in vertical artefact dispersal between sizes >1 cm and <1 cm (chips) as both show a similar unimodal vertical distribution pattern. However, the mean weight of the artefacts decreases clearly from top to bottom (Fig. 12). In the lowest levels (-50 to -70 cm) the mean weight is only half that of the artefacts in the upper levels, which indicates that small artefacts have migrated deeper than large ones.

The distribution of the charred ecofacts, although contemporaneous with the lithic artefacts, deviates from this pattern (Fig. 12). The amount of charred hazelnut shells gradually increases with depth and the highest proportion is situated in the deepest sample of -60/70 cm. The distribution of calcined bones on the other hand shows two peaks below -40 cm.

-cm	lithic <1cm (n=3831)	lithic >1cm (n=1536)	lithics mean weight	calcined bone (6.52 gr.)	hazelnuts (2.4 gr.)
0-10	4%	5%	1,75	0%	0%
10-20	6%	7%	1,72	4%	0%
20-30	10%	13%	2,15	4%	0%
30-40	23%	23%	1,92	7%	5%
40-50	24%	22%	1,58	44%	20%
50-60	19%	18%	1,24	11%	27%
60-70	13%	12%	1,07	31%	48%

Figure 12. Vertical distribution of the lithic industry, calcined bones and charred hazelnut shells (gr.) at Haelen.

-cm	Early Neo (n=76)	Bronze Age (n=242)	Iron Age (n=1026)	Early Medieval (n=97)	Late Medieval (n=77)
0--10	6%	14%	12%	24%	29%
10-20	9%	16%	28%	38%	40%
20-30	24%	36%	34%	25%	19%
30-40	24%	25%	18%	8%	6%
40-50	26%	6%	5%	3%	3%
50-60	9%	0%	1%	2%	1%
60-70	3%	3%	1%	0%	1%

Figure 13. Vertical distribution of the different pottery types at Haelen.

3.2.2. Pottery

The overall distribution of the pottery (Fig. 13), independent of its chronology, is different compared to the lithic assemblage with most sherds occurring in the upper 30 to 40 cm. However, a clear pattern of increasing depth is noticeable as the pottery is dated older. The oldest pottery, belonging to the Early Neolithic *La Hoguette/Begleitkeramik*, clearly has the deepest position, with a peak between -20 cm and -50 cm (ca. 73 %) and is therefore partially overlapping with the lithic assemblage. Pottery from the Bronze Age and Iron Age peaks between -20 and -40 cm, while Medieval pottery has the highest stratigraphic position (0-30 cm).

4. Discussion

Both case-studies presented in this paper, demonstrate that intense bioturbation does not necessarily lead to the -often claimed- irrevocable mixing of archaeological remains from different occupation events. The vertical distribution analysis of lithic, ceramic and chronological evidence on both sites clearly shows that there is a rather well-established relationship between the vertical distribution and the age of the finds. Clearly the older the archaeological remains are dated, the deeper they have migrated. Ultimately, this results in the formation of a latent stratigraphy, which allows a separation of the occupation remains from different chronological events to a certain degree.

On both sites, most archaeological remains belonging to the Early Mesolithic, i.e. lithics, calcined bones (Haelen) and charred hazelnut shells, are situated between -20/30 cm and -45/60 cm deep. This deviates from other Early Mesolithic sites in the Dutch-Belgian sand belt. On the sites of Verrebroek 'Dok 1' (Crombé, 1998) and Verrebroek 'Aven Akkers' (Sergant and Wuyts, 2006; Crombé et al., 2009), both situated in the vicinity of Bazel 'Sluis', the bulk of Early Mesolithic artefacts is situated in the upper 15/20 cm and the maximum vertical displacement is 30 cm. Considering bioturbation as the main process responsible for the vertical displacement of artefacts, this marked inter-site difference in migration depth between Bazel and the other sites could indicate differences in the intensity and duration of biological activity. Both Verrebroek-sites are situated in coversand deposits, presenting a typical podzol soil (Louwagie and Langohr, 2005) (Fig. 14-3). It is well-known that podzol soils are acid environments (pH below 5) with limited biological activity. Therefore, it can be assumed that artefact migration on these sites pre-dates the formation of the podzol soil. Unfortunately, it is difficult to date the podzolization precisely at the Verrebroek-sites, but the fact that both sites were covered by peat at the start of the Subboreal (ca. 3600-3300 cal BC) onwards, points to a podzol formation in the course of the Atlantic period. Hence, it is likely that faunalturbation already ended during the Atlantic or even the Boreal. In contrast, the sites of Bazel and Haelen do not present traces of podzol formation (Fig. 14-1, 2). This might imply that bioturbation, and thus vertical migration, continued longer at these sites. At Bazel, bioturbation might have ended when peat started to grow over the sandy elevation, i.e. from ca. 3500/3100 cal BC at the earliest. This date fits with the archaeological evidence, which situates the end of human occupation on the sandy elevation around the middle of the 4th millennium cal BC. The site of Haelen remained an open, uncovered site with ongoing bioturbation until its excavation.

Another difference between the Bazel/Haelen sites and the Verrebroek-sites, which could partially explain the vertical differences, is the occupation length and formation process. In contrast to the multi-occupation sites of Haelen and Bazel, the Verrebroek 'Dok 1' site was occupied during the Early Mesolithic only. Although the site was frequently revisited over a timespan of one millennium, probably on a seasonal basis, this did not lead to the formation of a large cumulative palimpsest (according to the definition by Bailey, 2007), as at Haelen and Bazel. Instead, reoccupation at Verrebroek 'Dok 1' resulted in an extensive spatial palimpsest, characterized by numerous spatially separated artifact concentrations, which probably represent single occupation events (for discussion cf. Crombé et al., 2013a). As a result of the limited occupation length and spatial arrangement of settlement waste, the possible effects of trampling caused by the human activities within the artefact clusters, on the vertical displacement of finds, is probably more limited in comparison with cumulative palimpsest sites such as Bazel and Haelen. Several experiments have demonstrated that trampling can result in the vertical displacement of artefacts to depths varying between 1-2 cm (Barton, 1987) and 10-16 cm (Stockton, 1973; Villa and Courtin, 1983). Therefore, trampling cannot be held responsible for the ca. 30 cm deeper migration of Early Mesolithic artefacts at Haelen and Bazel by itself. Nevertheless, intense trampling most probably contributed to a certain extent, which is supported by the generally smaller dimensions of potsherds, collected at Bazel, in comparison to other nearby sites (e.g. Doel; Crombé et al., 2011).

Finally, the deposition of sediments might also have been a factor in the burying of artefacts. Different processes might have resulted into the deposition of sandy material on top of the surface. One could imagine that intense trampling, both by humans and animals, destroyed the local vegetation to such a degree that deflation was reactivated. Recent studies have provided firm evidence of Early to Middle Holocene aeolian erosion linked to

Figure 14. Photos of typical sandy soil profiles:

1 Bazel: humiferous soil affected by intense bioturbation processes (top at 2.0 to 2.5 m below actual surface);

2 Haelen: color-B horizon soil (Bw) with numerous roots (top = actual surface);

3 Verrebroek-Dok 1: Podzolic soil with typical A-E-Bh horizons (top at ca. 1.5 m below actual surface).

human activities before the introduction of agriculture (Tolksdorf and Kaiser, 2012; Kasse et al., 2018). However, grain-size analyses conducted at Haelen did not yield any proof of post-depositional sedimentation (Bats et al., 2010). Another well-known process, already documented by Darwin (1896), is the deposition of worm-casts at the surface, called vegetable mound formation, a process which gradually leads to the covering of ancient occupation levels. According to calculations objects can get covered by 2.5 to 5mm thick casts every year (Atkinson, 1957). Combined with artefacts descending through individual and collapsing galleries, this might explain the deep vertical distribution at Haelen and Bazel.

5. Conclusions

The existence of a latent stratigraphy on prehistoric occupation sites situated in sandy soils has major implications for future archaeological augering surveys. To date archaeological augering in view of detecting prehistoric remains (Crombé and Verhegge, 2015) mainly focuses on a sampling of the upper 30/40 cm of the Pleistocene substrate. This strategy is based on the general assumption that prehistoric sites, in particular those dating to the Mesolithic and Neolithic, are situated at shallow depths. However, the presented case-studies have clearly demonstrated that this only applies to sites situated in podzol soils which formed during the Atlantic/Subboreal period. Sites situated in other soil types, such as at Bazel and Haelen, may have a deeper stratigraphical position as a result of a prolonged exposure to biological processes. This particularly holds for sites dated to the beginning of the Holocene, corresponding archaeologically to the Early Mesolithic (ca. 9000-7300 cal BC). Both case-studies have shown that these are generally situated between 20/25 cm and 50/60 cm depth. Also interesting is the overall deeper migration of charred hazelnut shells compared to lithic artefacts. Considering this, in future augering survey projects the sampling depth should be adapted to the different soil types occurring in the Belgian-Dutch sand belt. This most likely also holds for the sandy loam and loam regions, in which different types of soils occur, some of which, e.g. soils with colour or structural B-horizon, are characterized by intense and deep bioturbation (30-50 cm) (De Coninck et al., 1986).

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APPENDIX: Bayesian modelling

The chronological relations of the prior beliefs and dates are schematized using Oxcal terminology (further in italic) on figure 15 for C1 and figure 16 for C2. In this study, the priors include the differentiation of dated material types and the latent stratigraphic order of the sample depth ranges. A separate Oxcal *sequence* was modelled for every dated material category in a separate C1 and C2 *phase*. These *sequences* are randomly arranged as a *phase*. Within each *sequence*, different dates belonging to the same sample depth range are ordered randomly as a *phase*. In every *sequence*, the different depth range *phases* are ordered assuming a younger age for shallower sample depth ranges. The vertical transitions between the samples do not represent hard, but artificial stratigraphic *boundaries* due to the excavation methodology. Therefore, a *sigma boundary* is used for the depth range *phases* within the *sequences*. This type of *boundary* assumes normally distributed probability distributions of events within a *phase*, including extension outside the *phase boundary* and overlapping with another *phase boundary* in the *sequence*. As similar vertical distributions were observed in the archaeological artefacts distributions as well, this *boundary* type is appropriate (see above).

The raw data is available (Table 1) in the online version of this paper (see *doi* references on the title page).

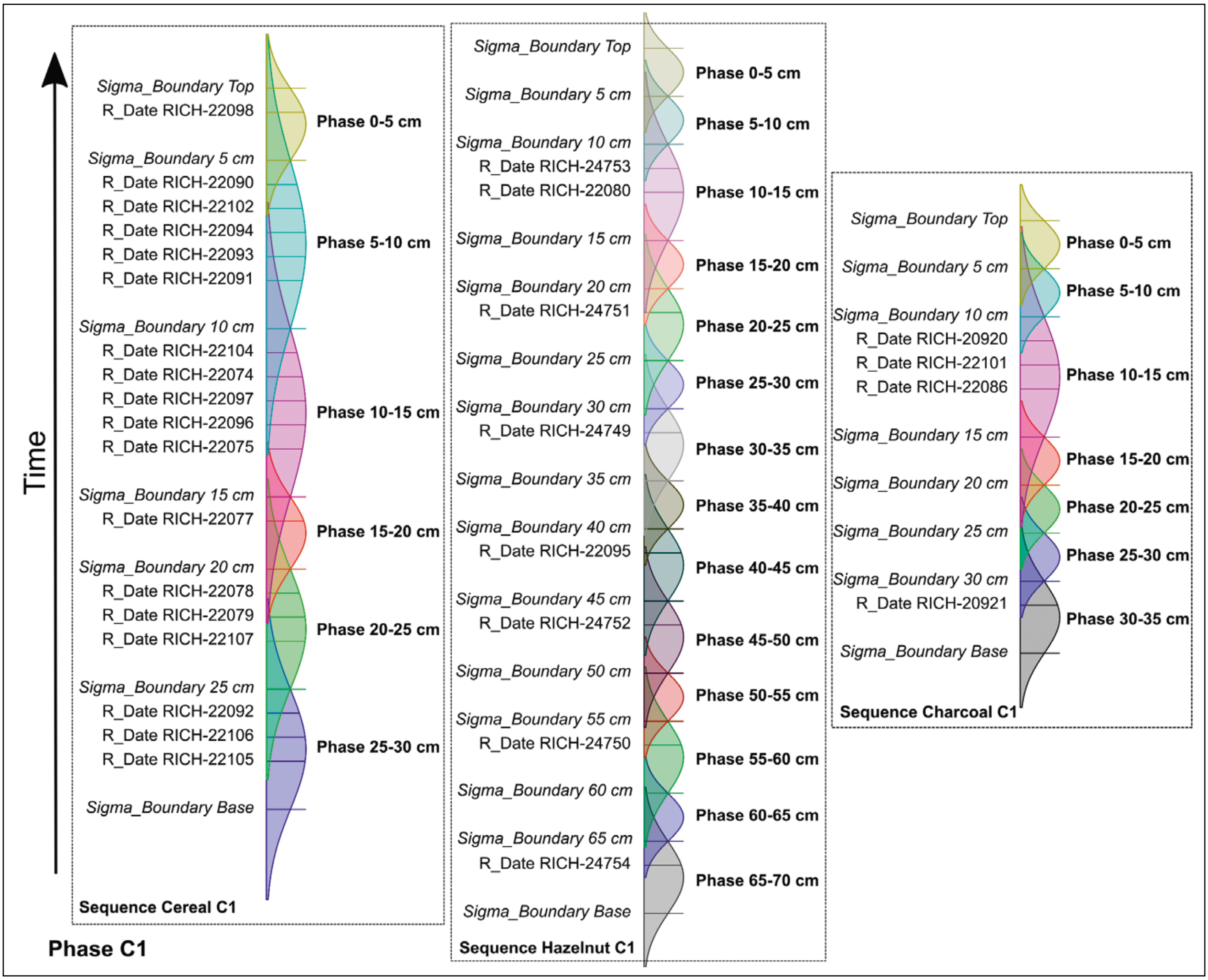
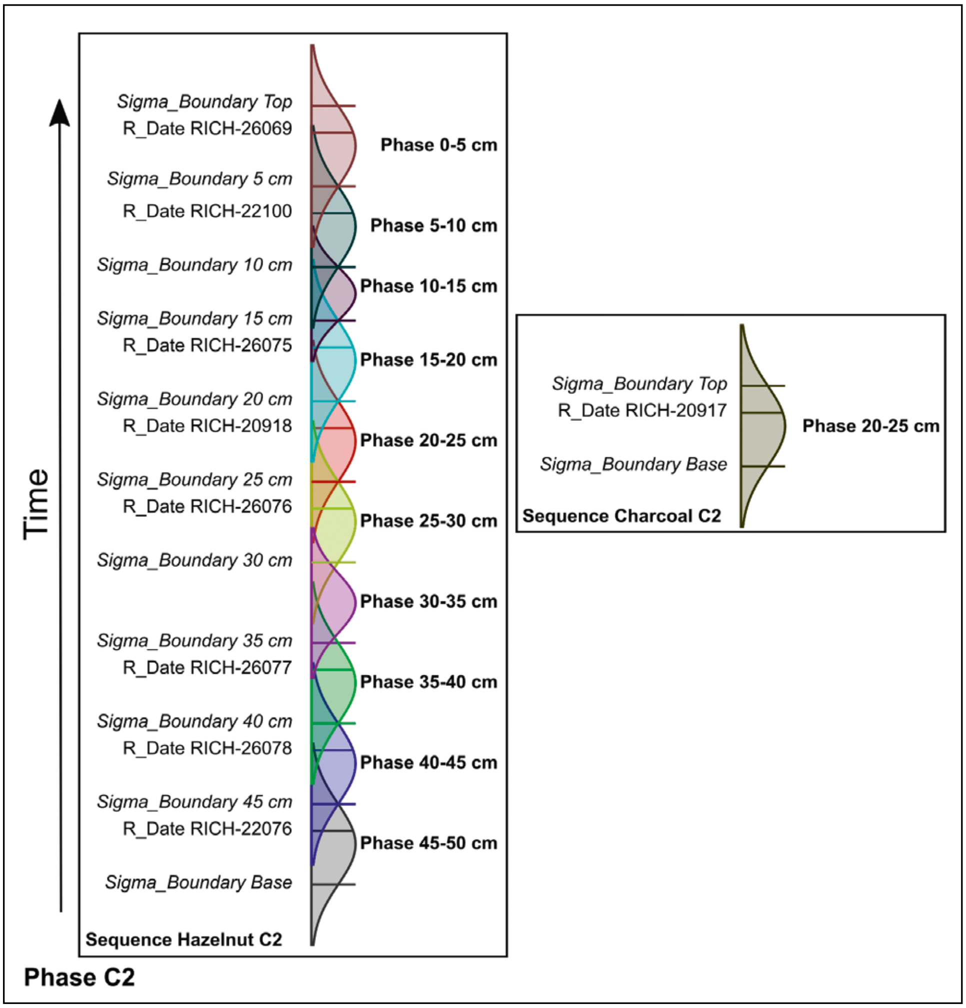


Figure 15. Schematic relationships of prior beliefs and dates from C1 at Bazel.

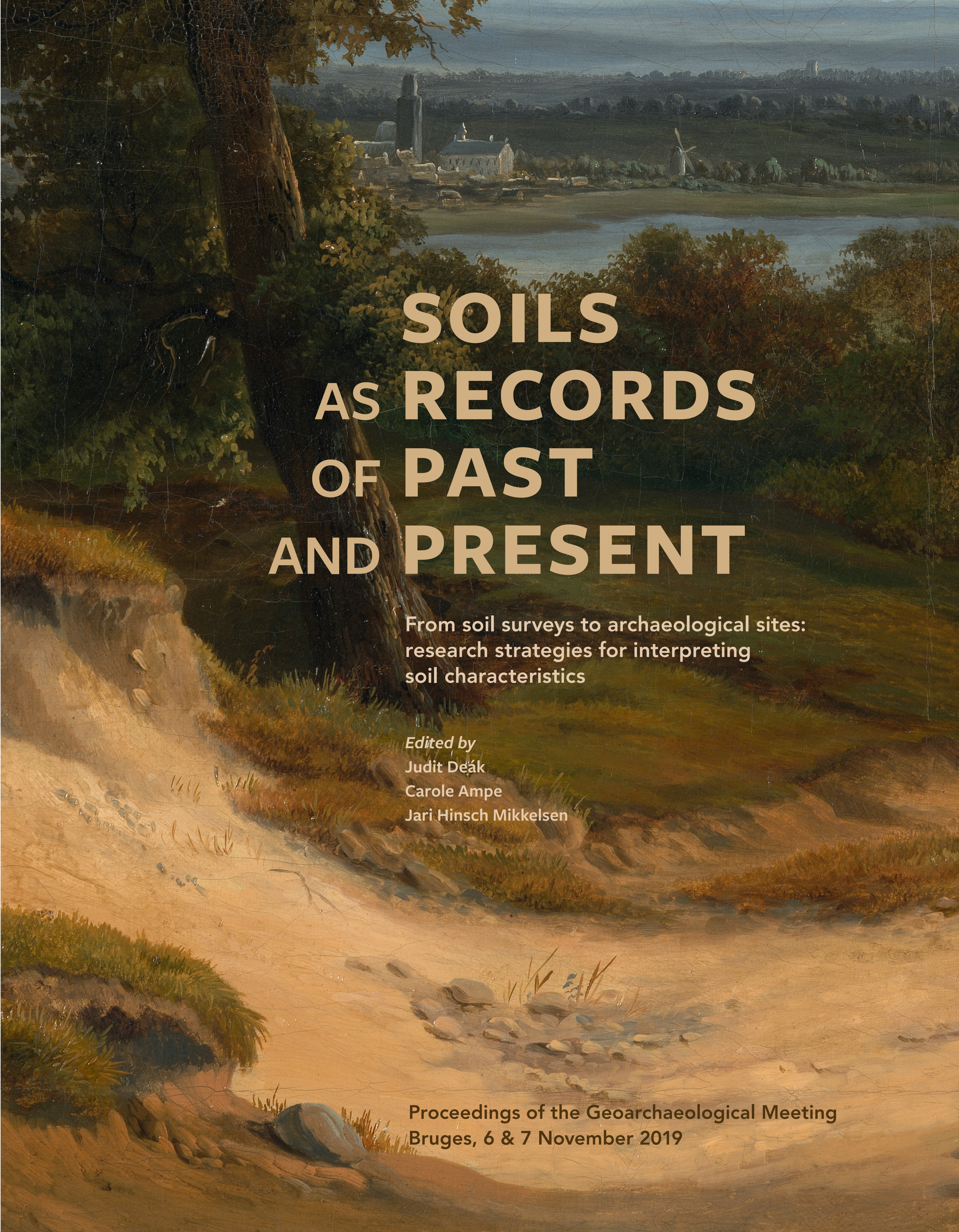
Figure 16. Schematic relationships of prior beliefs and dates from C2 at Bazel.



Name	Unmodelled (BC/AD)						Modelled (BC/AD)						Indices Amodel 86.7 Aoverall 86.8				
	from	to	%	mu	sigma	median	from	to	%	mu	sigma	median	Acomb	A	L	P	C
Sigma_Boundary Top Charcoal C2							-4372	-4059	95,4	-4248	91	-4265					99,9
R_Date RICH-20917	-4356	-4336	95,4	-4345	5	-4346	-4356	-4335	95,4	-4345	5	-4346		94,8			100
Phase 20-25 cm Charcoal C2																	
Sigma_Boundary Base Charcoal C2							-4652	-4323	95,4	-4450	96	-4431					99,9
Sequence Charcoal C2																	
Sigma_Boundary Top Hazelnut C2							2291990	10178800	95,3	6431360	2514780	6766280					83,1
R_Date RICH-26069	-3944	-3796	95,4	-3883	44	-3898	-3943	-3796	95,4	-3883	44	-3897		97,2			99,9
Phase 0-5 cm Hazelnut C2																	
Sigma_Boundary 5 cm Hazelnut C2							46228	3241250	95,4	1465480	976154	1275200					78,9
R_Date RICH-22100	-4546	-4486	95,4	-4515	16	-4515	-4546	-4486	95,4	-4515	16	-4515		99,6			100
Phase 5-10 cm Hazelnut C2																	
Sigma_Boundary 10 cm Hazelnut C2							-7281	921776	95,4	327361	297119	238139					95,2
Phase 10-15 cm Hazelnut C2																	
Sigma_Boundary 15 cm Hazelnut C2							-8777	472671	95,4	126331	168629	65327					98,7
R_Date RICH-26075	-7600	-7585	95,4	-7592	3	-7592	-7600	-7584	95,4	-7592	3	-7592		88,8			100
Phase 15-20 cm Hazelnut C2																	
Sigma_Boundary 20 cm Hazelnut C2							-12342	57910	95,4	6934	29109	-2124					99,8
R_Date RICH-20918	-4998	-4943	95,4	-4970	16	-4971	-4998	-4943	95,4	-4970	16	-4971		99,5			100
Phase 20-25 cm Hazelnut C2																	
Sigma_Boundary 25 cm Hazelnut C2							-23833	7681	95,4	-6828	8643	-6453					99,9
R_Date RICH-26076	-7939	-7756	95,4	-7842	53	-7831	-7939	-7756	95,4	-7842	53	-7831		99,2			100
Phase 25-30 cm Hazelnut C2																	
Sigma_Boundary 30 cm Hazelnut C2							-96281	-373	95,4	-24251	36040	-11673					99,7
Phase 30-35 cm Hazelnut C2																	
Sigma_Boundary 35 cm Hazelnut C2							-215712	-2729	95,4	-62169	73580	-35356					97,6
R_Date RICH-26077	-7655	-7594	95,4	-7618	20	-7608	-7656	-7593	95,4	-7618	19	-7609		92,7			99,9
Phase 35-40 cm Hazelnut C2																	
Sigma_Boundary 40 cm Hazelnut C2							-831230	-6071	95,4	-267665	275349	-175636					87,4
R_Date RICH-26078	-7716	-7605	95,4	-7654	32	-7649	-7716	-7605	95,4	-7654	32	-7649		99,4			100
Phase 40-45 cm Hazelnut C2																	
Sigma_Boundary 45 cm Hazelnut C2							-3060332	-7281	95,4	-1251822	967972	-1026862					65,5
R_Date RICH-22076	-7174	-7080	95,4	-7126	30	-7124	-7173	-7081	95,4	-7125	30	-7124		99,3			99,9
Phase 45-50 cm Hazelnut C2																	
Sigma_Boundary Base Hazelnut C2							-10193402	-1783282	95,4	-5969662	2736670	-6256492					77,1
Sequence Hazelnut C2																	
Phase C2																	
Sigma_Boundary Top Charcoal Charcoal C1							62623	268812	95,4	178090	64138	189107					91,4
Phase 0-5 cm																	
Sigma_Boundary 5 cm Charcoal Charcoal C1							-4075	201573	95,4	87326	64157	76368					91,2
Phase 5-10 cm																	
Sigma_Boundary 10 cm Charcoal Charcoal C1							-4541	-811	95,4	-3358	2776	-3893					96,7
R_Date RICH-20920	-4045	-3990	95,4	-4015	16	-4013	-4045	-3990	95,4	-4016	17	-4014		96,3			99,9
R_Date RICH-22101	-4330	-4257	95,4	-4293	22	-4293	-4330	-4257	95,4	-4292	22	-4292		97,4			100
R_Date RICH-22086	-4343	-4268	95,4	-4316	26	-4331	-4344	-4268	95,4	-4316	26	-4331		92,8			100
Phase 10-15 cm Charcoal C1																	
Sigma_Boundary 15 cm Charcoal C1							-7420	-3886	95,4	-4952	1819	-4520					98,8
Phase 15-20 cm Charcoal C1																	

Name	Unmodelled (BC/AD)						Modelled (BC/AD)						Indices Amodel 86.7 Aoverall 86.8				
	from	to	%	mu	sigma	median	from	to	%	mu	sigma	median	Acomb	A	L	P	C
Sigma_Boundary 20 cm Charcoal C1							-63266	-4243	95,4	-25674	18651	-20426					98
Phase 20-25 cm Charcoal C1																	
Sigma_Boundary 25 cm Charcoal C1							-93369	-6579	95,4	-46403	24656	-42572					96,3
Phase 25-30 cm Charcoal C1																	
Sigma_Boundary 30 cm Charcoal C1							-119380	-17549	95,3	-67124	27984	-65144					77,7
R_Date RICH-20921	-4584	-4501	95,4	-4543	19	-4542	-4585	-4502	95,4	-4543	19	-4542		98,3			100
Phase 30-35 cm Charcoal C1																	
Sigma_Boundary Base Charcoal C1							-277948	-113058	95,3	-209876	52701	-221755					83,5
Sequence Charcoal C1																	
Sigma_Boundary Top Hazelnut							266446000	...	95,4	426376000	83188300	447949000					95,7
Phase 0-5 cm Hazelnut C1																	
Sigma_Boundary 5 cm Hazelnut C1							139457000	506105000	95,3	326534000	103984000	336537000					91,7
Phase 5-10 cm Hazelnut C1																	
Sigma_Boundary 10 cm Hazelnut C1							38866500	415723000	95,4	226653000	108036000	223726000					75,8
R_Date RICH-24753	-4461	-4371	95,4	-4421	26	-4415	-4461	-4371	95,4	-4421	26	-4415		94,7			100
R_Date RICH-22080	-4603	-4522	95,4	-4557	20	-4553	-4603	-4522	95,4	-4557	20	-4553		98,4			99,9
Phase 10-15 cm Hazelnut C1																	
Sigma_Boundary 15 cm Hazelnut C1							-55369	125998000	95,4	57929600	36471100	51927600					77
Phase 15-20 cm Hazelnut C1																	
Sigma_Boundary 20 cm Hazelnut C1							-114558	98613100	95,4	40616900	30160300	34096800					94,5
R_Date RICH-24751	-4546	-4496	95,4	-4522	14	-4523	-4546	-4496	95,4	-4522	14	-4523		99,2			100
Phase 20-25 cm Hazelnut C1																	
Sigma_Boundary 25 cm Hazelnut C1							-308567	31624000	95,4	11127800	10260200	8224550					95,9
Phase 25-30 cm Hazelnut C1																	
Sigma_Boundary 30 cm Hazelnut C1							-574919	22242500	95,4	6459900	7416940	4027050					98,9
R_Date RICH-24749	-7939	-7749	95,4	-7824	52	-7812	-7939	-7749	95,4	-7824	52	-7812		99,3			99,9
Phase 30-35 cm Hazelnut C1																	
Sigma_Boundary 35 cm Hazelnut C1							-1349312	6029620	95,4	1286860	2052650	643395					99,3
Phase 35-40 cm Hazelnut C1																	
Sigma_Boundary 40 cm Hazelnut C1							-2230572	3181960	95,4	252621	1246210	81097					99,8
R_Date RICH-22095	-7585	-7547	95,4	-7568	11	-7572	-7585	-7546	95,4	-7568	11	-7572		96,7			100
Phase 40-45 cm Hazelnut C1																	
Sigma_Boundary 45 cm Hazelnut C1							-6852272	987021	95,4	-1081942	2584050	-135932					99,7
R_Date RICH-24752	-7731	-7611	95,4	-7675	34	-7676	-7732	-7612	95,4	-7675	34	-7676		99,7			100
Phase 45-50 cm Hazelnut C1																	
Sigma_Boundary 50 cm Hazelnut C1							-28998902	207696	95,4	-6887482	10393300	-2602152					97,8
Phase 50-55 cm Hazelnut C1																	
Sigma_Boundary 55 cm Hazelnut C1							-47832602	8754	95,4	-16215602	15608200	-11335902					95,6
R_Date RICH-24750	-7736	-7612	95,4	-7680	33	-7683	-7736	-7613	95,4	-7681	33	-7683		99,9			99,9
Phase 55-60 cm Hazelnut C1																	
Sigma_Boundary 60 cm Hazelnut Hazelnut C1							-158038002	-298703	95,5	-69450202	47771800	-60160402					92,5
Phase 60-65 cm Hazelnut C1																	
Sigma_Boundary 65 cm Hazelnut Hazelnut C1							-209294002	-14637302	95,3	-110685002	55316500	-105851002					77
R_Date RICH-24754	-7716	-7604	95,4	-7652	32	-7647	-7716	-7604	95,4	-7652	32	-7647		99,4			99,9
Phase 65-70 cm Hazelnut C1																	
Sigma_Boundary Base Hazelnut C1							-526143002	-176558002	95,4	-382375002	109600000	-406235002					84
Sequence Hazelnut C1																	

Name	Unmodelled (BC/AD)						Modelled (BC/AD)						Indices Amodel 86.7 Aoverall 86.8				
	from	to	%	mu	sigma	median	from	to	%	mu	sigma	median	Acomb	A	L	P	C
Sigma_Boundary Top cereal C1							-3924	81277	95,4	20093	33270	3862					59,7
R_Date RICH-22098	-3944	-3798	95,4	-3879	45	-3879	-3944	-3797	95,5	-3875	46	-3876		96,4			99,9
Phase 0-5 cm cereal C1																	
Sigma_Boundary 5 cm cereal C1							-3963	-3394	95,4	-3723	167	-3760					99,2
R_Date RICH-22091	-3930	-3784	95,4	-3865	48	-3887	-3930	-3785	95,4	-3872	46	-3889		94,5			99,9
R_Date RICH-22093	-3954	-3806	95,4	-3860	44	-3847	-3955	-3807	95,4	-3866	46	-3850		97			100
R_Date RICH-22094	-3955	-3807	95,4	-3861	45	-3847	-3955	-3808	95,4	-3866	47	-3850		96,9			100
R_Date RICH-22102	-3961	-3814	95,4	-3891	57	-3858	-3961	-3814	95,4	-3898	56	-3941		100,5			100
R_Date RICH-22090	-4336	-4262	95,4	-4293	23	-4283	-4336	-4261	95,4	-4289	21	-4281		100			100
Phase 5-10 cm cereal C1																	
Sigma_Boundary 10 cm cereal C1							-4305	-4016	95,4	-4162	74	-4165					99,9
R_Date RICH-22075	-4239	-4067	95,3	-4157	51	-4175	-4241	-4071	95,4	-4174	47	-4184		101,4			99,9
R_Date RICH-22096	-4327	-4246	95,4	-4291	24	-4297	-4328	-4247	95,4	-4292	23	-4298		99			100
R_Date RICH-22097	-4338	-4266	95,4	-4298	25	-4284	-4339	-4266	95,4	-4299	26	-4286		95			99,9
R_Date RICH-22074	-4459	-4370	95,4	-4413	25	-4410	-4458	-4370	95,4	-4412	25	-4409		96,8			100
R_Date RICH-22104	-4708	-4613	95,4	-4660	29	-4666	-4705	-4610	95,4	-4651	29	-4640		96,6			100
Phase 10-15 cm cereal C1																	
Sigma_Boundary 15 cm cereal C1							-4604	-4404	95,4	-4518	52	-4529					99,8
R_Date RICH-22077	-4613	-4542	95,4	-4575	21	-4574	-4606	-4541	95,4	-4569	19	-4567		102,3			99,9
Phase 15-20 cm cereal C1																	
Sigma_Boundary 20 cm cereal C1							-4729	-4499	95,4	-4596	65	-4583					99,7
R_Date RICH-22107	-4229	-4048	95,4	-4136	54	-4136	-4231	-4050	95,4	-4160	53	-4159		100,9			100
R_Date RICH-22079	-4539	-4465	95,4	-4506	18	-4507	-4540	-4466	95,4	-4507	18	-4509		100,3			100
R_Date RICH-22078	-4607	-4532	95,4	-4566	20	-4565	-4607	-4534	95,4	-4567	20	-4566		98			100
Phase 20-25 cm cereal C1																	
Sigma_Boundary 25 cm cereal C1							-6456	-4722	95,4	-5376	571	-5232					98,8
R_Date RICH-22105	-4577	-4499	95,4	-4536	17	-4538	-4579	-4499	95,4	-4537	17	-4538		98,6			99,9
R_Date RICH-22106	-4689	-4598	95,4	-4644	27	-4646	-4689	-4599	95,4	-4645	26	-4647		100,1			100
R_Date RICH-22092	-4707	-4613	95,4	-4659	29	-4663	-4706	-4613	95,4	-4660	29	-4667		96,8			99,9
Phase 25-30 cm cereal C1																	
Sigma_Boundary Base cereal C1							-24213	-5084	95,3	-11543	9422	-8813					67,8
Sequence Cereal C1																	
Phase C1																	



SOILS AS RECORDS OF PAST AND PRESENT

From soil surveys to archaeological sites: research strategies for interpreting soil characteristics

Edited by
Judit Deák
Carole Ampe
Jari Hinsch Mikkelsen

Proceedings of the Geoarchaeological Meeting
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